

Noise in Digital Photography: What is it? What causes it? How to reduce it?

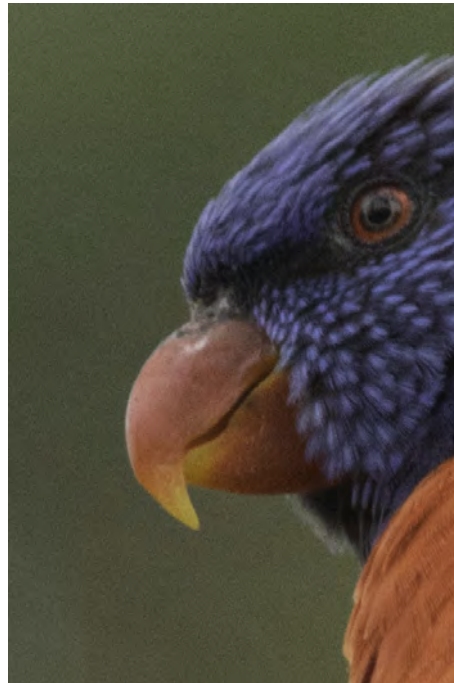
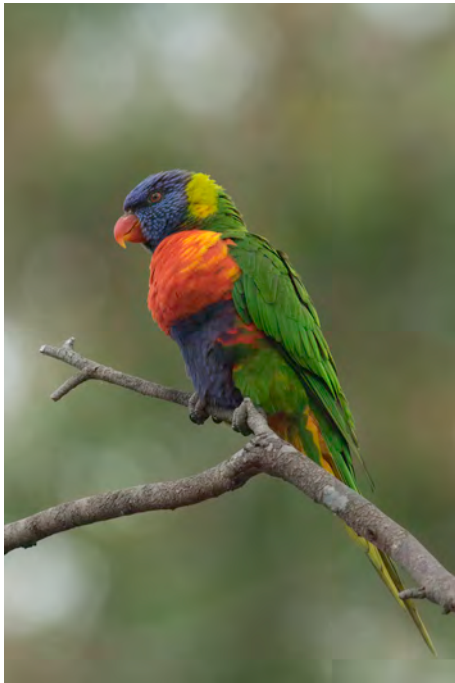
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What is noise?

Digital noise is the speckled or 'grainy' appearance in digital photographs that results in a degradation of image quality. 'Image quality' is, of course, subjective. The grainy appearance of film is a look that many artistic photographers strive for and for which there are plenty of presets, filters, plug-ins and settings in commonly used image processing software such as Adobe Photoshop and Lightroom. These 'after effects' are predictable, controllable and consistent across the image. Noise, on the other hand, is rarely desirable and occurs (mostly) randomly in an image.

Luminance noise occurs when random pixels display different brightness values giving a speckled, grainy appearance in flat areas of the image, e.g., open blue skies or out-of-focus backgrounds. Luminance noise is often disguised by underlying detail in the image, e.g., it is less noticeable in areas with natural grain or texture, such as a sandy beach or background foliage, or fine detail, such as close-up detail in a bird's feathers.

The following image (RAW file straight out of camera) was shot on a Pentax K-3 (crop sensor, 24mp) camera at ISO 1600. At low resolution, the image does not appear to have much noise but when magnified to 200%, there is a distinct speckling of luminance noise, most obvious in the out-of-focus, plain coloured background.



Colour (chrominance or chroma) noise occurs when pixels display the incorrect colour and usually only occurs on very long exposures or very high ISO settings. Colour noise is more objectionable to the eye than luminance noise so needs to be avoided or reduced to make images usable.

This image was taken in very low light (approx. 30 mins after sunset) at ISO 25600 on a Pentax K-3 (crop sensor 24mp) camera. A 100% magnification of part of the image shows the extreme colour noise.



What causes noise?

Noise is caused by inconsistencies in the way individual pixels are generated to display the colour and luminosity (brightness) that we see in the resulting image. The camera sensor is made up of a matrix of tiny photosensors (or photosites) that convert light into electric charge. The camera's computer reads the electric charge and converts it into a coloured pixel. Noise occurs where there is contamination of this process. In ideal conditions, the amount of noise is negligible compared to the light hitting the sensor (creating the expected signal to the camera's computer) but several factors can reduce the signal to noise ratio to the point where the noise degrades the image.

Sensor size and pixel density

Small sensors are more likely to have the individual photosites closer together (higher pixel density). Each photosite generates a small amount of electrical noise of its own and can pollute its neighbours. The further apart the photosites, the less cross contamination occurs. In addition, large sensors are more likely to have larger individual photosites, enabling them to capture more light, therefore increasing the signal to noise ratio. So, generally speaking, a larger sensor and lower pixel density will produce a higher quality image (less noise) than a smaller sensor with higher pixel density, which is why, in part, the most expensive, professional level cameras, e.g., Canon 1Dx II or Nikon D5, will produce images with less noise than the higher pixel count cameras: they have high quality sensors with larger photosites that are spaced further apart (as well as a bunch of other technical capabilities that don't hurt either).

Low light

In low light, there is simply not enough light to properly expose the image, i.e., to create pixels with the correct luminosity and colour. In this situation, the noise is much more obvious because the signal is low. This is why noise is usually more noticeable in the darker areas of an image.

Slow shutter speed

Generally, slow shutter speeds (= long exposures) are used because there is not enough light to properly expose an image, so this effect is confounded with the low light problem noted above. However, the shutter speed itself has an effect—put simply, the longer you have the shutter open, the more noise will be introduced.

High ISO

There is a misconception that raising the ISO setting on your camera increases the sensitivity of the sensor. This is not true. Each sensor has a fixed sensitivity to light, commonly referred to as the 'native or base ISO'. Raising the ISO simply tells the computer in the camera to amplify the signal resulting in a correct exposure but the noise is amplified as well. Hence, the higher the ISO, the more noise in an image. Modern DSLR cameras have high quality sensors that have low underlying noise levels so they can handle higher levels of amplification before the noise becomes obvious. Some cameras have a feature (sometimes called 'step under ISO') that allows you to set the ISO to a value lower than the native ISO. This means you can get slower shutter speeds but it does not improve the image quality; in fact it can reduce the dynamic range of the image because the camera is over exposing and readjusting to produce the expected image exposure.

Minimising noise in camera

In an ideal world, the best way of avoiding noise is to use a professional level camera with large, low pixel-density sensor at the lowest possible ISO and a fast shutter speed in good light. Economic and environmental realities dictate that this not always (if ever) possible: not everyone can afford a high end camera and high quality, fast lenses and we rarely get to shoot in ideal lighting conditions that allow fast shutter speeds at low ISO. So, more often than we would like, we have to deal with noise. As a generalisation, the underlying principles are worth following: use the best camera and fastest lens you can afford, use the lowest ISO possible and shoot the fastest shutter speed possible. These last two factors are in direct opposition, so there will often be a judgement call for the photographer to decide what is more important—high shutter speed or low ISO. This will depend on the requirements of the image you are shooting. If you are shooting a landscape, then a fast shutter speed may be irrelevant or undesirable if you deliberately want to slow the shutter speed down to blur moving water or clouds but the slow shutter speed will increase noise as well. On the other hand, if you are shooting birds in flight, then a fast shutter speed (ideally 1/2000 second or faster) is best, so you will need to compromise on ISO, thereby increasing noise in your image, particularly when shooting in low light.

Not all is lost! Modern DSLR cameras have in-camera settings that can reduce noise caused by high ISO and slow shutter speeds.

High ISO Noise Reduction

The camera's computer analyses the image and tries to identify different luminance (brightness) values from one pixel to another and smooth these out. However, the camera needs to be able to distinguish between random luminance noise and fine detail, e.g., sand grains on a beach or fine feather detail on a bird or stars in a night sky shot, and avoid smoothing these areas of the image. This requires sophisticated algorithms and a lot of processing power to differentiate between random noise and non-random patterns, so, as for most things, the more expensive, professional cameras handle this better than others. The reality is that if you have a lot of noise, the noise reduction will usually reduce the detail across the whole image. My preference is to turn this setting off and rely on manual control of noise reduction in post-processing software, where you get to decide how much and in which areas of your image you want to reduce the noise.

Long Exposure Noise Reduction

Noise from long exposures is more predictable than high ISO noise. Some photosites on the sensor are more likely to 'behave badly' under long exposures than others. The Long Exposure Noise Reduction (LENR) setting tells the camera, typically when shooting at shutter speeds longer than 1 second, to take two exposures every time you release the shutter: the first is the normal exposure, the second 'exposure' is taken without opening the shutter and is commonly referred to as a black frame. The black frame will include pixels that show some luminance despite no light actually hitting the sensor. The camera's computer then subtracts the black frame from the normal exposure, removing the rogue hot pixels. In some circumstances this is very effective but (there's always a but...) this means every image you shoot will take approximately twice as long to make the exposure and then longer in camera to process the image and display it on the LCD screen. So, if you don't like waiting, LENR may not be for you.

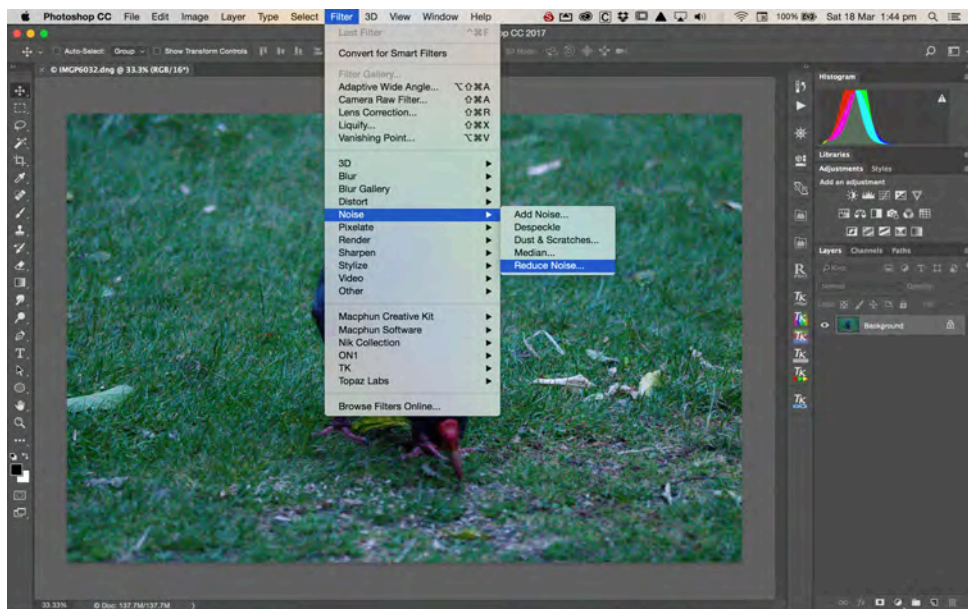
Reducing noise in post-processing using Adobe Photoshop

Adobe Photoshop has several tools for reducing image noise. These tools often combine reduction of colour and luminance noise but, for the sake of clarity (no pun intended), I will treat these separately in this discussion. Adobe Lightroom has identical tools to Camera Raw Filter in Adobe Photoshop (discussed below) but cannot be managed in layers so I prefer using Photoshop for complex tasks such as noise reduction but once you've learned one, the skills are easily transferable.

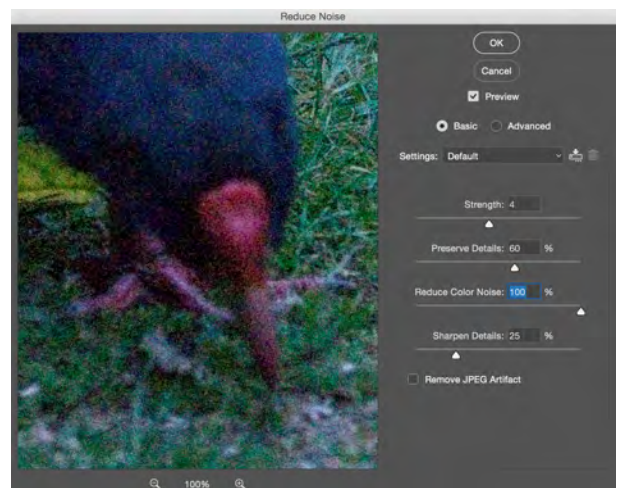
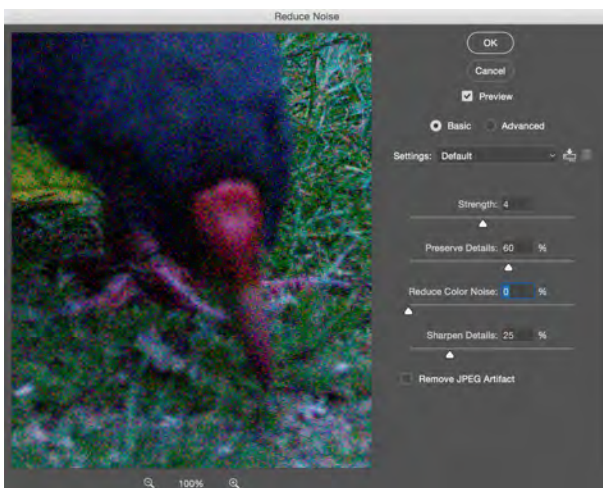
Reducing Colour Noise


Most modern DSLR cameras are very good at handling colour noise under normal shooting conditions. I have used an extreme example in the demonstrations below to emphasise the differences between methods.

The traditional method of removing all noise in Photoshop is to use the Reduce Noise Filter [Filter > Noise > Reduce Noise]



A pop-up Dialog box provides sliders to alter the strength of the noise reduction and preserve and sharpen details as well as reduce colour noise. If you check the Preview box, you'll see the changes 'live' at 100% magnification. Sliding Reduce Colour Noise to 100% removes some of the severe colour noise but not all of it.



A better method is to use the Camera Raw Filter [Filter > Camera Raw Filter]. Click on the Detail  tab and slide the Color slider to the desired amount (I used 100 in the example below). This results in a cleaner reduction of the colour noise but there is a slight loss of contrast, which can easily be rectified with subsequent post-processing. Further adjustments of the Color Detail and Color Smoothness sliders can be used to bring back some of the detail if required.



Colour noise reduction with Reduce Noise filter
(no other adjustments)



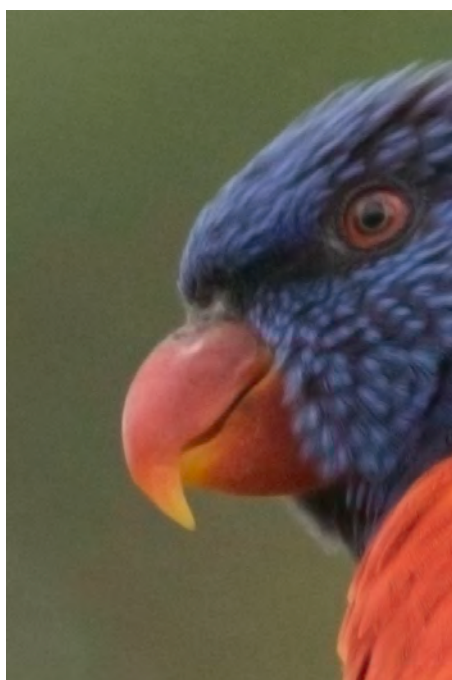
Colour noise reduction with Camera Raw filter
(no other adjustments)

Reducing Luminance Noise

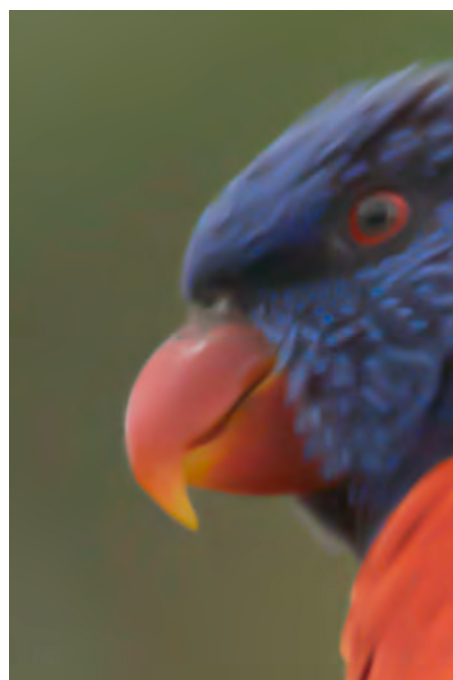
The Reduce Noise Filter does a reasonable job of reducing the background noise but, for my eye, it is not strong enough, whereas the Camera Raw Filter does a great job of smoothing out the background.



RAW file straight out of camera



Reduce Noise Filter
Strength = 10, other sliders = 0



Camera Raw Filter
Strength = 100%

However, in the latter case, the bird has also been blurred way beyond anything that sharpening can recover. Natural texture in the scene, for example, sand on a beach, wood grain, foliage, feathers on a bird, fur on an animal or hair on a person is also smoothed out with global noise reduction—any reduction in noise will also smooth areas where texture is important. When this happens it is useful to be able to differentiate between flat areas in an image where you don't want to see noise and textured areas where you don't want to lose the texture. Here lies the power of Photoshop – Layer Masks.

Here's one way of using Layer Masks to preserve the detail in the bird and reduce the noise in the background. This method is useful when there is a clearly defined background that can be easily selected.

1. Duplicate the existing layer (Control/Command J, Right click on the layer and select Duplicate layer or drag the Layer onto the New Layer icon bottom right of screen)

2. Select the Magic Wand Tool

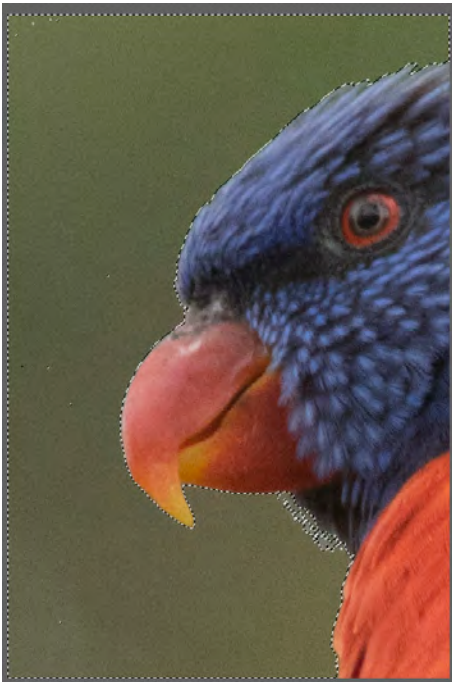
- Set Sample size to suitable resolution (I prefer 3x3 or 5x5 Average as a starting point—these are small enough to allow you fine control of the selection but not so small that you have to select individual pixels).
- Set Tolerance to a suitable level (Tolerance is the range of colours that will be selected—the smaller the number the less variation in colour will be selected. In the case of the image used here, the background is almost uniform in colour so I dropped the Tolerance to 10.)
- Click anywhere in the area you want to select (in this case the background). The tool will select all the contiguous pixels of the same colour +/- the tolerance chosen. If too much is selected, just click on the areas you want to deselect. If you missed pixels, hold down the Shift key and keep clicking on pixels until all the areas you want are selected.

3. Create a Layer Mask

- Copy the selection (Control/Command-C).
- Click on the Layer Mask icon (bottom right of screen). A Mask is added to the Layer with the your selection active, i.e., all the pixels you did not select with the Magic Wand will be masked out. You may notice a few pixels that you missed in the selection. These are easily brushed out. Invert the Mask (Select the Mask and click Control/Command-I). Select the brush. Ensure the Foreground colour is set to black and brush over the left over pixels. When you're done, Invert the Mask again.

4. Apply whatever filter or treatment you want to the masked layer—in this case Filter > Camera Raw Filter > Details and slide the Luminance slider (and Luminance Detail + Luminance Contrast if required) to the desired level.

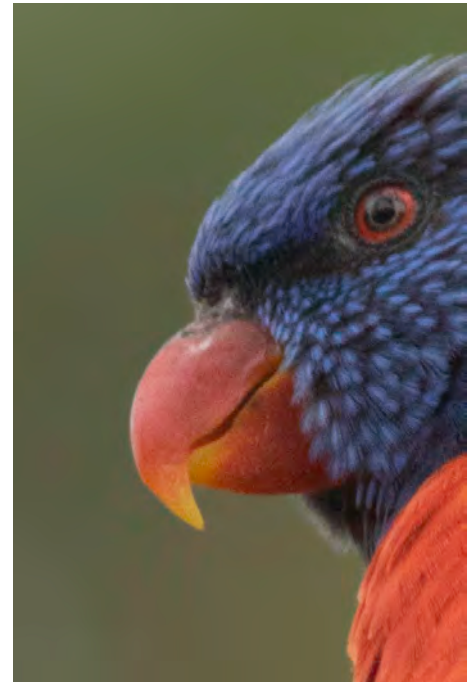
Done! The background is blurred out, the bird remains untouched.



Select the background with the Magic Wand tool



Create a Layer Mask with the inverse of the selected area



Make the adjustment that will now only affect the selected area.

Plug-ins

There are additional tools that handle noise reduction, many of which plug directly into Adobe Photoshop so you can use them in your Photoshop workflow. The common ones include:

- Nik Dfine2 (part of the Nik Collection, free from Google)
- Topaz Labs DeNoise
- Noiseless (part of the Macphun Creative Kit – Apple Mac only) – my favourite as it has very easy to use presets.

Conclusion

There's no single best way or best tool to avoid or reduce noise. The different causes of noise mean that the strategies to avoid it in-camera and tools and techniques to reduce it during post-processing are all compromises. Try, practice and evaluate as many as you can and identify and perfect the ones that work for you. I try and remove basic background noise as early as possible in my post-processing workflow so I avoid increasing the noise when adding contrast, clarity, vibrance, saturation, sharpness, etc. It is harder to remove noise if you have accentuated it with other settings. However, I know others who leave it until close to the end of their workflow. Try both and see what works for you.