HDRI

High Dynamic Range Image

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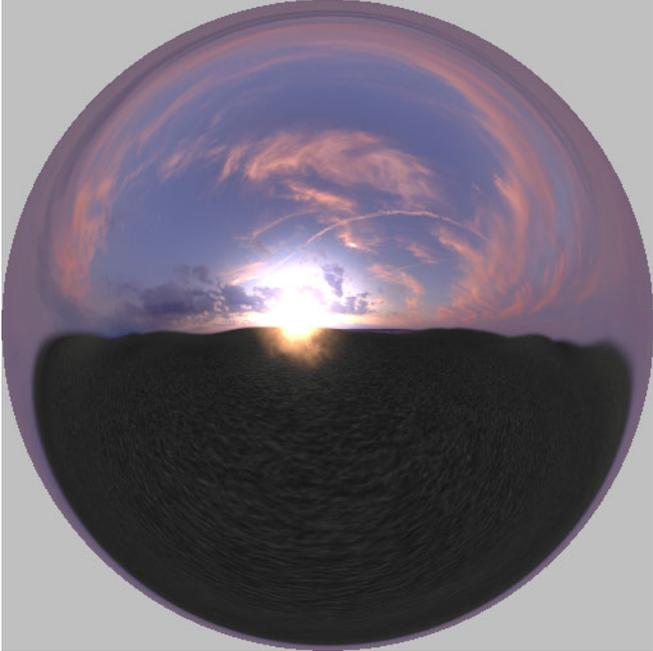
LightProbe Sample with HDRI

Sphere Settlement

For the use of HDRIs as an lighting (illumination) technology there are not many, and sometimes no standards at all in the various rendering programs. Also can the mapping format for textures be different from the one for lighting. Lightwave3D for instance uses for textures latitude/longitude-depictions, and for ImageWorld (environments) a picture exclusively in the LightProbe-format. That's why this appendix tries to explain these mapping formats or panorama formats in a bit more detail:

Latitude/Longitude

The best known spherical mapping method is the latitude/longitude-format. The depiction is twice as wide as high. The X-axis of the depiction directly corresponds to the Heading/Yaw-angle (0…360) and the Y-axis corresponds to the Pitch-angle (-90…0…90 degrees). The horizontal center line represents the equator of the sphere, and the top & bottom lines will translate into the poles. Due to distortions, and the concentration of pixel near the poles, a re-editing of the picture is possible only to a limited extent.
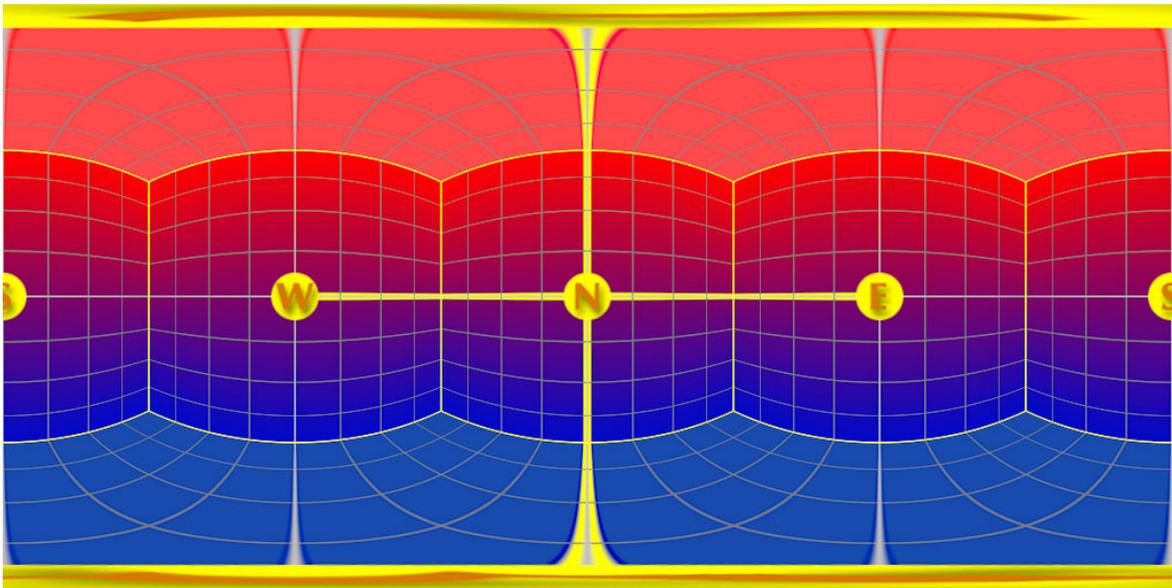
Latitude/Longitude-format.

W=West; N=North; E=East; S=South

Up is the top line; Down is the bottom line

Horizontal-Cross, Vertical-Cross

These two mapping methods represent cubic mapping procedures. The six sides of a cube are seen as six aspheric quadratic photos which are taken with a 90-degree photo lens. They show the 4 points of the compass, as well as vertical views from the top and the bottom. The individual photos are arranged in such a way that –once cut out- they can be folded back into a cube-shape. The combination of individual photos looks like a cross which lies either horizontally (H-Cross) or vertically (V-Cross) in the picture. This type of mapping is particularly useful for assessment of the spatial geometry and for retouching, since straight lines in the environment (inside the photo) can again be represented as straight lines, and also because floor (bottom) and ceiling (top) remain distortion free.
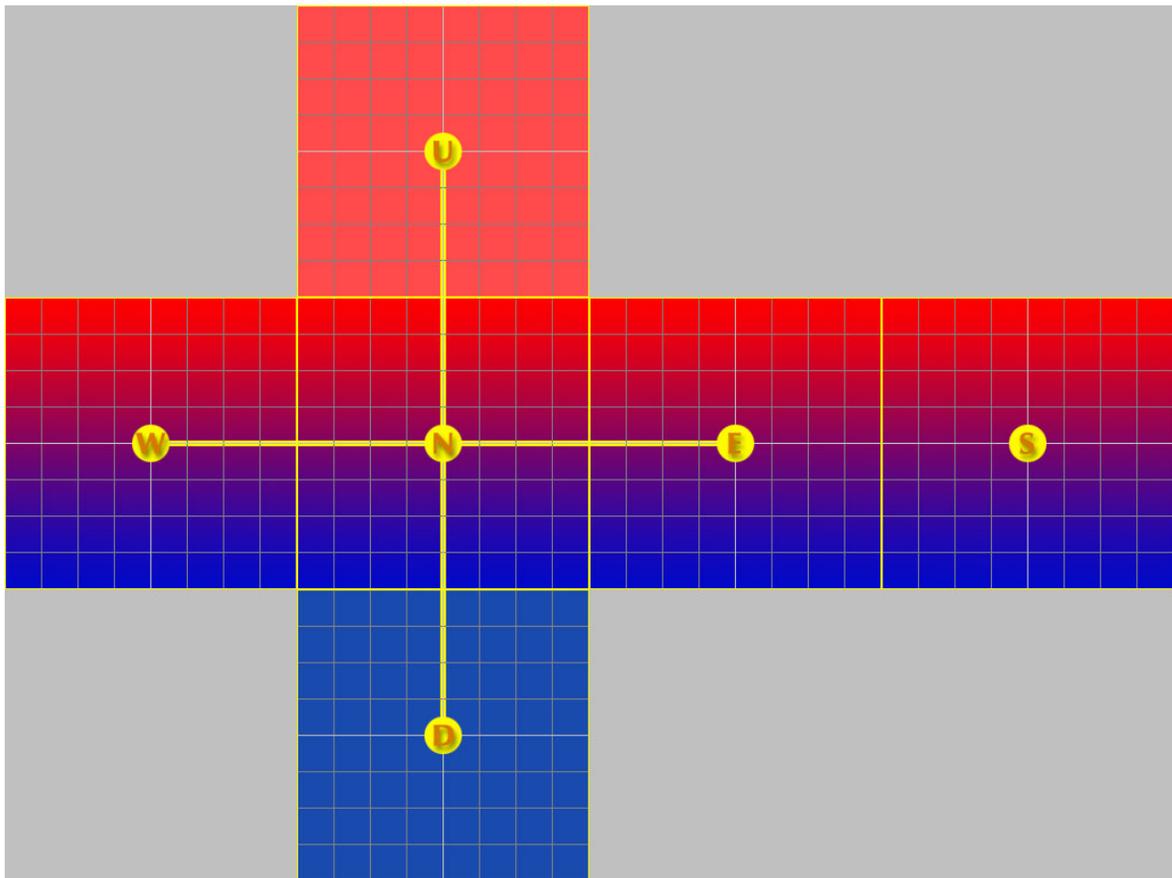

H-Cross-format.

W=West; N=North; E=East; S=South; U=Up; D=Down
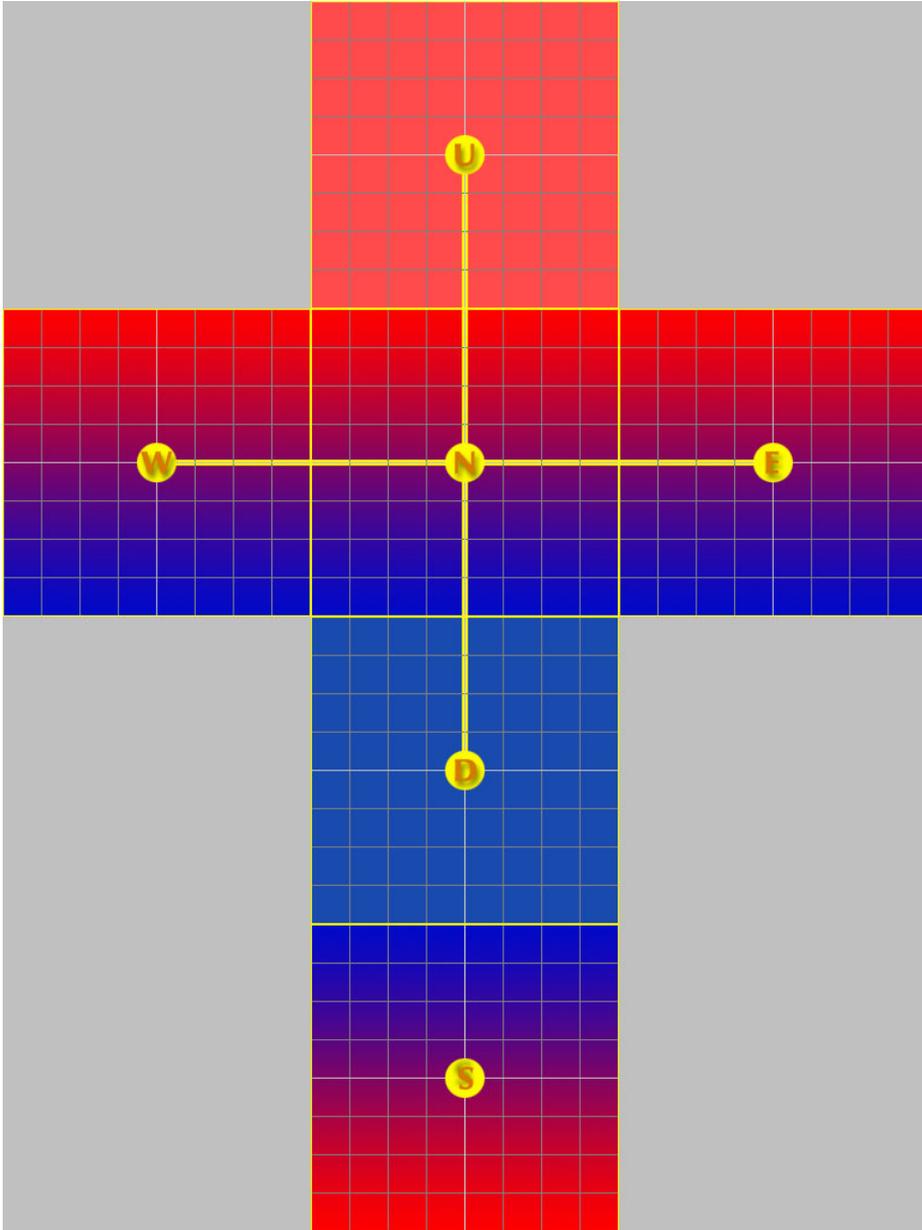
V-Cross-format.

W=West; N=North; E=East; S=South; U=Up; D=Down

Mirror-Ball

This depiction is not used by rendering programs, but instead is created when photographing a mirror ball. For this the mirror ball is set in the center of a space, and the tele-lens equipped camera positioned at some distance … pointing at the sphere. From the full-frame sphere image or its mirror image all other mapping formats can be calculated. The picture shows almost 360 degrees of the environment in a heavily distorted form. What will be depicted here at the highest pixel resolution, is the camera man!
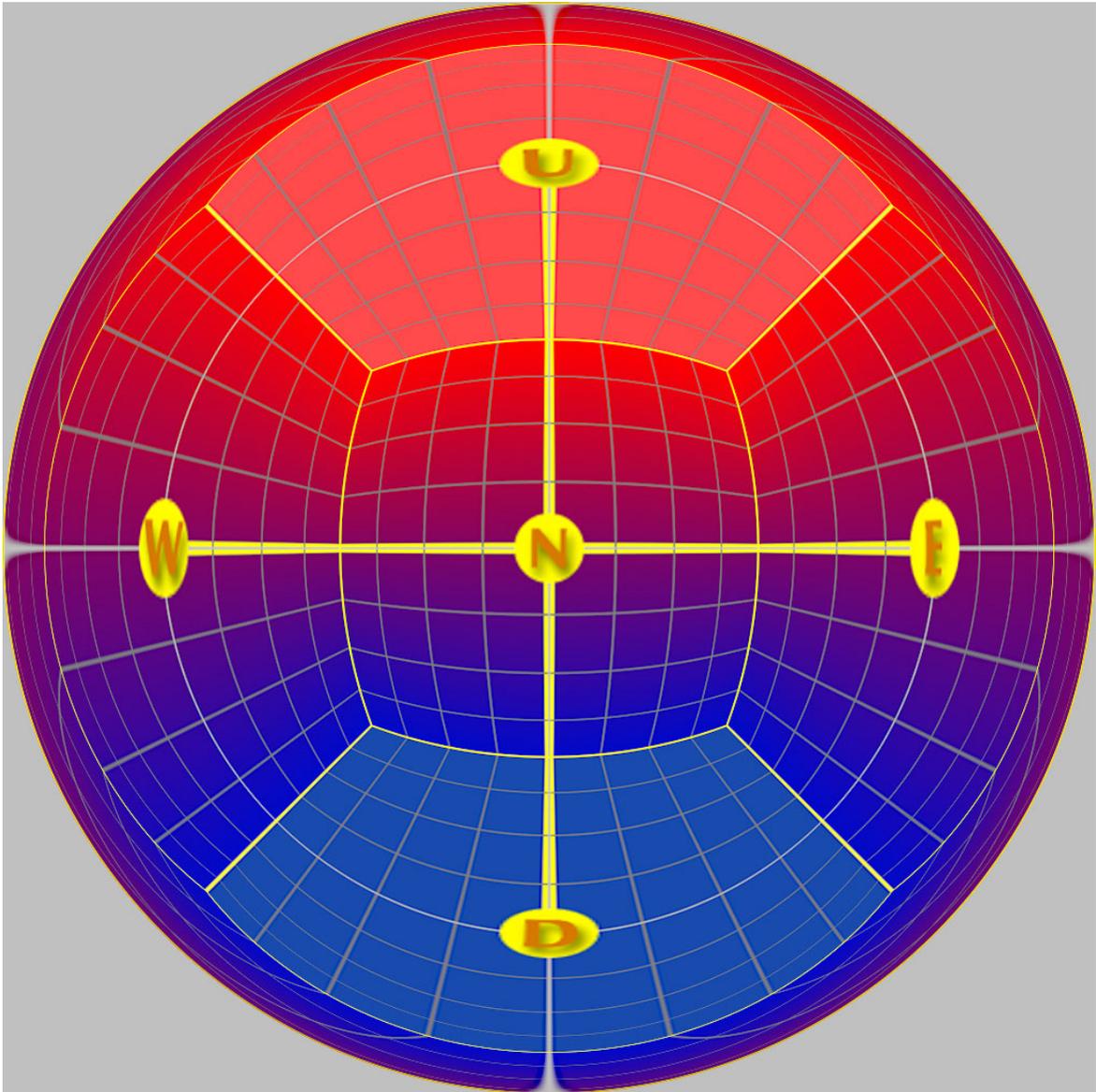
Mirror-Ball-Format.

W=West; N=North; E=East; U=Up; D=Down;

South is the circular edge around grid area

LightProbe

A LightProbe is a 360-degree fish-eye image (angular map). The square picture contains a circular image which represents the actual mapping. The area outside the indicated circle does not contain any information. The center point of the picture shows the view forward, and the edge of the circle represents the view backwards. Right, left, top (up) and bottom (down) are points at half-radius of circle. Retouching is very difficult due to the strong distortions, and the hard-to-figure out geometry.
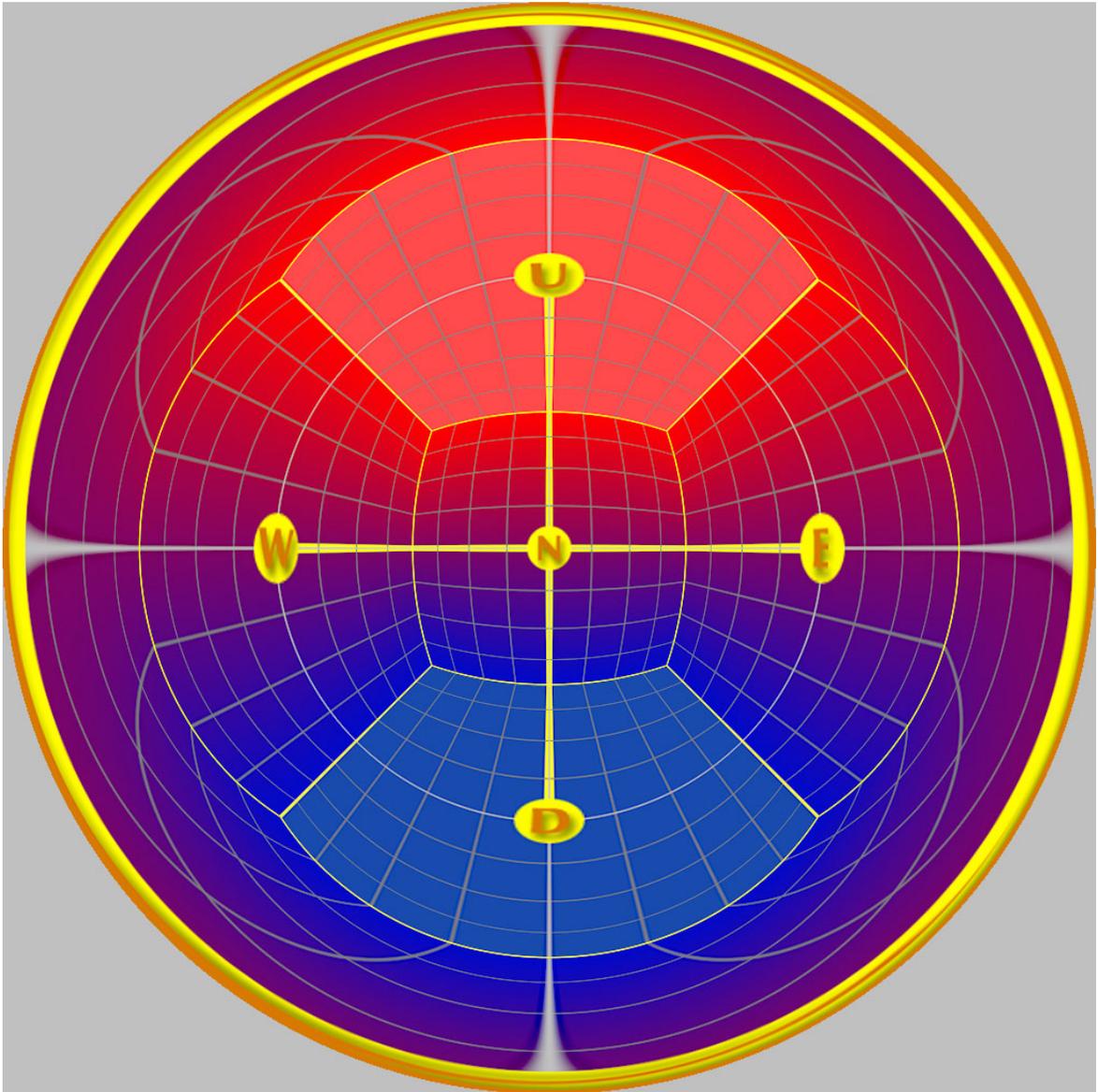
LightProbe-format.

W=West; N=North; E=East; U=Up; D=Down;

South is the circular edge around grid area

Dynamic of the Image

When we review an image on a computer screen or from a print-out it will only show a small portion of the brightness range in the environment. By the skills of the photographer, or through the automatic exposure controls of the camera, only that brightness range will be recorded which sets the motive „in the right light". This is normally sufficient since the human eye can readily process only double the dynamic range (as compared to a digital picture). With a printed picture that range is even lower for many colors.

In order to demonstrate the term and concept of „dynamic range" let's take a look at an HDRI of a cluster of trees. As already mentioned we can only print a small portion of the picture's dynamic range here; it is therefore necessary to examine the HDR-image in several individual steps (i.e. images with various exposure settings).

When we load an HDRI in a proper viewer we first see what we would expect to see in a „normal" picture (Image 1). The tree leaves are illuminated correctly, the sky is brimming with light, and the details in the underbrush are hard to distinguish in the low light/low contrast at ground-level.

When we decrease (dim) the brightness (luminosity) of the photo (Image 2) then the bright, white sky in a normal picture (24 bit, 8 bit for each color channel) will turn into a grayish area. No information is stored in the picture which transcends white (color hue, saturation, contrast). In the HDRI however the sun will clearly be distinguishable from the surrounding clouds.

When increasing the pictures exposure (Image 3) the bit resolution of the normal depiction is not sufficient in order to show the details in dark areas to any realistic degree. Color transitions are not smooth, but display noticeable „steps" (Quantization noise) and when using a digital camera one would see the "noise" of the CCD-picture sensor. The uniqueness of HDR-images is that they distinguish not only dark and black, but many nuances in between. As far as the real environment (e.g. dust, haze, diffuse light) provides it, and the quality of HDR-image photography (aperture, lens-reflex etc.) is sufficient, one can brighten the image at will and still recognize details in the dark shadows.

Image 1: Photo just like from an automatic camera. The sky is full of light and dark areas are shown as black. This is also the normal appearance of an HDR-image.

Image 2: Lower-exposure photo. Information beyond white are lost in a 24-bit image (left). The HDRI (right) however still shows distinct sky features.
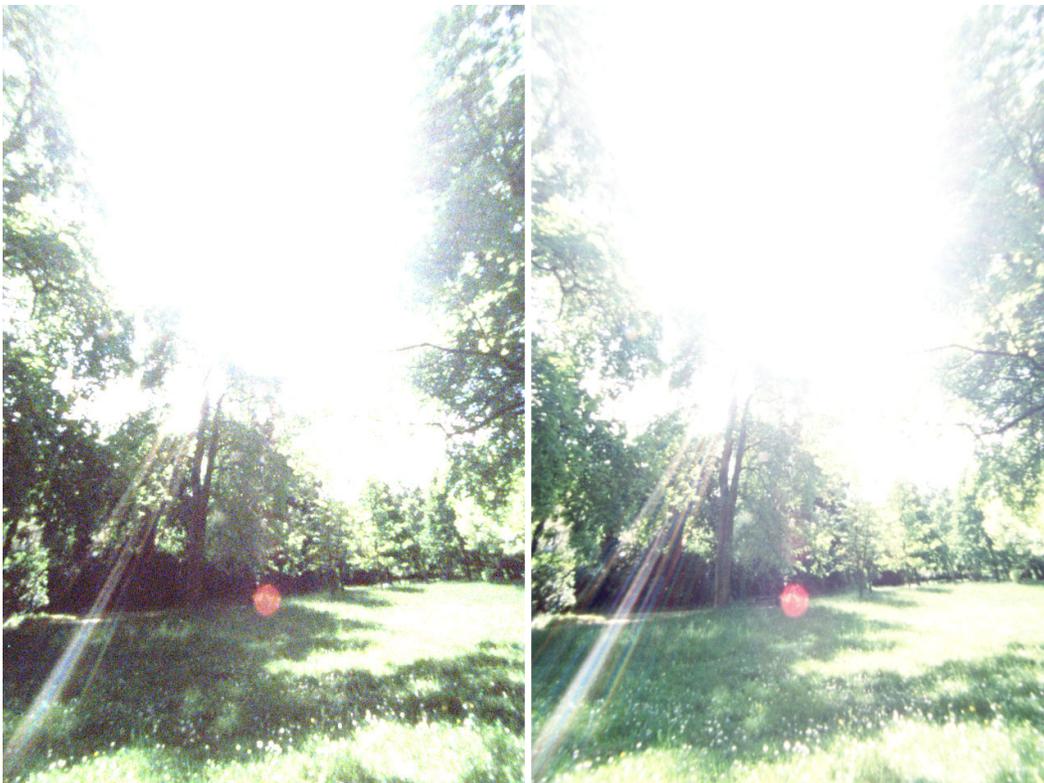
Image 3: Higher-exposure photo. The 24-bit image (left) reveals quantization problems (grainy; low detail). The HDRI (right) successfully depicts details in the dark areas.

File formats

Processing HDRIs requires arithmetic which allows representing values "above & beyond white" as well as the precision to distinguish subtle nuances in the dark/black color range. What better to choose for this purpose than floating point representation. Indeed many rendering programs already calculate pictures alternatively in the IEEE-Floating-Point-format (32 bit per number; 12 byte per pixel). The following formats are common for saving the HDRIs in a file:

PFM

The simplest file format is the Portable-Float-Map (PFM). After a simple ASCII-header follow the 3 color values for each pixel directly as IEEE-Floating-Point values. Because of it's simplicity it is well suited for programming small filters and converter, however it offers no compression, and will consequently occupy 12 bytes on the hard-drive for each & every pixel in the picture. A PFM-picture file is therefore 4 times larger than an uncompressed 24-bit picture.

TIFF - Float

The TIFF-format definition doesn't only contain 8-bit and 16-bit color channels, but also stores picture info as 32-bit floating point numbers (IEEE). Data compressions is not a feature in this file format, which results in significant use of hard-drive capacity (factor 4).

TIFF – Pixar Log

This format which was developed by PIXAR allows storing of the 3 color channels as 11-bit values. Every value is stored as a logarithmic value, and can therefore cover a very large dynamic range. Logarithmic storage offers the benefit of a constant signal/noise-ratio across the entire brightness/luminosity range. Finally, the picture data is compressed without data-loss by using a ZIP-algorithm.

TIFF – SGI 24/32 Bit LogLuv

This format was developed by SGI, and it stores the brightness (luminosity) as a logarithmic 10/16-bit value. The color information is converted into a u-v-color range, and stored with 7/8-bit each. This results in memory requirements of 24/32-bit per pixel, which is therefore smaller than the raw-data (floating point) by a factor of 1.333 (i.e. 4/3)

SOFTIMAGE|XSI Map

The 3D-program SOFTIMAGE|XSI provides its own data format for storing HDRIs. Those files are called "Memory-Mapped-Image", and they have the file-extension **.MAP**. Picture in the **.HDR**-format can be converted into a MAP-file by using he program HDRITOXSI.EXE (**http://www.xsiturkiye.com/temp/hdrtoxsi.exe**).

HDR

This format was first published in 1987, and also known as the „Radiance-format".

Having been developed for the „Radiance"-program by GREG WARD, the pictures were stored with the **.PIC** file-extension. The pictures which we find today have the file-extension .HDR in order to prevent confusion with other PIC-formats. After a simple, but expandable ASCII-Header follows the picture data. The color is stored as a 24-bit RGB-value that is independent from brightness levels. On top of this there is an 8-bit exponent which returns the standardized color to the correct brightness. The thereby derived 32-bit are compressed line-by-line using a Run Length Encoding (RLE) process. The picture is ca. half the size of an uncompressed 24-bit picture.

OpenEXR

The most recent file format was created by a company called ILM for editing their large cinematic movies. The file-header also can contain additional information like camera position and –settings, color corrections and parameters for editing programs. Besides the picture data storing as 32-bit floating point numbers (**float**) there is also a memory-saving 16-bit floating point number (**half**) variation. Although the dynamic range of **half** (as compared to **float**) is reduced, it is quite sufficient for editing and storing HDRIs, and it does not result in significant limitations for practical use. Besides the color channels (RGB or YUV) there are also further channels like Alpha, depth and surface vectors which can be added. For compression of the channels there are 3 methods available – all without data-loss – which (according to ILM) can reduce the memory requirements (disk space needed) by 50%. Further information and free C++ sources can be found at

http://www.openexr.net.

HDRIs in use

When a 24-bit picture is put out by a rendering program then the result is mostly final in terms of brightness. Editing the picture beyond this point is possible only to a quite limited extent. Many rendering programs by now support saving the HDR-image as an actual HDRI-file, and that's how many of the amazing effects and possibilities only become possible, using the HDRI-technology to its maximum. Here are some samples:

A general advantage of pixel values with a higher bit-resolution is that multiple filters can be use simultaneously (back-to-back; e.g. brightness, contrast, gamma-value, color balance), without quantization effects (abrupt, visible transitions) of the color value. If filters are applied to a 24-bit picture then a noticeable deterioration of the picture will occur after only a few modification runs.

Anybody who starts playing around with the spot-light feature of the rendering program, will quickly end up with an over or under exposed picture. When the test rendering is saved as HDRI it is rather easy to assess the lighting-effects by the brightness changes in the viewer without having to alter the intensity of all light sources. There are also PlugIns available which will facilitate an automatic brightness correction – similar to the light meter of a photographic camera.

Image 4: Various mirror balls show the dynamic of their environment or surroundings. They reflect at 100%, 30% und 10%.
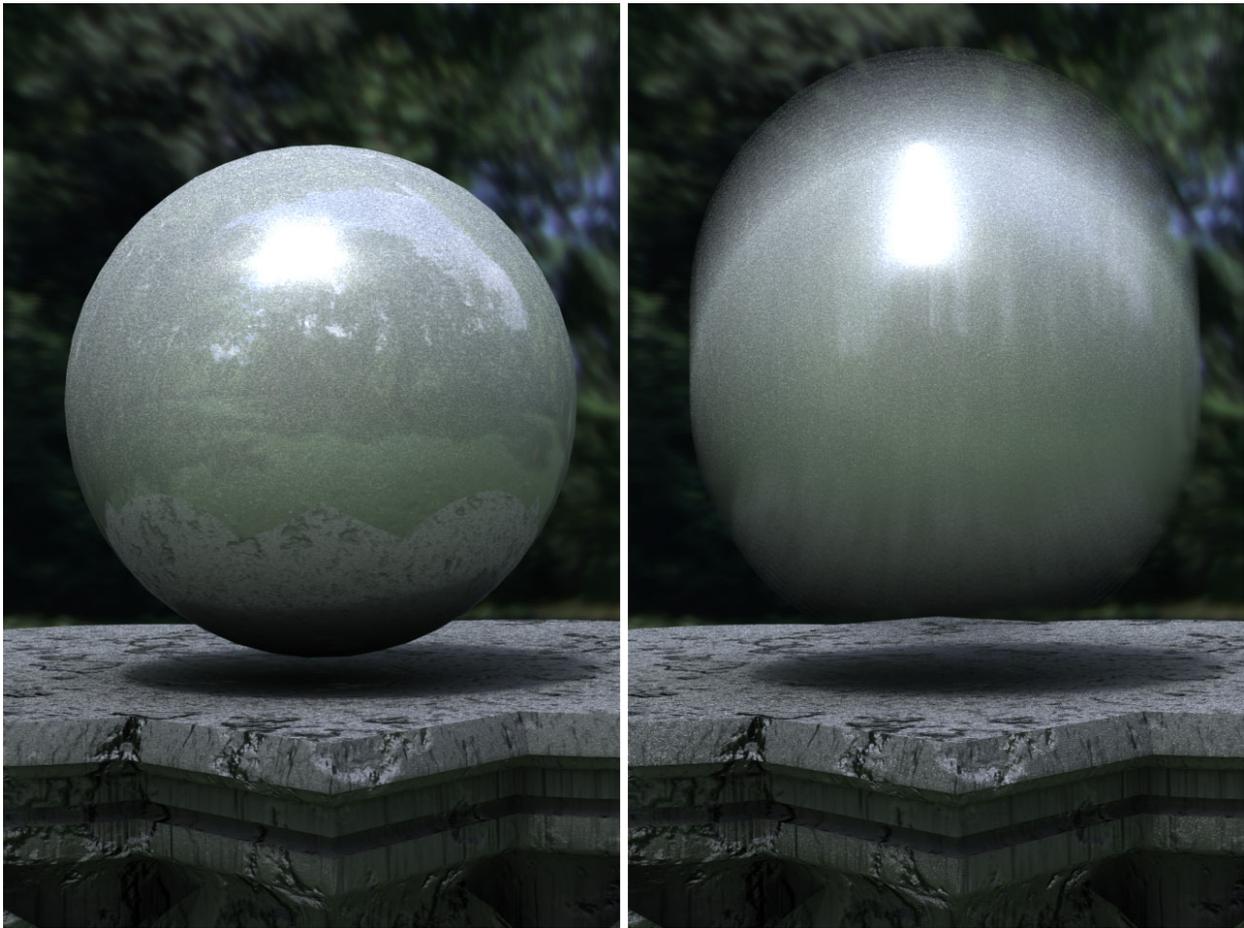
Image 5: A moved object blurs the highlights. With HDRIs the glow (effect) remains white and therefore correct.

If -for instance- a chrome sphere is placed into the rendering program then the brightness of the environment will be represented 1:1; i.e. the very bright sky will again appear as a white area (reflection) on the chrome sphere. Darker reflection materials however (e.g. a black billiard ball) will only reflect part of the light, and the mirrored image of the surroundings is therefore darkened, allowing more environmental features to become visible. As can be seen in Image 4, clouds and the outline of the sun is visible rather than a merely gray, undistinguishable sky area.

When an object is moved quickly within a scene then this will be accentuated in most rendering programs due to the „motion blurring"-effect. This effect results from the many individual pictures of the moved object being later superimposed (centered). If the moved object has a light reflex (specularity, reflectivity) or its own, texture-based light source, then the center alignment of the motion blurring will turn a white dot into a gray stripe. If the white dot is directly or indirectly based on a light in the HDRI then the actual brightness (brighter than white) is taken into account during center alignment, as demonstrated in Image 5.

A subsequent adding of a glow-effect (for reflexes and light sources) only becomes realistically feasible through the use of HDRIs. While 24-bit pictures only provide information like „white" or „dark" (for glow-effect), the HDRI also provides quantitative brightness information (e.g. how much brighter than „white" ...) regarding each pixel.

The glow-radius can be calculated using that specific information.

Similar to the glow-effect, brightness information can also be used for effect intensity when adding or editing lens-flares. A light source in the picture is brighter than white by multiples, and is therefore easy to distinguish for a filter in post production.

A very good example for all the previously mentioned HDRI-advantages are the animations „Rendering with Natural Lights" (**http://athens.ict.usc.edu/RNL**.) and „Fiat Lux" (**http://www.debevec.org/FiatLux**) von Paul Debevec (et al).
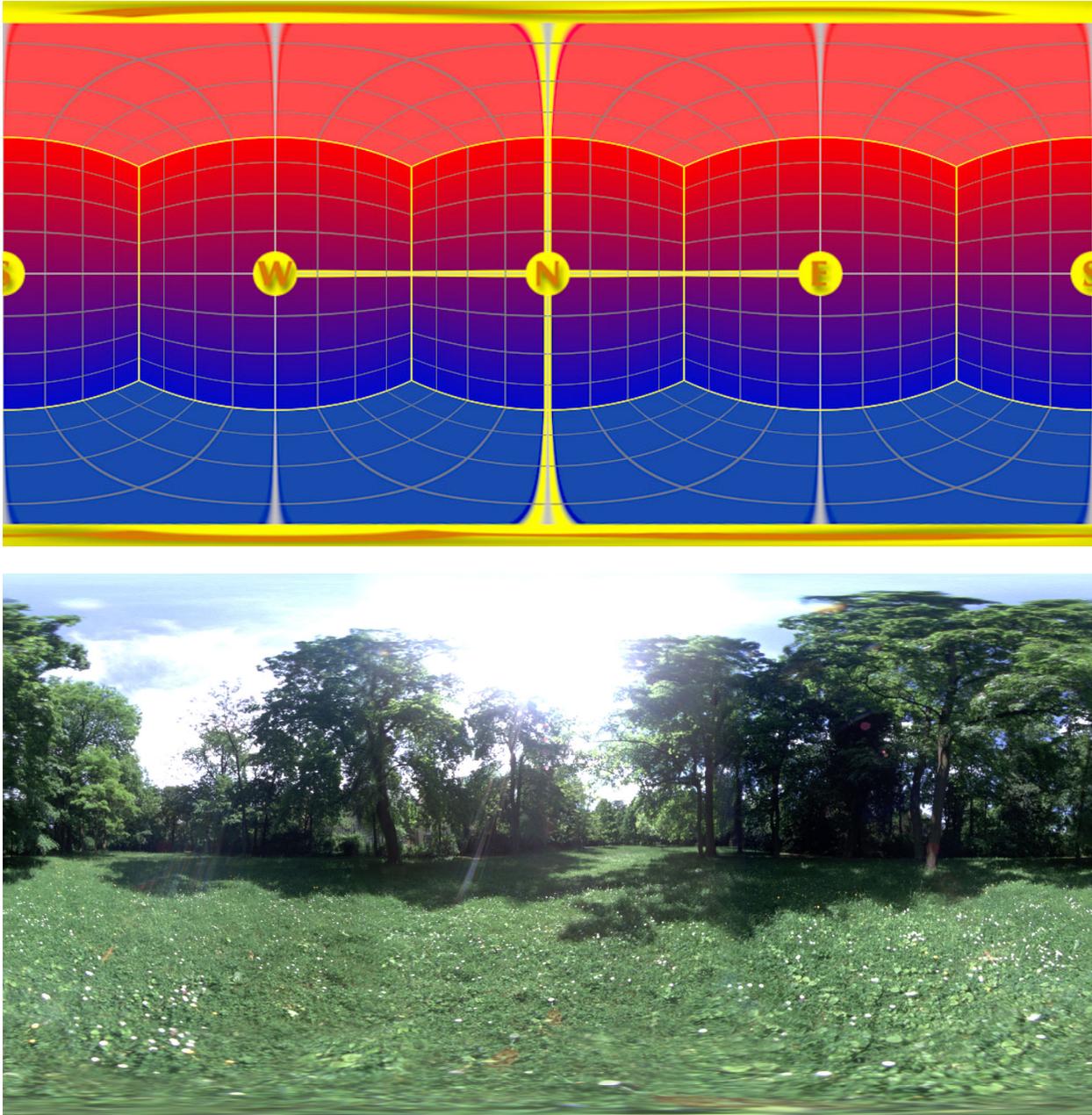

Image 6: Latitude/Longitude-mapping of the HDRI surrounding for the cover image and samples in Image 7.

Spot out – Lights on!

The most amazing, yet also simplest use of HDRIs is that as a light source (Image Based Lighting). This makes all other light sources (spots, distant lights, area lights etc.) unnecessary or certainly redundant.

Many rendering programs offer the possibility to load a picture as an „image world" (surroundings/ambient information). That way the picture is not only a spherical background, but also provides the illumination information during the use of the „Radiosity" feature. One can think of this concept as follows: every pixel on the surrounding Image-World sphere functions as a small spot-light which glows with the respective color and brightness of that pixel. Because of the distribution of the spot-lights (pixel) all over the sphere's surface the object is being illuminated from all sides.

Let's look again at the sample picture of our tree group, and expand it to a 360-degree view of its surroundings (Image 6 shows the sphere mapping (latitude/longitude), which was used for the renderings as Image-World). The greatest influence on the illumination have the pixel of the sun which are 100-1000 times brighter than the other pixel of the HDRI. Due to their large area, the sky-pixels, too contribute significantly to the overall light-quantity, and thereby to the existence and appearance of shadows. On the object side which predominantly faces the trees and the meadow (rather than the sky), various green tones will have the prevailing impact on color reflection and overall mood of the rendered image. Also will those somewhat darker areas of the HDRI be the basis for the diffuse ambient light, and therefore for the softness of the shadows.

A natural surrounding which was captured with an HDRI-camera can be projected –as Image-World- onto the 3D-object which is being rendered. The object will be illuminated exactly in that way as if it had stood in the very location where the camera was positioned when the HDR-image was taken. The result is a photo-realism which was pretty much impossible to achieve with pre-HDR photo-technology. What previously (in the „old days") required a time-consuming and often elaborate setting (and re-setting) of individual light sources is now as simple as loading a new HDRI ... with all the technical and easy-of-use HDR-advantages.

One source of a variety of surroundings and light-moods is the HDRI-product line by DOSCH DESIGN (http://www.doschdesign.com).

In order to demonstrate how powerful this lighting technology is we have placed the same 3D-object in various HDRIs, thereby giving it the HDRI's distinct surroundings and illuminations. Nothing was changed, except for switching from one HDRI to another ...

The results can be seen in Image 7.

Image 7: Examples for various HDRI-illuminations of the same scene with the matching LightProbe-picture. The first picture was calculated with a standard illumination.

The white and gray china (porcelain) texture of the dragon reflects the light and picture information of its surroundings very well. Meanwhile, the weathered pedestal nicely displays the interchanging light and shadow features. Lastly, the mirror ball permits an untainted –albeit distorted- look at the surroundings.

Glossar

HDR	High Dynamic Range
LDR	Low Dynamic Range
EV	Exposure Value

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