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Criteria for High Dynamic Range (HDR) Imaging of Photomicrographs

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Not so long ago, film cameras were used to collect images of microscopic and macroscopic objects for documentation. The usual procedure was to load the camera with film, set the camera on a tripod, copy stand or microscope and begin the photo documentation process. Exposures were taken at the "best" exposure setting using a light meter with a gray card or a suitable region in the microscopic field of view. Exposures above and below this "best" setting were also collected, in case there were features of interest that were not well exposed at the "best" exposure setting.

By using this exposure bracketing technique, images with suitable contrast and detail were routinely collected. With the tripod and copy stand, lighting was controlled by flash or by flood lights that were adjusted to provide even illumination for the object of interest. Shooting items outdoors on a cloudy day was also an excellent alternative, especially when using film balanced for daylight. Even illumination was especially important when using the microscope, although the microscope allowed a range of illumination techniques that entailed their own set of challenges!

Many dedicated photographers and photomicrographers insisted on using the correct color temperature and the slowest film speed practical by employing the most powerful and well balanced illumination that could be manipulated into compliance (usually after some struggle and some spent film) to produce images with excellent resolution, uniform illumination and balanced color.

Of course, most of us back then sent our film out to be professionally processed. The "mom and pop" print shops and film processors would "adjust" our hard work by letting the computer decide the correct colors and exposures during printing. This meddling inspired photomicrographers to produce a set of baseline images using slide film (color positive film) for each photographic technique employed. The positives were necessary to train the film processors the proper way to print an image of, for example, a quartz sand grain taken with crossed polarizers: Do not let the background be 18 percent gray; it is to be black and only black!

By now, I probably have lost most readers who have never experienced loading film into a 35 mm camera or had to retrieve the end of the film in a 35 mm cassette that has been inadvertently wound up (I still have a couple of the slick little tools invented to grab the end of a film roll that has been swallowed by a 35 mm canister). They have never blown a whole roll of film that was processed only to reveal that the film had never advanced due to improper loading, or opened a camera back to reveal that the film had never been rewound completely! Ah, those were the days!

With the passing of film and the acceptance of digital cameras, exposure techniques (hardware and software) have been developed to improve the quality of digital images. As computers process more data faster, the software used for image processing becomes cheaper, faster and easier to use. Specifically HDR, or High Dynamic Range imaging, has the potential to increase the range of contrast in images taken with a digital camera on a copy stand, tripod or with a stereomicroscope by combining multiple

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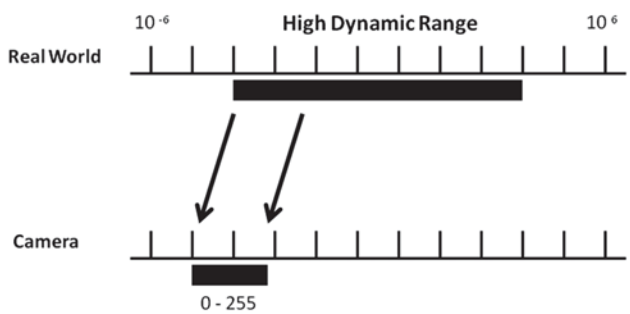
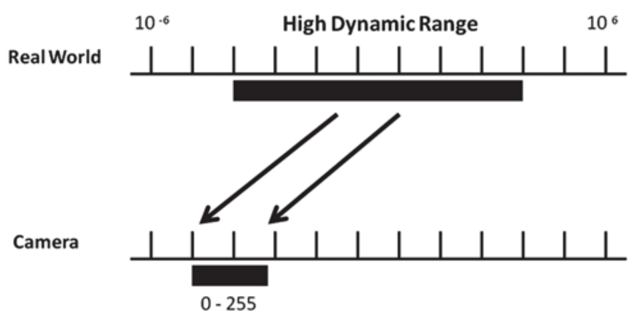
exposures and taking the "best" exposure from each area of the image.

In the real world, the range of light intensity varies almost infinitely from absolute darkness to blindingly bright. In today's camera, print and display technology, the light intensity can only vary in discrete increments from, say, 0 to 255. So, each exposure made is going to be a compromise, only capturing a small subset of the entire range of light intensity.

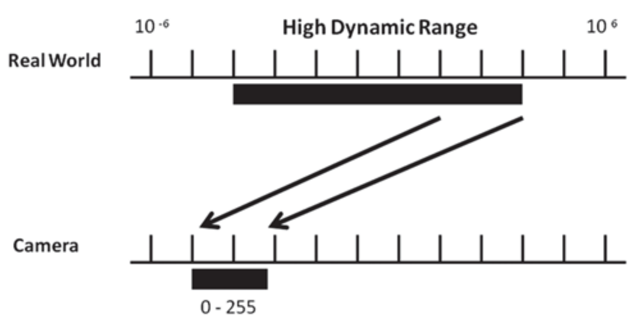
In a long exposure, we tend to capture the dimmest areas of the scene, and all brighter areas will be shifted to "white":



In a standard exposure, we will capture details in the middle-brightness areas of the scene, many dimmer areas will be shifted to "black", and many brighter areas will be shifted to "white":



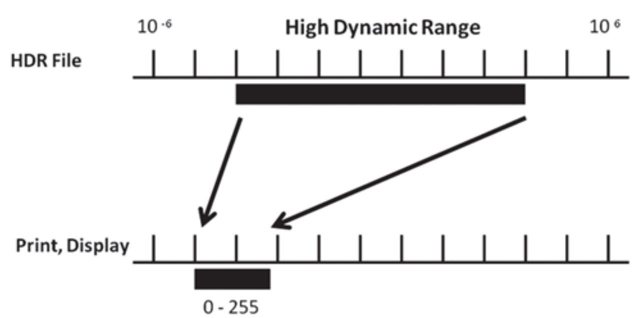
A short exposure will capture details in the brightest areas of the scene, and all dimmer areas will be shifted to "black":



The first step in High Dynamic Range photography is to take multiple photographs of various exposures and recover the underlying HDR intensity information. If the purpose of this effort were to produce numerically accurate absolute radiance information, then we would have to use knowledge of the response curve of the electronic sensors in the camera. If our purpose is to produce visually pleasing results which correspond to what we can see with our own eyes, then we can dispense with this requirement. By combining the multiple exposures in Figures 1-4, sand grains, regardless of color, can be combined to produce a single image with properly exposed sand grains (Figure 5).

A common procedure is to take an exposure that is suggested by scene-averaged metering, and then add additional exposures at, say, +/-1 EV (Exposure Value), and possibly also +/-2 EV. A mathematical algorithm (first described in Recovering High Dynamic Range Radiance Maps from Photographs Paul E. Debevec and Jitendra Malik, SIGGRAPH 1997) is then used to recover radiance information for each pixel. This produces a High Dynamic Range radiance map, where each pixel has a value such as:

By convention, the red/green/blue values are in the range 0-255, and the exponent is in the range 2^{-127} to 2^{127}. Once the High Dynamic Range radiance map has been recovered, we have to process it further. Current print and display technology is Low Dynamic Range. So, our task is to provide this mapping:



This procedure, commonly referred to as "tone mapping" has to accomplish this conversion in a manner that is pleasing to the eye and does not contain apparent artifacts. The procedure will involve compressing the image's dynamic range while preserving darker areas and reducing blown highlights, but mini-

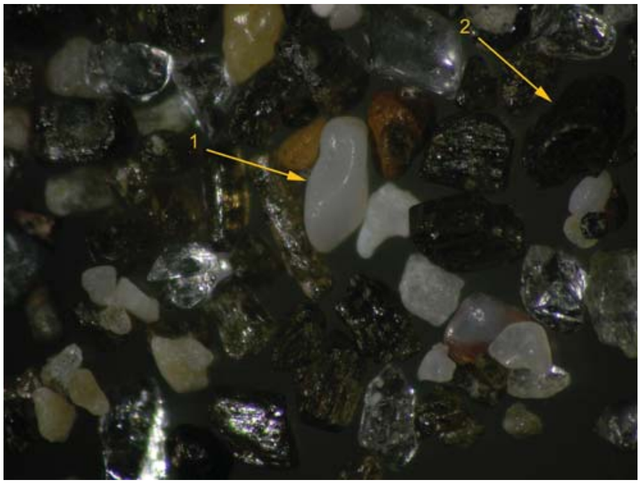


Figure 1. EV -1: Arrows denote sand grains that require different exposures to be properly imaged with reflected light.

Figure 2. EV 0: White grain is properly exposed and the green grain is too dark.

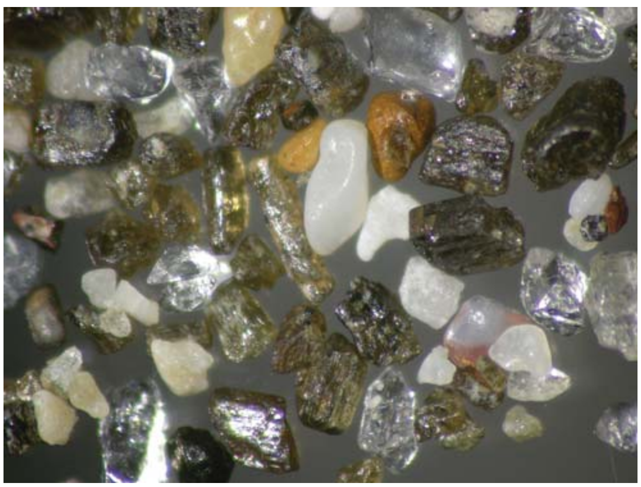


Figure 3. EV +1: The dark green sand grain is still too dark and the white grain is still only slightly overexposed.

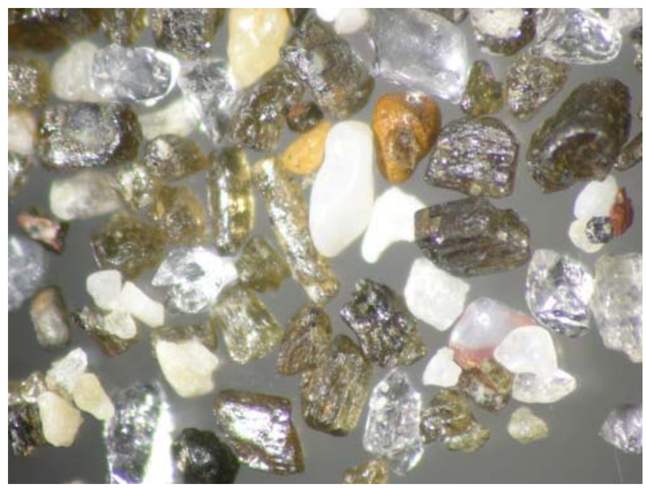


Figure 4. EV +2: The dark green grain is properly exposed but the white grain is overexposed.

mizing artifacts in areas of high contrast by taking in to account adjacent pixel values.

A software program which provides all of the above functionality yet remains easy to use is called easyHDR. The first step of recovering HDR information from multiple exposures can be done automatically, and the second step of tone mapping is accomplished using simple parameter sliders that give immediate visual feedback (Figure 6).

The three most important functional elements which control the output are the compression section, the mask section, and the local contrast section.

The tone mapping compression is the global operator which governs the shape of the curve that maps the high dynamic range information of the entire image. Adjusting its shape determines how dark the dim areas will be, how much brightness is kept, the accentuation of middle-bright areas, and color saturation.

The mask section determines how the software uses local pixel information to adjust brightness. Without this processing, artifacts would be present whenever a very dark area is adjacent to a very bright area. Adjusting the sliders lets you see the effect immediately. The local contrast section allows you to boost details that are otherwise lost when dynamic range is compressed. If the image seems to have a washed-out appearance in some sections, this is a good parameter to adjust.

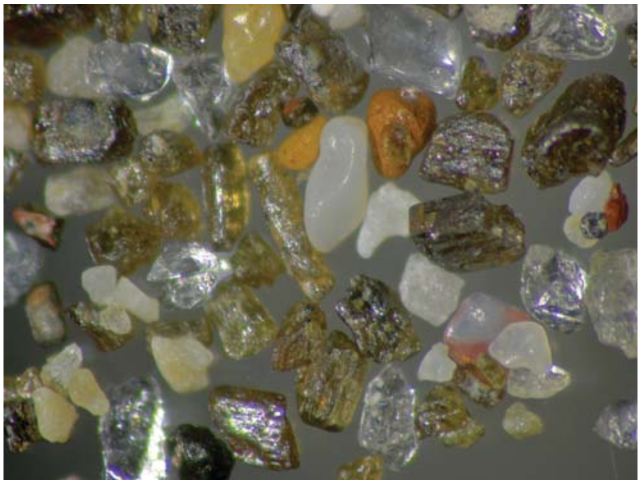


Figure 5. This HDR image, which was constructed from exposures in Figures 1-4, shows properly exposed sand grains reproducing a contrast ratio that cannot be obtained in a single exposure.

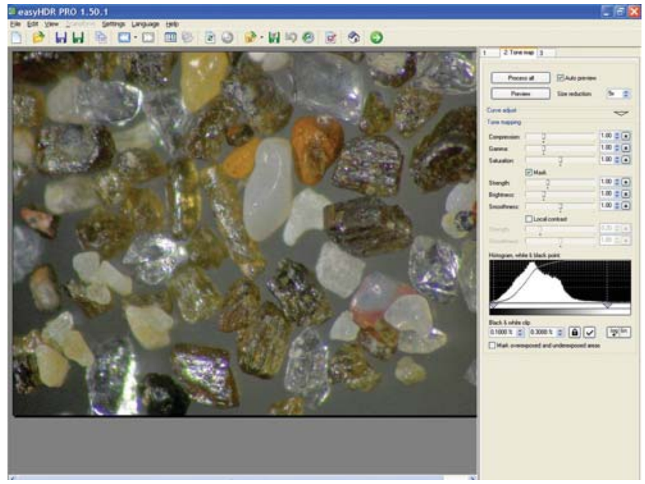


Figure 6. This HDR image, shown on the interface of the easyHDR software program, was created from multiple exposures prior to tone mapping, which is accomplished using parameter sliders that give immediate visual feedback.

Until camera sensors can be improved and manufactured to capture a greater dynamic range than is presently available, HDR images will provide a means to recover some of the contrast that is discarded by today's digital cameras. A quick internet search on HDR will return a range of articles, books and software that can be explored to educate and excite even the most accomplished digital photomicrographers.

All you need is the software (many versions can be used on a trial basis at no cost), a reflected light stereomicroscope using brightfield or darkfield illumination, and a rigid mounting so each image exposure is in the exact position as the last.

Good luck, have fun and never throw an overexposed or underexposed image away again!