



An Introduction to Using mental ray in Autodesk 3ds Max Design 2014

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AV2742 Using the mental ray rendering engine in Autodesk 3ds Max Design software can be an intimidating effort. This class primarily focuses on demystifying global illumination (GI) and final gather (FG) within the context of the interior and exterior rendering types that are typical of architecture, engineering, and construction (AEC) visualization. Included in the class materials are tutorials complete with ready-made scenes to help you practice with the mental ray rendering process as well as experiment with mental ray settings on your own.

Learning Objectives

At the end of this class, you will be able to:

- Explain what mental ray is, what it does, how it works, and how it fits into your rendering workflow;
- Create compelling high-quality renderings with the global illumination and/or final gather features in mental ray;
- Optimize your use of GI and FG to lower rendering times;
- Consistently use mental ray for common AEC visualization scenarios

About the Speaker

Matt is the senior AEC applications and Building Information Modeling (BIM) implementation technical specialist for CADapult Ltd., an Authorized Autodesk Silver reseller servicing the Mid-Atlantic region.

Matt specializes in training architects, engineers, and builders of all kinds on all of the applications in the Autodesk Building Design Suites, focused primarily on implementing BIM on the Revit platform, Navisworks, and related applications. He regularly provides BIM implementation and related consultation services to his customers.

Matt also provides specialized BIM support services for the construction industry, such as construction modeling, shop drawing production, and project BIM coordination.

Matt has been using Autodesk® software since 1987 and has over 20 years of experience as a CAD and IT Manager for several A/E firms in Delaware, Pennsylvania, and Boston, Massachusetts. This is his 10th year speaking at Autodesk University.

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Section I: Introduction

Class Objectives

This class is intended primarily to provide users of 3ds Max Design 2014 a basic understanding of the mental ray rendering engine and its primary features. It is not an exhaustive summary of every feature or option. The goal is to provide a fundamental education on the following three concepts:

1. Understand the base theory behind mental ray's ray tracing and sampling techniques;
2. Understand each of the primary functions in mental ray: Photon Mapping (Global Illumination), Final Gather, Daylight Systems, Ambient Occlusion, and Caustics
3. Understand how to apply each of these functions to your scenes without a lot of guesswork and wasted rendering time

Things we may mention in class but won't explicitly cover in detail:

- Every single button, dial, switch, checkbox, and edit box available in the various mental ray functions;
- Backburner-based network rendering and Distributed Bucket rendering;
- Importons and Irradiance Particles;
- mental ray proxy objects;
- Animated scenes;
- Lighting analysis tools;
- Specific issues with importing models from Revit and other applications.

Additional information on some of these mental ray and 3ds Max Design topics can be found on the Links page of this handout.

Courseware

The course materials provided with this class consists of a 3ds Max Design project with several models, some created specifically for this class and some pulled from the 3ds Max Design 2014 tutorials. One of the included models is the beach house scene from the “Interoperability Tutorials > Using Autodesk Revit” section.



I chose this scene because it should provide good practice for you to try out the concepts we talk about during class. You can find the complete 3ds Max Design 2014 tutorials at <http://usa.autodesk.com/adsk/servlet/item?id=21379230&siteID=123112>

The Cornell Box models referenced in this handout are from the DVD included with Jennifer O'Connell's book Mastering mental ray: Rendering Techniques for 3D and CAD Professionals. They are not provided with the class materials but are available here: <http://mastering-mentalray.com/CGSchool/>. Although a bit dated for 3ds Max Design 2014, I can still highly recommend this book as it goes into every single detail about the mental ray rendering engine.

Using the Dataset

The dataset .ZIP is a 3ds Max Design project directory that contains the models and assets used in class. To use it, simply expand the .ZIP to your C:\ drive. The paths inside the AV2742 Mental Ray in 3ds Max Design.mxp project file are relative to the root of the project folder, but also include paths to the standard C:\Program Files\Autodesk\3ds Max Design 2014\ installation folder for maps.

In 3ds Max Design, on the Quick Access toolbar, click the Project Folder button in the Quick Access Toolbar and set your current project to **C:\AV2742 Mental Ray in 3ds Max Design**



Basic Concepts

What is mental ray?

Mental Ray - stylized “mental ray,” no uppercase - is the premier production-quality rendering engine found in most of Autodesk’s applications, such as 3ds Max / 3ds Max Design, Maya, Revit, Navisworks, and AutoCAD. mental ray has a long history of high achievement in the entertainment world, having been used in such films including Star Wars Episode II: Attack of the Clones, Hulk, The Matrix Reloaded and the Matrix Revolutions, and many others.

Over the years mental ray has gathered a huge following in with designers and artists, who rely on its ability to create high impact architectural and engineering visualizations of outstanding quality and realism. mental ray’s sophisticated ray tracing and sampling techniques allow for fast renderings on any hardware platform, and its highly optimized parallel render engine scales very well with multi-processor machines as well as across a distributed network of machines for optimum performance.

History

mental ray was initially developed by a company called mental images GmbH, a CGI software firm in Berlin, Germany. The company was founded by physicists and computer scientists to provide photo realistic rendering and 3D modeling technology to the entertainment, AEC, and scientific visualization industries. The mental ray software project was started in 1986 and early versions of the software were used in mental images’ own computer animation division, but quickly became adopted by the special effects industry, winning an Academy Award for Technical Achievement from the Academy of Motion Pictures and Sciences in 2003.

In December of 2007 mental images became a wholly owned subsidiary of NVIDIA Corporation. After the acquisition the company was renamed the NVIDIA Advanced Rendering Center (NVIDIA ARC gmbH), who continues development of mental ray along with its cousin, the iray® photorealistic rendering solution also found in 3ds Max, 3ds Max Design, and Maya.

Implementation in Visualization Software

Autodesk began licensing and integrating mental ray into 3ds Max 6 in 2003, while it was still developed by mental images. Autodesk works closely with NVIDIA to support mental ray and iray as it implements the software into their various applications.

This relationship is important for a number of reasons. First, understand that 3ds Max Design and mental ray / iray develop independently of 3ds Max Design and each other. NVIDIA ARC may pump out several point iterations of mental ray within a single 3ds Max Design release year. NVIDIA drops off a new version at Autodesk’s door, which may contain some new whiz bang features, which Autodesk may incorporate into a new 3ds Max Design release or as part of a service pack. This is one of the reasons why 3ds Max Design may have 6 or 7 service packs a year while Revit has one or two. For example, 3ds Max Design 2013 Service Pack 6 included a new version of iray that supported hardware rendering on the newer Kepler-based NVIDIA graphics cards.

Second, while 3ds Max Design, Revit, Navisworks, AutoCAD, and Maya all have the mental ray rendering engine, the interface in each application, as well as the number of settings exposed to you for tweaking, are all quite different. That is because it is Autodesk’s job to implement the user interface and determine the level of interaction with mental ray. Autodesk can easily assume settings for mental ray in Revit and

AutoCAD that are good for 99% of the time and bake them in the software, whereas 3ds Max Design and Maya have those controls fully exposed as yet another check box, knob, or button in the user interface.

Third, when NVIDIA releases a new version of mental ray for Autodesk to implement, they may not put everything together in the user interface for a particular product release. The feature may exist but be accessible only through scripts or mental ray String Options, which is sort of like a command line for driving mental ray. For example, in mental ray 3.11 present in 3ds Max Design 2014, NVIDIA has included hardware-accelerated Ambient Occlusion¹. Folks with NVIDIA CUDA-powered graphics card (that is to say, anyone with an NVIDIA card that is less than 5 years old) can have the GPU calculate AO, essentially getting this special effect for free. However, it is not yet exposed as a formal user interface with rollouts and buttons and dials. To use GPU AO you have to use String Options or a script. See here: <http://forum.nvidia-arc.com/showthread.php?12503-3dsMax-2014-and-mental-ray-AO-on-the-GPU>.

Future Releases of mental ray Look Bright

Unlike Autodesk, Microsoft, Adobe, and most other software companies, NVIDIA ARC actively promotes new features planned for upcoming releases of mental ray and iray. Recently NVIDIA announced that every release of mental ray from here on will include at least one GPU-capable function². Meaning, instead of that function taking CPU cycles to calculate, it can be done on the (NVIDIA only) graphics card and complete much, much faster. Most conservative estimates say GPU-based rendering is about 12x faster than CPU-based rendering.

Features of mental ray

mental ray is such a fully featured renderer it is hard to know where to begin to define exactly what it does. Let's first look at what features mental ray brings to the table:

Adaptive ray tracing and sampling. mental ray's approach to processing an image is to "spray" the scene with rays and trace their paths through the scene, which are affected by the surface materials they interact with to provide the indirect illumination. mental ray can and will adapt itself to use very fast scanline techniques where it can, and scenes that can take advantage of this often render faster. mental ray's sampling mechanism (discussed later) will adapt itself to spend time where it needs to in order to refine small details, but plow through areas where it is not necessary.

Highly parallelized processing. Rendering jobs are highly parallel in nature; that is, the entire rendering task can be broken down into smaller chunks which can be processed separately and independently from each other. This allows your rendering jobs to automatically take full advantage of multi-core processors and multi-processor machines, as the rendering will scale up with the capability of the machine.

To facilitate this parallel nature, mental ray uses a technique called **Bucket Rendering**. mental ray renders out scenes in square areas called buckets. Each bucket is independently handled by a single processing core on your computer, and is processed before moving on to the next bucket. Once a bucket is done with that round of processing - mental ray usually makes several passes across an image to produce the final result - the renderer automatically jumps to the next easiest bucket to manage.

¹ <http://www.nvidia-arc.com/products/nvidia-mental-ray/nvidia-mental-ray.html>

² <https://twitter.com/mentalray/status/390446138815303680/photo/1>

32-bit High Dynamic Range (HDR) environment. mental ray fully stores render data as 32-bit floating-point values, which stores absolute luminance values for each pixel, allowing an image to be displayed using different exposure settings. HDR images contain the full dynamic range of color and light and is essential for accurate daylighting analysis.

Ray traced shadows. Ray-traced shadows are very crisp and accurate, support transparency, and use little memory at render time. They are created by casting a ray from a sample back into the scene to a rendered surface then on to the light sources. If the ray is blocked from getting to the light by another object, a shadow is generated on the surface. You should always use Ray traced shadows with mental ray.

Energy conserving materials. To allow mental ray to produce realistic results, the materials you use in your scene need real-world properties embedded in them to accurately respond to light. The Arch & Design and Autodesk materials found in 3ds Max Design (and all other Autodesk applications that include mental ray) are in fact mental ray specific materials. They are termed “energy conserving” because they follow the simple rule that light energy being reflected from or refracted through a surface never exceeds the light energy striking the surface. There is always light energy absorbed by materials, but there can never be a case where light energy increases after striking a surface. mental ray materials necessarily need to support High Dynamic Range (HDR) to provide the correct surface appearance and provide accurate lighting analysis.

Support for photometric lights and the Daylight System. mental ray supports 3ds Max Design’s photometric lights and supplies a few of its own. This includes the mr Sun and mr Sky, used in the mental ray Daylight System (also called the mental ray Sun and Sky solution). mental ray also provides a third light called an mr Sky Portal, which is a special light that is used to assist in bringing exterior sunlight into an interior scene.

mr Physical Sky environment map. The mr Physical Sky environment map (also called a shader) is typically assigned automatically when you create a mental ray Daylight System and is designed to work with the mr Sky and mr Sun lights to represent the background.

mr Photographic exposure control. An improvement over the older Logarithmic exposure control, the mr Photographic exposure control produces excellent results when combined with the Daylight System and the mr Physical Sky environment map. When you create a Daylight System it will also want to assign the mr Physical Sky environment map as well as assign the mr Photographic Exposure control to create a cohesive system of integrated lighting, environment, and exposure control settings.

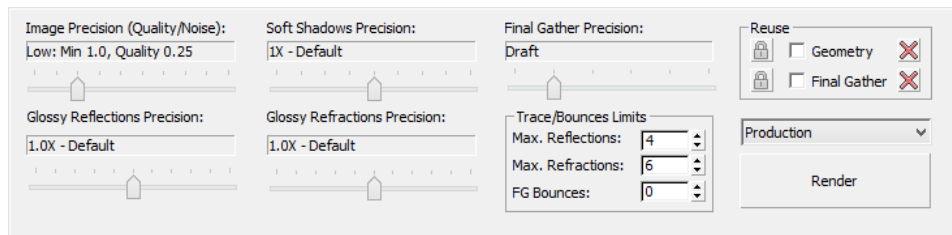
Distributed bucket rendering and Backburner network rendering support. Because of this subdivision of labor, mental ray can make use of processors on your machine and on remote machines as well. To mental ray there is no difference between a bucket rendered locally and one rendered a few feet - or thousands of miles - away. Just tell it where to send the job and a remote machine can pick up the labor. Once the bucket is rendered it is sent back to the originating machine and assembled into the final image.

Backburner is Autodesk’s network rendering software that is included in 3ds Max Design and is typically installed with the program. Backburner provides the plumbing for assigning rendering tasks to different computers in your rendering farm and coordinating how the jobs are processed. Note that distributed bucket rendering and Backburner are separate things; you don’t use Backburner to manage distributed bucket rendering jobs. However, you can use both together to speed up your renderings even more than using either one separately.

Lighting analysis tools. With the combination of the mental ray Daylight System, mr Physical Sky, and mr Photographic exposure control, mental ray provides an accurate means of measuring illuminance, or light energy, at specific places in your scene. mental ray's lighting analysis capability can assist designers to produce documentation used for Leadership in Energy and Environmental Design (LEED) certification.

Efficiency with presets and maps. mental ray has several features that allow you to save rendering preparation and calculation time. mental ray comes with a series of presets that will dial in mostly proper values for Image Precision and Final Gather, which make it easy to create low cost test renderings for evaluating the scene as well as the final rendering. mental ray also allows you to pre-calculate and store the results of expensive operations such as Global Illumination and Final Gather, and save those calculations in map files that can be written to and read from disk. These maps can be recalled at a later time to produce the final rendering more quickly. This class will provide some tips and tricks for making the most of this to ensure render times are kept low.

Simplified Rendered Frame Window controls. When mental ray is set as the renderer, the Rendered Frame Window provides a series of simplified mental ray specific controls at the bottom which establish the precision settings for anti-aliasing, soft shadows, glossy reflections and refractions, and Final Gather. This was designed to lower the learning curve and provide the fine tuning knobs required. For still images, you are primarily concerned with fine tuning rendering quality versus rendering speed.

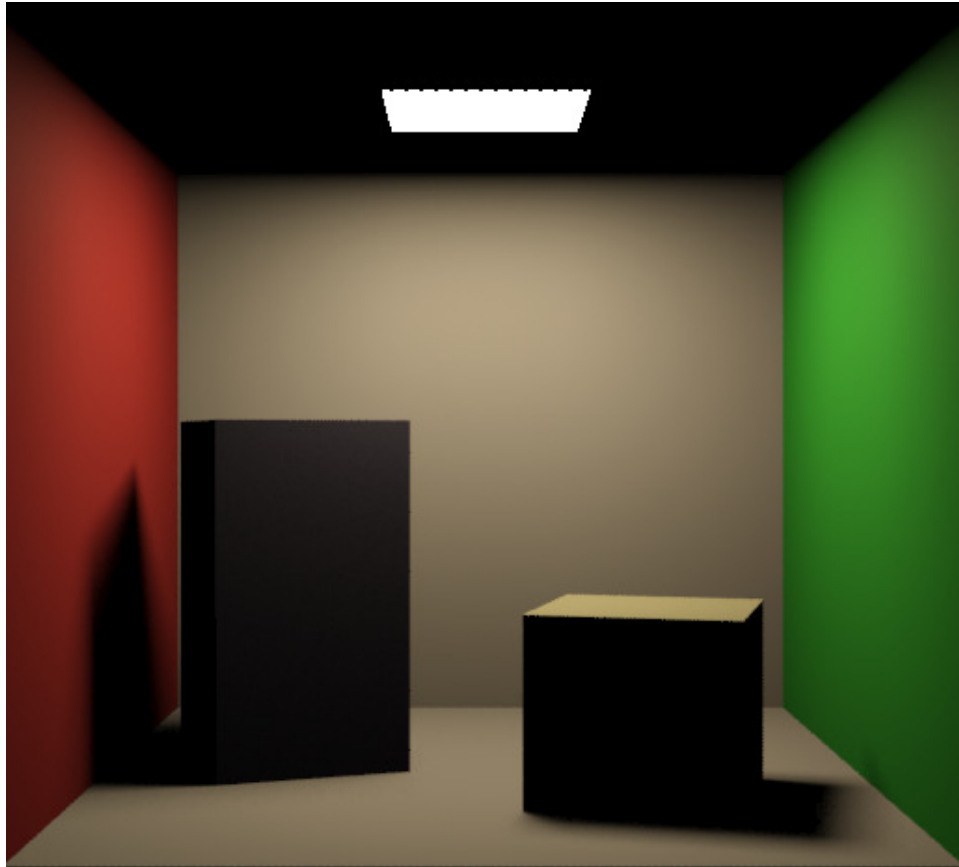


mental ray includes additional features, such as Adaptive and Unified Sampling, that are best left to more technical discussion in the next section.

Direct and Indirect Illumination Theory

The basic premise of any photorealistic renderer is to simulate both direct and indirect illumination. Direct illumination is the light rays which originate from a light source and shine directly on surfaces. It does not bounce off of, reflect from, or refract through the surfaces it hits.

Images that only use direct illumination are flat and do not represent reality, because areas which do not receive direct illumination are pure black. This is perhaps best exemplified in the following image:



The Cornell Box model above was provided on the companion DVD to Jennifer O'Connell's book *Mastering mental ray: Rendering Techniques for 3D and CAD Professionals*³. The Cornell Box is an industry standard test model aimed at determining the accuracy of rendering software. It was created by Cindy M. Goral, Kenneth E. Torrance, Donald P. Greenberg, and Bennett Battaile at the Cornell University Program of Computer Graphics for their paper 'Modeling the Interaction of Light Between Diffuse Surfaces' published and presented at SIGGRAPH'84.

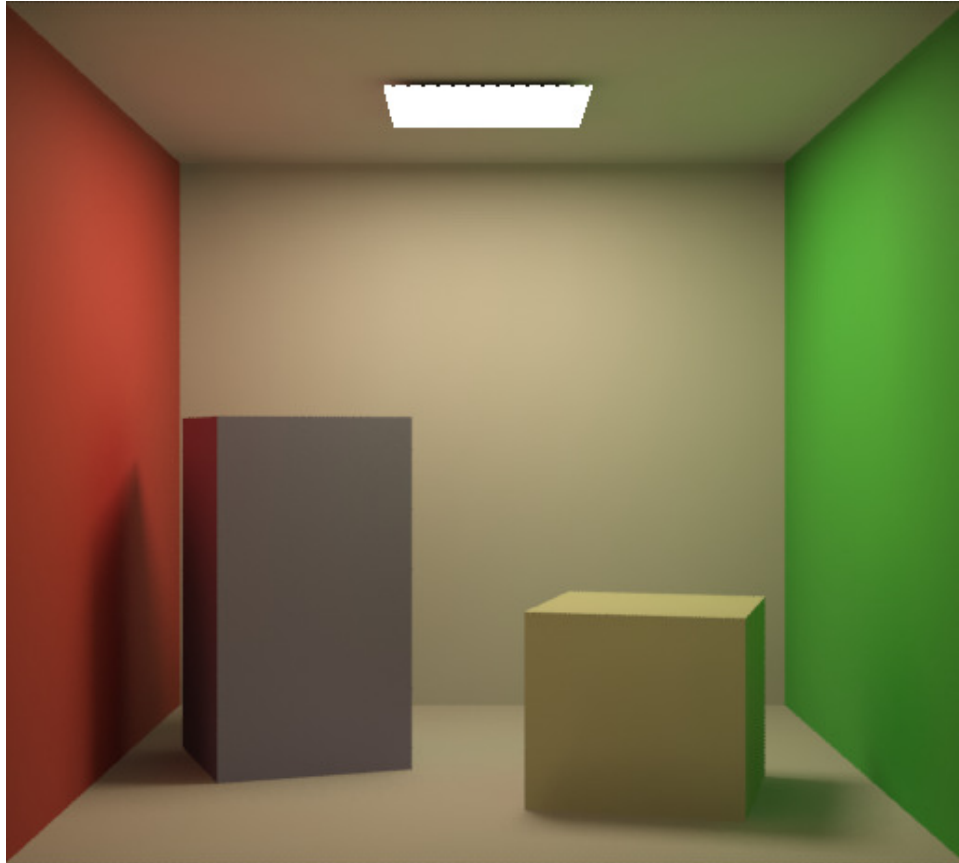
The above rendering is using direct light only. Note there is no illumination on the top of the room or on the front sides of the boxes that are occluded from the light source above.

Indirect illumination is the light that is bounced off of and refracted through objects in your scene. It is the very nature of light to interact with the surfaces it hits. Nearly all objects reflect at least some light energy

³ Note: All rendering in this document was performed by Matt Stachoni.

(they would be invisible if they did not) and thus become sources for indirect illumination as the light propagates from one object to another. It is the resultant color of that light which is of interest to the mental ray engine as that is the color that meets your eye.

Now add indirect illumination (here provided by Final Gather alone, using the default settings):



Here you see the dramatic effect of bounced light influencing the surroundings with active color bleed on neighboring surfaces.

Why does this happen?

Remember from grade school physics that the color of an object is simply(?) the wavelength of the visible light portion of the electromagnetic spectrum that is reflected by the object. A pencil is yellow because the paint absorbs all of the visible light wavelengths other than that for yellow. Black objects absorb all visible light wavelengths, whereas white objects reflects all visible light wavelengths. Therefore, when an object reflects light energy, that energy has now by definition changed to that of the color of the object that we see. The physical properties of the materials encountered will determine how much of that light energy wavelength is reflected, absorbed, and refracted.

Additionally, the light energy hitting the object is of a particular wavelength (color) itself, which will impart its color on the surface, combine with the material's properties, and thus return the reflected color. That reflected color is influenced by the light color hitting it. In this manner colors will bleed from one object to the next as the reflected light energy changes colors from object to object, as seen in the above image. As light bounces around from surface to surface it will impart a color change on the surface material -

altering the reflected color based on the input light color and surface material - and travel to the next object with a different color, where it will do the same thing. Refer to the section on Global Illumination which illustrates this concept.

It is the indirect illumination aspect of light which underpins the foundation of mental ray. The ray casting and sampling techniques used by mental ray are built to directly emulate the physical phenomenon of reflected (bouncing) and refracted (bent) light energy, and to turn that into a beautiful bitmap image. Indirect illumination is generated primarily by mental ray's tools Global Illumination (photon mapping) and Final Gather. Other aspects of mental ray, such as Ambient Occlusion, Caustics, and the mr Sky Portal provide lighting effects and utilities to better simulate how light behaves in certain situations, e.g. through a window, near the corners of a room, or as light passes through faceted glass.

Comparing mental ray in Revit to 3ds Max Design

For Revit users, there are some distinct advantages to exporting your scene and rendering in 3ds Max Design rather than the native application:

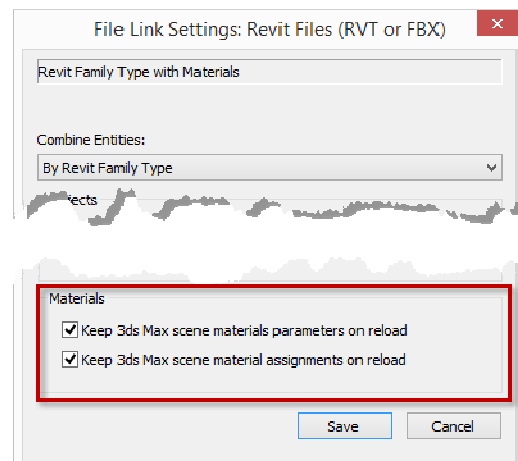
Better shadow studies. Revit's Sun Settings allow for somewhat limited shadow studies, are view based and get exported to FBX. They import into 3ds Max Design as a mental ray Daylight System complete with the mr Sun and mr Sky, mr Physical Sky environment map, and the mr Photographic Exposure Control. 3ds Max Design's sun settings include automatic Daylight Savings time adjustment.

More powerful material mapping. Materials in Revit do not expose their UV mapping, and as often the case with grained materials such as wood the grain is running in the wrong direction. Because of the way materials are assigned in Revit, they are often impossible to fix in that application.

Easily modify and override materials. Materials in Revit are typically set in the type properties of each element, and this one-material-fits-all approach is often not desirable. You may want to override a material in a particular area or on a specific face, but without the overhead of creating a whole new wall type or using the Split Face tool. With 3ds Max Design you can also override materials globally for critical lighting evaluation and tuning, and reduce material reflections or glossiness which can reduce render times considerably.

Preserve material changes through design iterations.

The Manage Links > Presets tab > File Link Settings dialog box provides an option exists to preserve the 3ds Max scene materials and assignments when the model is reloaded. You can make modeling changes in Revit, link it back into 3ds Max Design, and keep the material overrides and settings in the working Max scene intact.



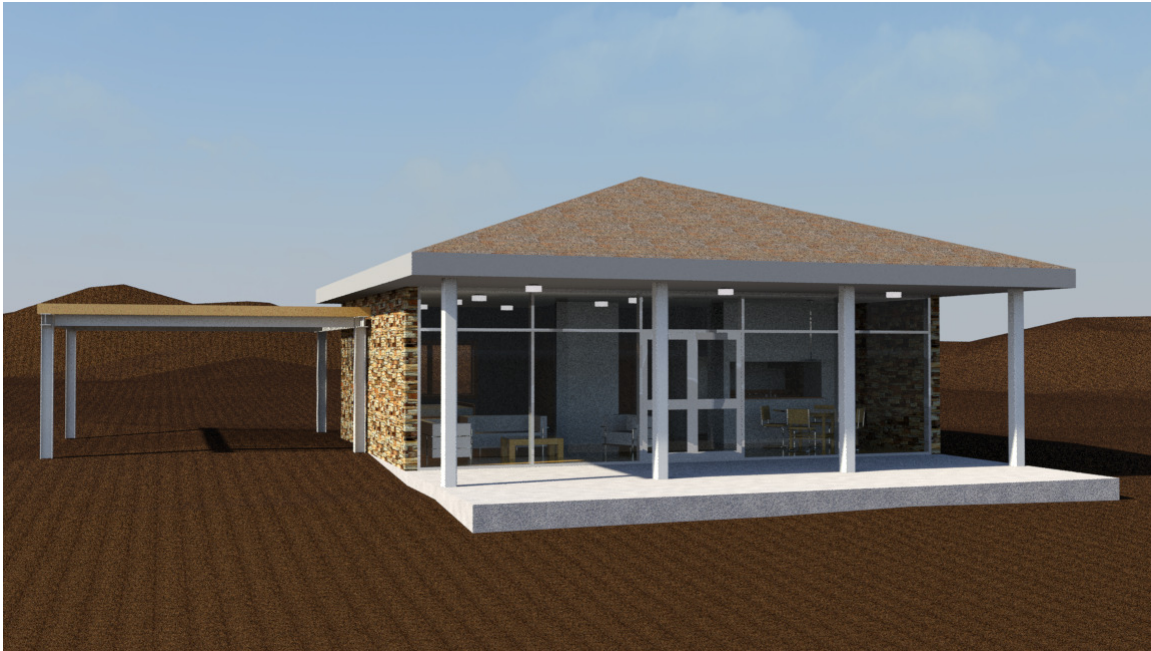
Generally faster and better quality rendering. For complex scenes it can take about twice as long to render a scene in Revit as it does in 3ds Max Design with the same comparable quality. However, Revit rendering is primarily based on presets and baked-in values, whereas much more of mental ray is exposed and able to be optimized in 3ds Max Design. It can never be a true apples to apples comparison because there are so many additional variables in 3ds Max Design, whereas most of the settings for mental ray rendering in Revit are expressed as a single number.

For example, Revit's "Image Precision" setting is expressed as a single number, and the difference between a setting of 4 (the Medium setting) and 6 (the High setting) can double the length of time it would take to render. This single number has no correlation to the settings available in 3ds Max Design's mental ray interface. That single number is most likely a combination of several individual mental ray settings.

Render quality can be markedly different between the two applications. The following image was rendered in Revit using strict Medium settings, resolution set to Screen. It took 10:24 (min:sec).



The file was exported as-is to FBX and linked into 3ds Max Design. The mr Photographic Exposure Control was set to an EV of 13, the resolution was set to 1152x648 in the Render Setup Common tab (the same render resolution as in Revit), and the Render button was pressed. It took 8:11 to produce this image.



In this case the total time to get the scene out of Revit and into Max and end up with a rendering is about the same, but as you can see the 3ds Max Design rendering is overall brighter with deeper contrast. Notice the additional details you can see inside the beach house in the Max rendering. To get the same quality in Revit would require adjusting post-render exposure and quality settings or, more likely, performing post work in Photoshop. My rule of thumb is that Revit is good for quick one-off renderings using a Draft or Low quality setting, but final renders will always look better in 3ds Max Design and are worth the export/import overhead.

Special Effects and Render Elements. 3ds Max Design includes atmospheric effects and depth of field. You can also export specific pieces of the rendering as separate HDR images and tweak them separately in a compositing program like Photoshop or Autodesk Composite.

Distributed bucket rendering and network rendering through Backburner. The best way to render large jobs in 3ds Max Design is to use multiple machines. Setting up a Backburner render farm is cheap (free) and well worth the effort, allowing you to produce more scenes in less time.

Ability to pre-compute and reuse Final Gather and Global Illumination maps. Final Gather calculations can be particularly time consuming. It's often best to pre-calculate the FG map using a lower resolution and reuse the map for the final large rendering.

Global Illumination (photon mapping). Revit only provides Final Gather as a means of creating indirect illumination. While it's very good on its own, using Global Illumination (GI) in combination with FG produces better results in less time than using Final Gather by itself, because FG will use the illumination provided by GI to get to the final render faster.

Material-specific Ambient Occlusion (AO). The ability to fine tune AO on a material by material basis is great for bringing out fine details without killing render times.

Built-in Lighting Analysis. 3ds Max Design has LEED-compliant lighting analysis functionality built in, whereas you would need an add-in such as ElumTools to analyze lighting in Revit.

mental ray Sampling

mental ray's primary job is to produce realistic bitmap imagery from 3D geometry and physically based lighting using ray tracing. Ray tracing is a point sampling process whereby rays strike the 3D model surfaces and calculate light intensities. These rays are infinitely thin; however, images are composed of pixels which have a specified width and can be only one color. Ray tracing shoots a single primary ray from the eye through the center of each pixel as it travels to the geometry, and uses the color of that ray sample as the color of the pixel. Think of it like a giant wire mesh screen placed in front of your 3D scene that you shoot your sampling rays through.

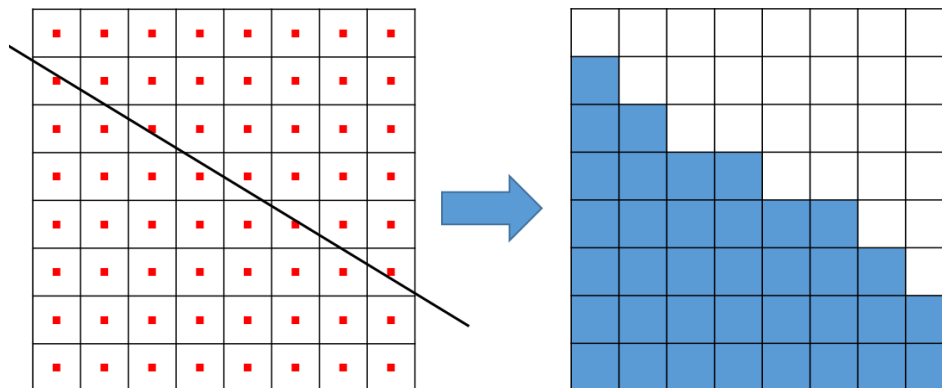
A problem occurs with this because the resultant color of the pixel is based on one infinitely small sample taken within the center of the pixel. The pixels are the same size, and edge artifacts called Aliasing will occur because the sampling rate (one sample per pixel) is often not enough to accurately describe the geometry it strikes. For small details or pixels that occur at edges, the square geometry of the pixel results in jaggedness and stair-stepping effects which reduces realism.

To solve this, final pixel colors are determined by looking at (sampling) adjacent pixels, interpolating these pixel colors together. This tends to blur the edges and softens them as the pixel takes on characteristics of its neighbors. As you can guess, the number of samples inspected has a direct impact on rendering times and the overall quality of the image. The trick is to adjust sampling rates such that the image and its render times is acceptable.



You can set sampling rates to sample less than each and every pixel (under sampling), once per each and every pixel, or several times per pixel (super-sampling). Fewer samples will render faster but without detail and be full of jaggies at the outlines of objects because each pixel along that edge doesn't take into consideration the surrounding pixels, and won't mix the colors properly.

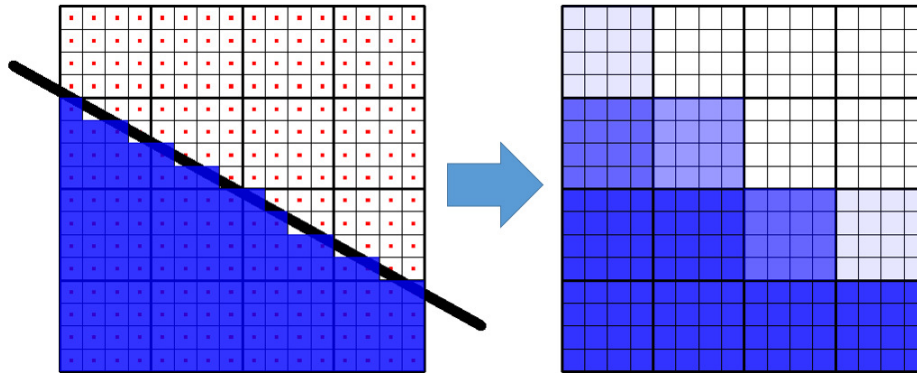
At a sample rate of one sample per pixel, you have the following result. The black line represents the edge of the blue box above. To translate the vector line into a map of pixels, a sample was taken at the center of each pixel; if the color at that point was white, it's a white pixel. If its blue, it's a blue full pixel.



This produces a very uneven, jagged edge, because the position of the line edge position within the pixel is infinitely variable, but the pixel colors are not. However, with super-sampling we can subdivide the same single square pixel into 4, 16, or 64 sub-pixels, and sample the centers of those, then mix the colors

of these samples together. If we have 16 subpixels and 4 of them are blue and 12 of them are white, the resultant pixel would be 4/16 blue and 12/16 white.

Performing the same test again with a 16-sample-per-pixel setting, we get this:



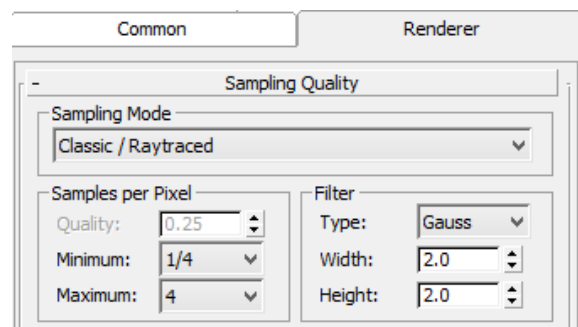
And the overall smoother the edge will look, because the pixels are a mix of blue and white instead of strictly one or the other. This effectively blurs the edge intelligently based on the vector position within the pixel.

Thus, the higher the number of samples per pixel the better approximation of the pixel color, but more calculations means slower rendering times. The beauty of mental ray is that it is adaptive in how it samples the scene, and can automatically work harder on areas that need it (areas of high contrast) and crank through areas with less detail. You can tweak this adaptive behavior to affect how mental ray's adaptivity works, which can save rendering time considerably. On the other side, you can force the renderer to sample pixels by the same amount, known as the brute-force method.

Super-sampling is but one part of the picture (argh, sorry). After the sub-pixel colors have been determined via sampling, they are not simply averaged together to produce the final pixel color, but are summed using one of several provided filtering methods to smooth the final image. This is formally called Anti-Aliasing and is a key feature of all 3D software. Different filters produce different image characteristics, either blurring or sharpening the image to varying degrees. Some filters produce softer looking images, some harsher, and with various impacts on rendering times.

When using this "Classic" method of sampling, you can control the adaptive behavior by specifying the minimum and maximum number of samples per pixel in the Render Setup dialog, under Sampling Quality. The numbers are expressed per pixel, so as shown below a fractional number of 1/4 for the minimum means one sample is taken for 4 pixels (under sampling) and the maximum is 4 samples per pixel (supersampled).

The Minimum value allows mental ray to work very quickly through areas of even coloring and low contrast, because it doesn't need sub-pixel sampling to provide the correct results. mental ray will step up the sampling subdivision to to the Maximum value, which is ultimately how much mental ray will work to resolve the fine details and areas of contrast.



Typically the minimum and maximum values should be around two to three steps apart for efficiency and no more than four steps apart, and they certainly should not be equal. 3ds Max Design's "Medium" preset is 1/4 and 4 and works well enough for fast test renderings. Remember that the higher these numbers the longer your rendering will take, and a value of 64 is rarely if ever needed. Conventional wisdom uses a Minimum = 1 and a Maximum = 16 for final renderings.

Of course, now that we've gone to Unified Sampling in 3ds Max Design 2014 (discussed next), you shouldn't have to set this, ever.

Unified Sampling

New in 3ds Max Design 2014 is an improved sampling method called Unified Sampling. Unlike the "classic" Anti-Aliasing sampling method where the sampling pattern inside a pixel was roughly a grid, Unified Sampling is a smarter sampling pattern that only takes samples where it needs to. This results in less wasted sampling, faster render times, and finer details in the image. Instead of a rigid grid of samples, they tend to look more like a shotgun blast within the pixel:

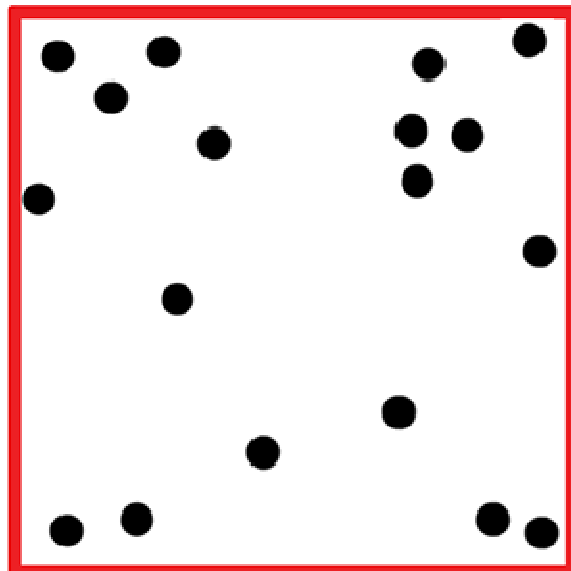
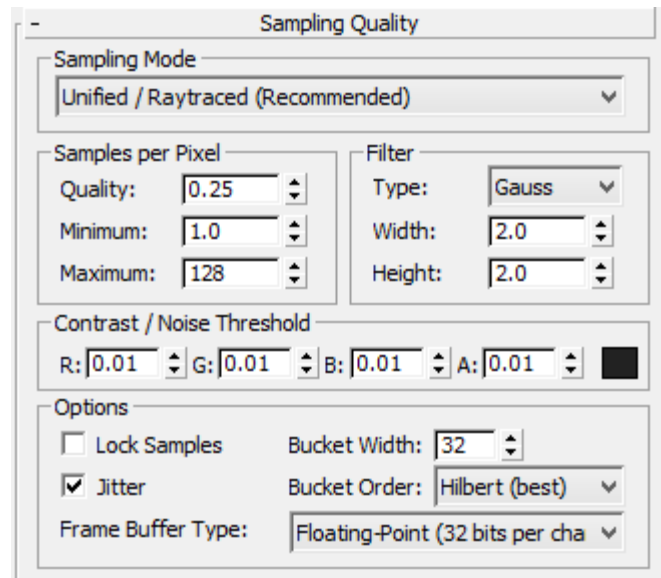


Image Source: <http://elementaray.wordpress.com/2011/11/30/unified-sampling-visually-for-the-artist/>

Here is a description taken directly from <http://elementaray.wordpress.com/2011/10/31/unified-sampling/>:

"Technically speaking, Unified is Quasi-Monte Carlo (QMC) sampling across both image space and time. Sampling is stratified based on QMC patterns and internal error estimations (not just color contrast) that are calculated between both individual samples and pixels as a whole. This allows unified to find and adaptively sample detail on a scale smaller than a pixel."

Unified / Raytraced sampling is turned on by default in the Render dialog > Renderer tab > Sampling Quality rollout. Although Classic / Raytraced and Rasterizer / Scanline sampling modes are still provided, Unified / Raytraced is the sampling method you should use. There are just a few knobs and dials to tweak here, with the defaults providing solid results. While you can adjust any of the settings in this rollout, you really just tweak the "Quality" setting, which sets the sampling limits. Lower values render faster but produce grainier images. Values are 0.1 to 20, with the default being 0.25.



There are now three easy knobs to adjust. Paraphrasing from <http://elementalray.wordpress.com/2011/10/31/unified-sampling/>:

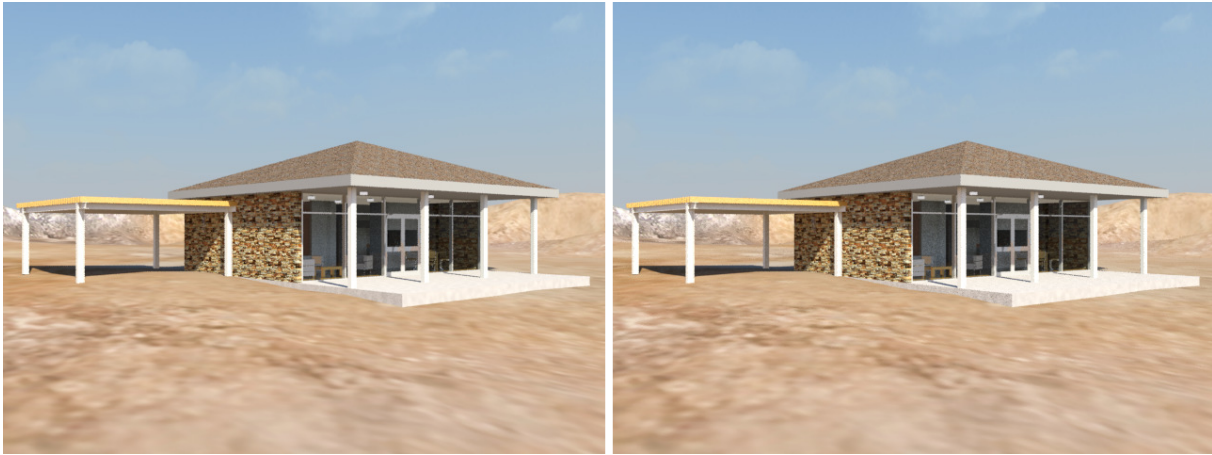
Quality: This is the knob to control overall image quality. Increasing quality makes things look better but takes longer. It does this by adaptively increasing the sampling in regions of greater error (as determined by the internal error estimations mentioned before). You can think of quality as a samples per error setting. Render time increases logarithmically with Quality.

Generally leave it somewhere between 0.5 for fast previews and 1.5, maximum. 1.0 is deemed “production quality.” You can go higher or lower if the situations demands it. Possible values are 0.01 and above.

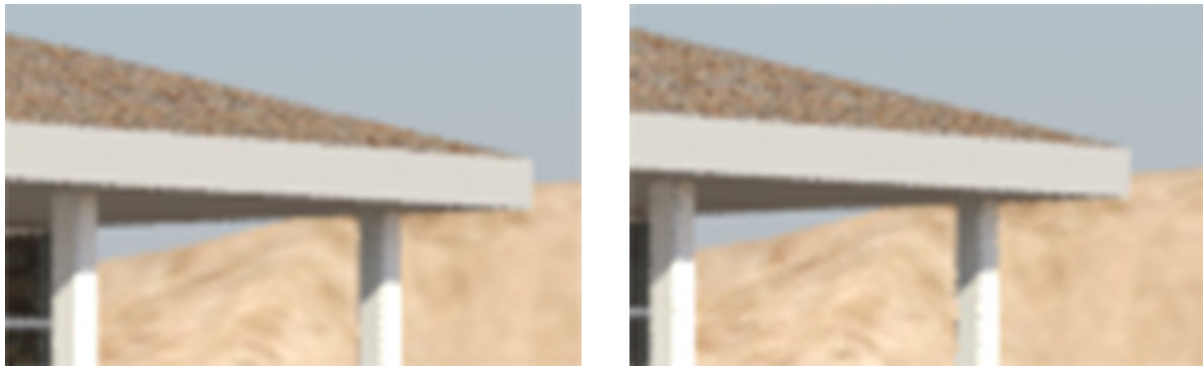
Minimum: The minimum number of samples taken per pixel. Set to 1.0. Don’t change this unless you have a pretty gosh darn good reason. Using a value less than 1.0 will allow undersampling, which could be useful for fast previews. This is only a limit; use “Quality” to control image quality. Defaults to 1.0.

Maximum: A limit for the maximum number of samples taken per pixel. The default setting of 128 will generally provide you with a large enough range of adaptivity for production work. Some situations, such as extreme motion blur or depth of field, may require more samples per pixel to reach the desired quality and to reduce unwanted noise. Setting Maximum to 200 or 300 in these situations can help. Again, this is only a limit. Defaults to 128.

This new sampling method can save considerable time. Using Classic / Raytraced sampling with a medium Image Precision setting of Min 1/4 / max 4, the rendering on the left took 1 minute and 55 seconds. Using Unified /Raytraced sampling with a default Image Precision (Min 1.0 / Quality 0.25) this rendering took 1 minute and 48 seconds.



Looking at the close-up detail of the roof edge, notice how the results are very similar:



Contrast / Noise Threshold (formerly Spatial Contrast)

Recall that mental ray will adaptively supersample pixels when it needs to. This last topic on sampling has to do with the controls for Contrast / Noise Threshold, which is the mechanism by which this magic works.

The Contrast / Noise Threshold setting is expressed as 4 values, one for each channel in an RGB color (Red, Green, Blue, and Alpha) that determines how mental ray will adaptively super-sample the image. mental ray compares the colors of neighboring samples, and if their colors differ by more than this color, mental ray will switch to a higher Samples per Pixel setting and subdivide the pixels. It will recursively subdivide the pixels and compare their contrast until the contrast is below this threshold or the maximum samples per pixel value is reached.

The RGB values are normalized to be between 0.0 and 1.0, where 0.0 is fully unsaturated (black) or fully saturated (white). The alpha threshold ranges from 0 for fully transparent and 1.0 for fully opaque. With Unified Sampling these now default to a very low 0.01, whereas in previous releases it defaulted to 0.051 per channel.

Thus, increasing the Contrast / Noise Threshold values decreases the amount of sampling done, and can speed the rendering of a scene at the cost of image quality. Lowering the Contrast / Noise Threshold will force more of the image to be supersampled. Typically speaking you really don't have to tweak this unless you really need to lower rendering times. With Unified Sampling it's simply easier to crank the quality knob.

Modeling, Lighting and Material Considerations

mental ray cannot produce a fantastic image by itself. The methods by which you create your 3ds Max Design scene largely determines the final rendered quality.

Units and Scale

To make mental ray work effectively you need to be always modeling in real-world units and at the proper 1:1 scale, and as close to the world origin as possible. Light attenuates using the inverse-square law, meaning the intensity of the light decreases exponentially with distance. Therefore it is critical that your scene is to use the proper units, and real-world sizes are observed in your models. Don't model an airport the size of a shoebox, or a shoebox the size of an airport. Go to the Customize → Units Setup to set this value.

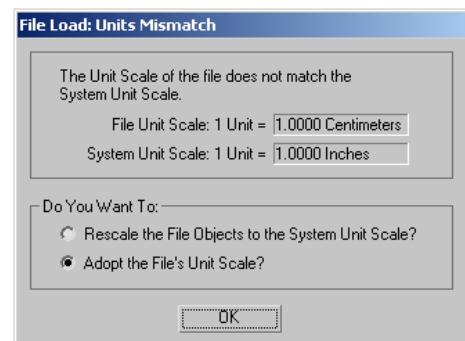
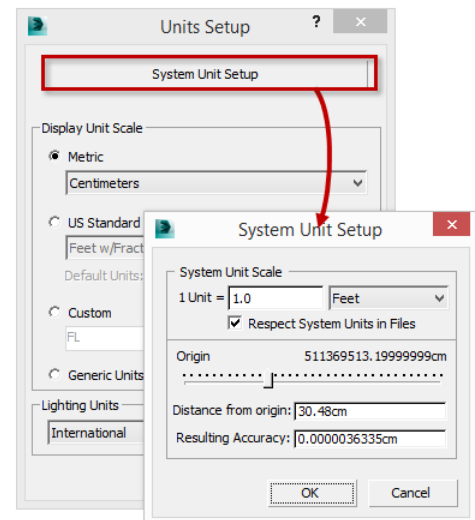
The System Unit Setup dialog box sets the real-world value for the System Unit Scale, which sets the overall floating-point accuracy for geometry and ensure imported scenes are the correct size and will attenuate light properly. Because of the limitations of floating-point accuracy at large values, the further you are from the world origin the less accuracy you will have. Therefore, larger System Unit Scales like Kilometer will report lower overall accuracy in the System Unit dialog box.

You should set the proper system units before you model or import any geometry, and it should not be changed in an existing scene. If you import a model that has different system units, 3ds Max Design will prompt you to either rescale the geometry to the System Unit Scale or to adopt the file's unit scale. Typically you want to adopt the file's unit scale.

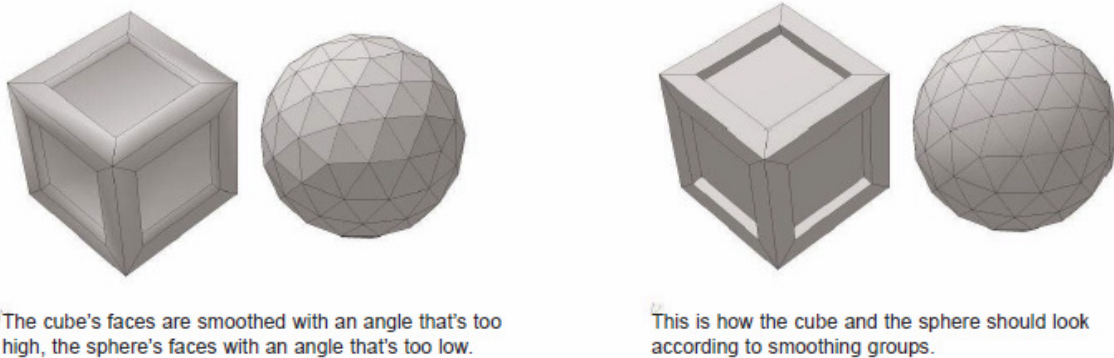
The Display Unit simply specifies what units are displayed in the interface and can be completely different from the System Unit. This value does not affect geometry, rendering, or lighting at all. For file originating in Revit this is not typically a problem because things will come over correctly. However, if you are modeling completely within Max, you need to ensure all objects are the correct real-world size and thus need to ensure the System Unit is set to the proper scale.

Modeling Considerations

When modeling inside of Max you also need to ensure that you do not have any modeling errors which could cause light leaks or erroneous renderings. Editable Poly is preferred over Editable Mesh for most modeling tasks, as Editable Poly is optimized for advanced modeling, they are more flexible, and you'll see fewer errors in renderings. Ensure that edges meet properly and don't have any coincident faces. Again, for models originating in Revit or AutoCAD, this should not be an issue because these are solid modelers - the geometry is always "watertight" and should not pose any issues with light leakage or reversed normals.



You may find that geometry imported from other applications does not shade properly in viewports due to information on smoothing angles (the angles between the normals of two adjacent faces) getting lost or corrupted. Try the Smooth modifier and see if that rebuilds the lost information.



Source: http://images.autodesk.com/adsk/files/mental_ray_white_paper_2012_en.pdf

Another problem may be flipped normals, particularly in surface modeling applications such as SketchUp. These appear as dropped faces on the geometry as the “front” of the face is pointing in the wrong direction. You can toggle Backface Culling in the object properties dialog box or add an Edit Poly modifier and use Flip on the offending faces. Also, two-sided materials can help fix the issue without spending a lot of time.

Lighting and Exposure Control

Obviously to get realistic results you need realistic lighting, which means employing photometric lights. While mental ray will support Standard Lights, Photometric lights work with the mental ray Photographic Exposure control to produce physically accurate results.

Exposure control is critical in mental ray. You must think of yourself as a photographer and understand some basic concepts to produce well exposed images. The mr Photographic Exposure Control provide both a “point and shoot” functionality - you can select a preset or just change one general Exposure Value (EV) setting - or have fine control over shutter speed, film speed, and aperture for professional level results. You also have control over mid-tones, highlights, and shadows. The mr Photometric Exposure control is described elsewhere in this handout.

Materials

No discussion of any rendering engine, including mental ray, goes very far without bringing up the subject of materials. Materials need to be designed for the renderer to provide acceptable results. For mental ray, this means your scene materials should be either Arch & Design or Autodesk materials.

The Arch & Design Material is a monolithic shader designed to reproduce most of the materials found in architecture, engineering, and product design. Plastics, metals, masonry, concrete, wood, and particularly glass are well represented. It is specifically tuned to provide fast glossy reflections and refractions, speeding render time considerably.

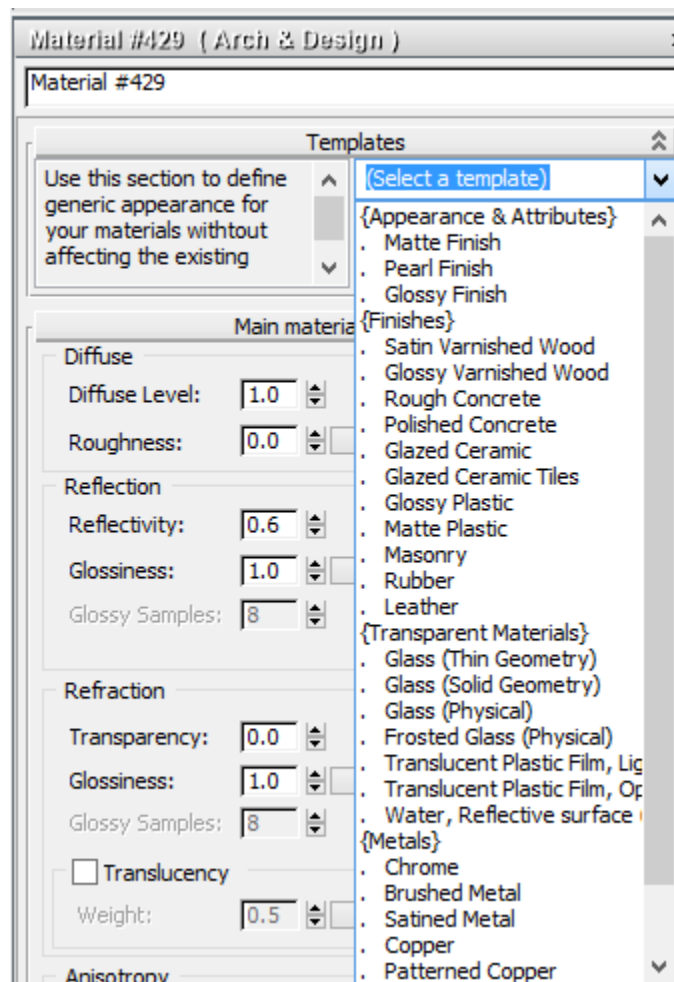
Generally speaking the Arch & Design Material is the most versatile of the materials used in architectural design with mental ray. It provides the most freedom to design material properties while resulting in fantastic images. The Arch & Design Material is designed to be used with physically correct lights, as well

as Final Gather and/or Global Illumination methods for producing indirect light. It is energy conserving, that is, it obeys the laws of physics when light hits it.

In fact, the Autodesk materials are really simplified versions of the Arch & Design Material. They have a simplified interface (not as many tweaks) but still drive the Arch & Design material under the hood. Furthermore, because Autodesk materials populates the single material library that ships with the Building Design Suite, all of these Autodesk applications will use this common library for material creation, meaning that transferring models from one application to another - e.g., linking an .FBX into 3ds Max Design - will bring along mental ray-compatible materials as a starting point for further refinement.

However, because the Autodesk materials have simplified interfaces, certain aspects of the A&D material are not present in the Autodesk materials. The Autodesk materials do not expose some things present in the A&D material, which may provide cleaner ways of improving your image and its rendering performance, so your scene may use a combination of the two where required.

Central to creating a particular material based on the Arch & Design Material is the templates rollout. This templates list allows you to select from many predefined material setups. Start your material creation by selecting a template that is most closely suited to the material you are creating.



Note the short description to the left of each template that you select from the list. You will also see tooltips of brief descriptions with all of the important parameters in the UI.

Other features of the Arch & Design Material are:

- Easy to use, flexible, and well organized.
- Transparent objects can be treated as either solid (refracting, built from multiple faces) or thin (nonrefracting, can use single faces)
- Round corners: Simulate fillets at sharp edges allows them to catch the light in a realistic fashion without modeling overhead.
- You can set final gather accuracy or indirect illumination on a per material basis.
- Allows powdery, diffuse surfaces such as clay
- Built-in ambient occlusion for contact shadows and enhancing small details.
- All-in-one photon and shadow shader built in
- Surfaces like waxed floors, frosted glass, and brushed metals are easy to set up.

Ambient Occlusion (AO)

Ambient Occlusion (AO) is a method spearheaded by Industrial Light & Magic on the 2001 film Pearl Harbor that emulates the look of indirect illumination using a special shader that calculates the extent at which an area is occluded from receiving light. It takes into account the proximity of objects to each other and produces a grayscale map that is darker in crevices or in corners. It has the added benefit of bringing out smaller details and creates “contact shadows” which better ground objects together, promoting realism.

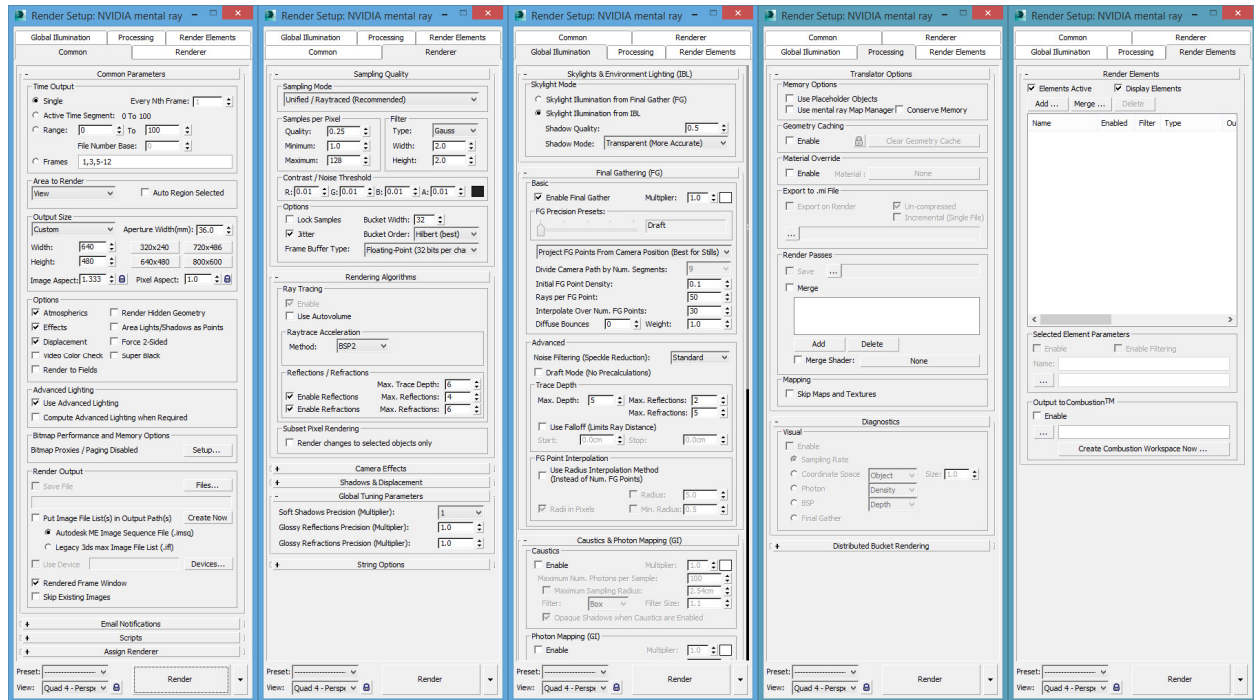


Ambient Occlusion can be enabled in all Arch & Design materials (under the Special Effects section) and Autodesk materials (under the Ambient Occlusion section). When setting AO, you want to specify smallish Max. Distance of about 10cm or about 4 inches.

The Rendering Dialog Box

When mental ray is set to the renderer, the Render Setup dialog box (accessible by the F10 key) can get a bit overwhelming. The Common and Renderer panels are always present no matter what the assigned renderer is. With mental ray, the other three panels present are Global Illumination, Processing, and Render Elements.

The numerous controls, once understood, are organized cleanly. Only a brief synopsis is presented here; the following tutorials will contain more detailed information on individual settings for particular scenarios.



The Common Panel:

The Common panel is where you first assign the mental ray renderer, if not assigned already. It has controls for setting the time output for animations, area to render, rendering output size, output to file, turning on options such as atmospherics and displacement, and other fairly self-explanatory settings. The Common Panel will also have the control for starting network rendering using Backburner.

The Renderer Panel:

The Renderer panel holds the controls for how the sampling mechanism works in mental ray. Other controls including global tuning of soft shadow precision and glossy reflection/refractions, which are also found on the Rendered Frame Window.

Global Illumination Panel:

This panel - which really should be called the Indirect Illumination panel as it was in past releases of 3ds Max Design - has controls for the major Indirect Illumination features found in mental ray. Controls for skylight illumination - either from Final Gather or Image-based lighting (IBL); Final Gather; Photon Mapping (Global Illumination); Caustics; and the reuse of Final Gather and Global Illumination photon maps are found here

Processing Panel:

This panel has several critical controls for mental ray users. The control for overriding all of the materials in the scene with a single material is a very useful feature used to analyze your lighting. With this you can replace all scene materials with a matte light gray material which allows you to see shadows and light dispersion clearly, without the added overhead of material reflections, refractions, or transparency. The other important controls are under the Diagnostics rollout, which allow you to see different things like the sampling rate, photon maps, Final Gather maps, and so on. The Processing panel also provides the controls to enable Distributed Bucket Rendering and Render Passes.

Render Elements Panel:

Render Elements allows you to separate different types of information, such as the important components in the Arch & Design material, by rendering them out to separate HDR image files. This allows you to fine tune each element in compositing.

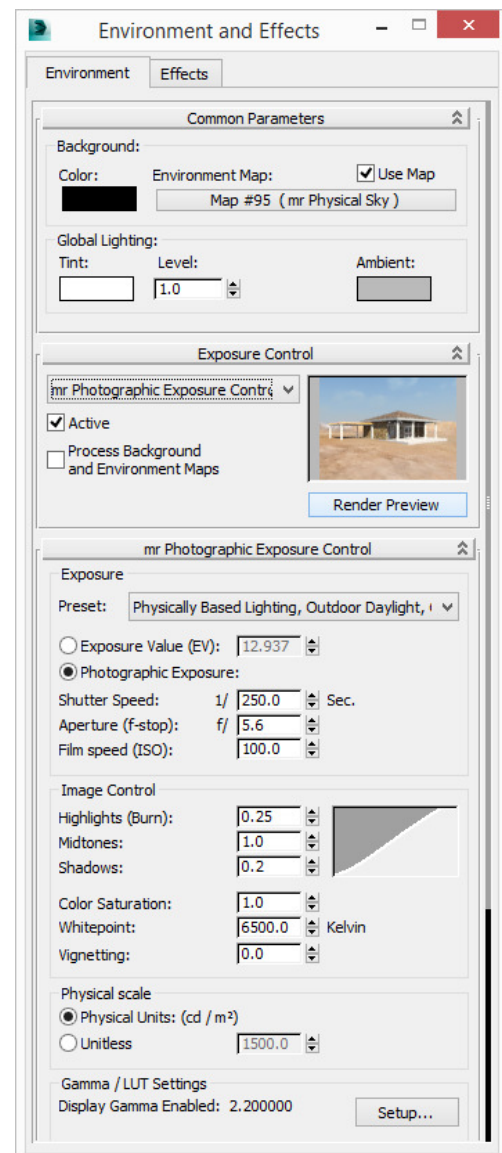
mr Photographic Exposure Control

Under the Render menu is the Environment and Effects dialog, accessible via the 8 shortcut key and at the top of the Rendered Frame Window. Here you can set up the Environment (background) channel and exposure control.

Exposure control is the software equivalent of the shutter and aperture settings on a camera. It controls the brightness and contrast of the rendered image. Exposure control doesn't alter the actual light levels of the scene, it simply adjusts the final render to work with the light levels similar to the way a camera does.

An improvement over the older Logarithmic exposure control, the mr Photographic exposure control produces excellent results when combined with the Daylight System and the mr Physical Sky environment map. When you create a Daylight System it will also prompt you to assign the mr Physical Sky environment map as well as assign the mr Photographic Exposure control to create a cohesive system of integrated lighting, environment, and exposure control settings. All you need to do is set the correct settings.

The best part of this dialog is the Render Preview function, which tells you right away if your settings work and the effects of changing them. In the Exposure group you have controls for enabling a Preset based on typical lighting scenarios, as well as your choice of using either a single overall Exposure Value (EV) knob or photographic exposure controls to set Shutter Speed, Aperture (f-stop), and Film Speed (ISO) independently.



Section II: mental ray Indirect Illumination tools

Working successfully in mental ray is simply not a matter of understanding what buttons to push. It is the result of a combination of understanding some basic theory and hard, cold practice. Section II of this handout is primarily about understanding the underpinnings of mental ray so that you can make sound decisions as you practice honing your rendering skills.

Daylight System, Environment, and Exposure Control

One of the first and most important things you will do in almost every 3ds Max Design rendering project is to create a Daylight System and environment that works with mental ray.

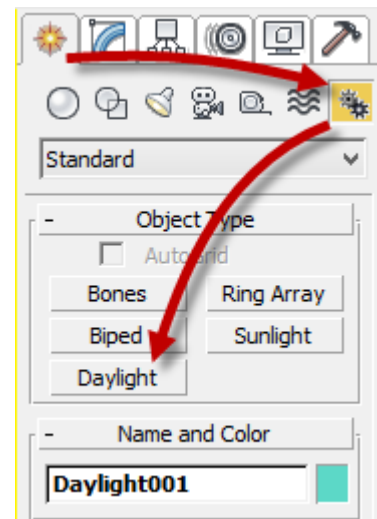
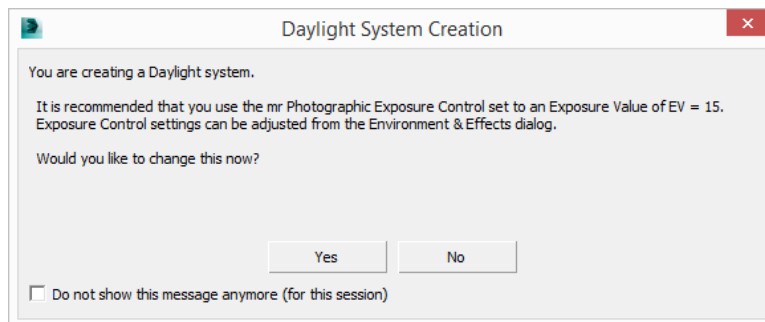
The Daylight system in 3ds Max Design is a complex but generic assembly composed of two lights - a sunlight and a skylight - that is designed to simulate the accurate positioning of the sun over the earth at a given location. When the mental ray renderer is set current, the sunlight and skylight component of the Daylight System is automatically set to use two mental ray photometric lights - mr Sun and mr Sky. For a non-mental ray solution you could also use the older IES Sun and IES Sky combination, also photometric, or the Standard light and Skylight combination, which are not photometric.

In the Daylight system, the sunlight component corresponds to the direct illumination as provided by the sun, and is modeled as a parallel light source constant over all surfaces of the scene. The skylight component is intended to simulate the diffused light that is scattered through the atmosphere, and is "modeled" such as it is, as a celestial hemisphere of infinite radius placed around the scene. The Daylight system provides the direct and diffuse illumination in the scene.

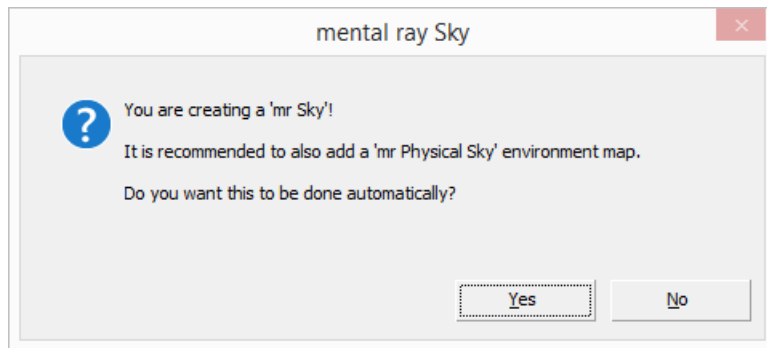
Creating a Daylight System

Creating a Daylight System is easy to create in any view. Go to the Create tab of the Command Panel > Systems > Daylight System:

As soon as you do this you'll get a prompt asking you to use mr Photometric Exposure control and set it to an initial value of EV=15. Hit Yes to accept this.

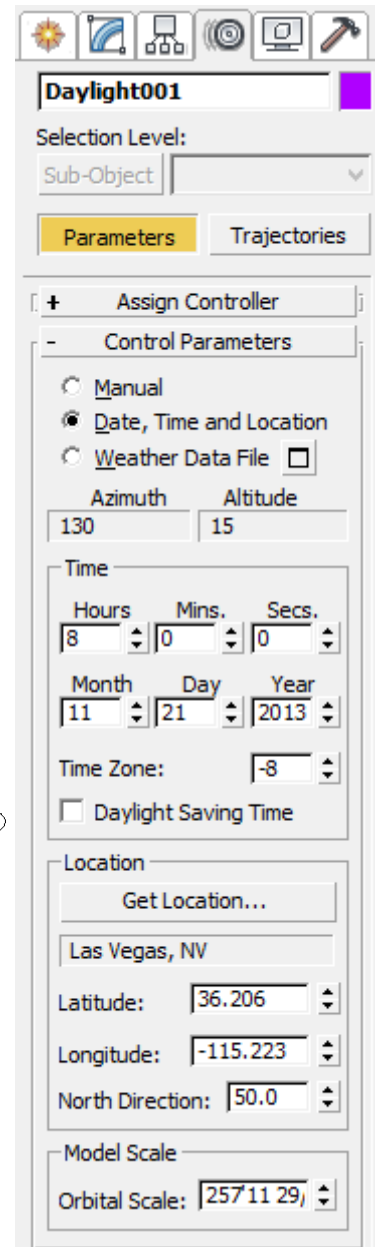
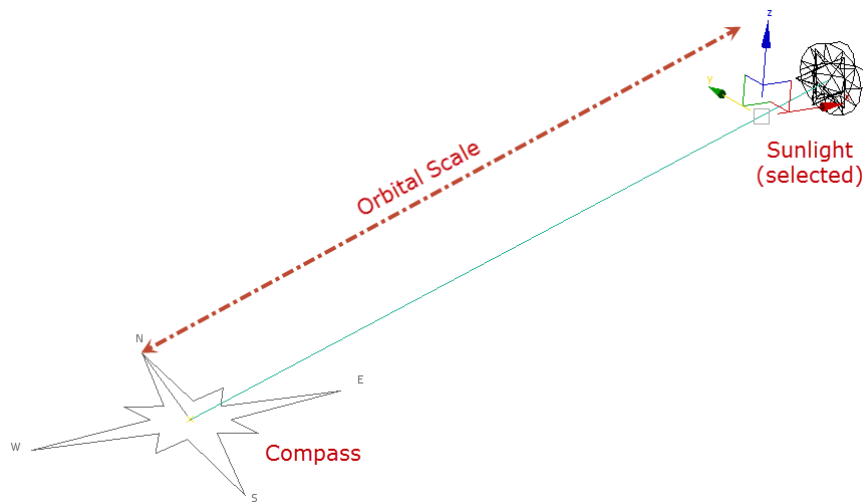


Click to place and drag the compass, after which you get this prompt to create the mr Physical Sky environment map:

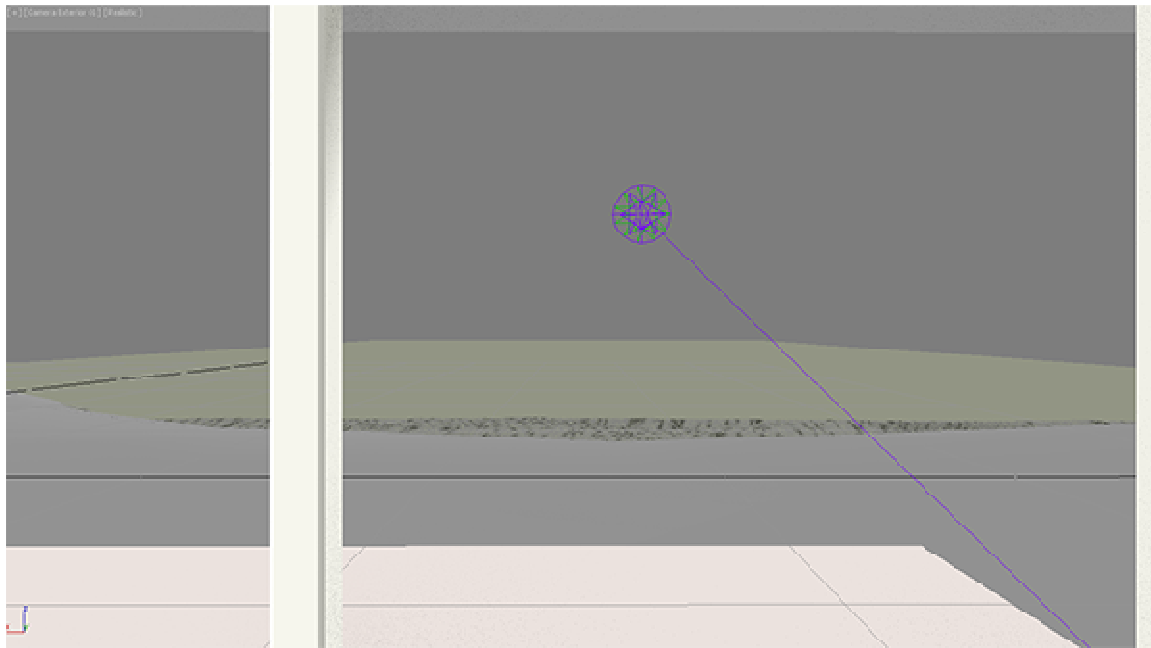


Which is what you want, so hit Yes. Then drag a second time to set the Orbital Scale of the Skylight. Once it is placed, hit enter to finish it (otherwise you will start creating an additional Daylight system, which would only make sense on Tatooine).

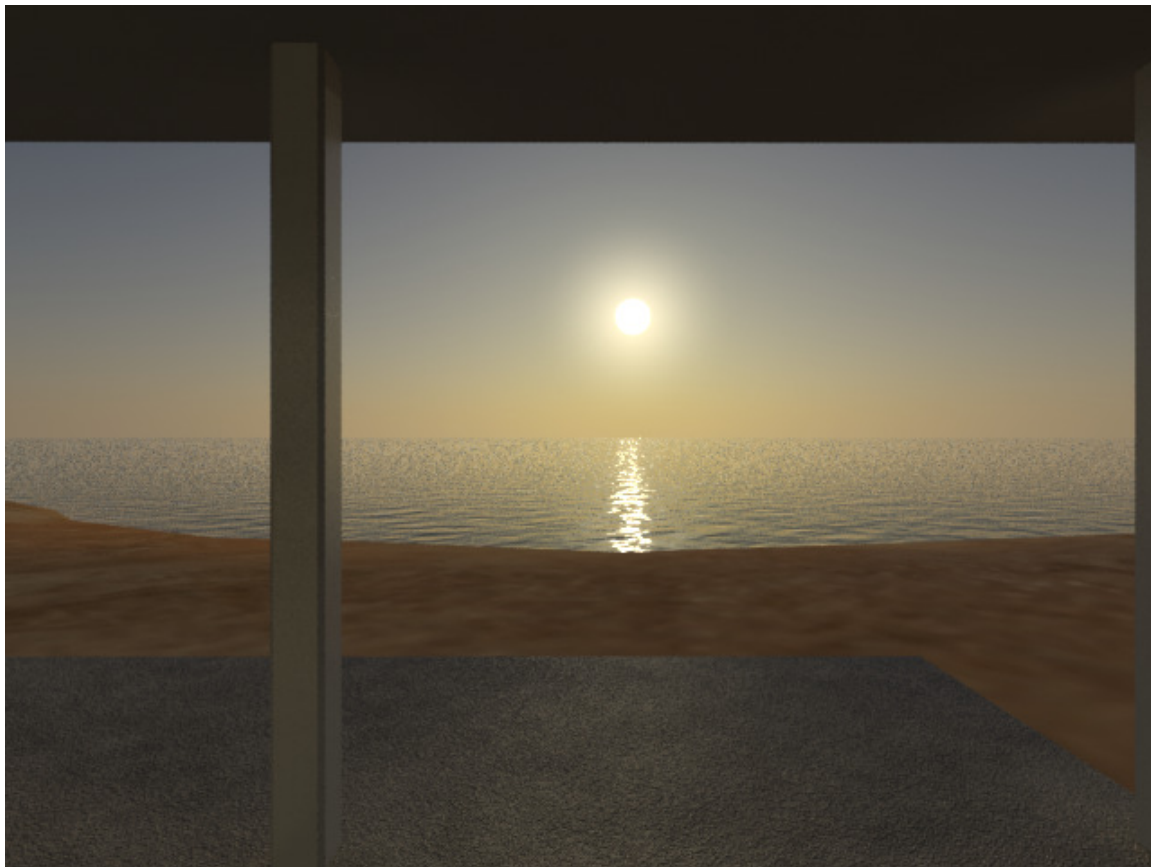
The compass, light, and the orbital scale are simply a representation of the sun and skylight orientation, not its true distance from the scene. You probably won't be able to set the orbital scale very far at first, so just place it for now and change it later by selecting it and editing the Orbital Scale value in the Motion panel, which will have the time and date settings for controlling the sunlight.



The location of the compass and the orbital scale in no way changes the amount of light the scene received; you typically set it high enough to get it out of the way. The light produced by the Sun component will fill the extents of the model with parallel light rays. The compass simply orients the sun in relation to True North based on the the Sun and Sky's time / day / month / year. The position of the Daylight System is important only in that the mr Physical Sky will place the sun disk at the location where the Daylight System's Sunlight object is projected onto the sky.



Daylight System sun



Las Vegas, NV at 8 AM on November 21, facing East. (EV = 14)

How the mental ray Daylight System Works

In the Modify panel you can change the settings for the Daylight System's sun and Sky. The Daylight Parameters rollout simply shows what is assigned to the Sunlight and Skylight components, and whether they are active or not. From here you can access the position of the system as well by hitting the Setup... button, which takes you to the Motion panel.

The parameters for the mr Sun and mr Sky are often the same and need to be in sync with each other for a physically accurate image. Notice that many of the settings are inherited from the mr Sky.

The mr Sky determines two things: the way the skylight lights the scene, and the way the sky looks. The way the sky looks is actually controlled by editing the mr Physical Sky environment in the Material Editor, which largely inherits the values from the mr Sky. The way the sky lights the scene is controlled by the mr Sky parameters, specifically the Sky Model (Haze Driven) and the value for the Haze. Both are explained next.

Daylight System Sky Models

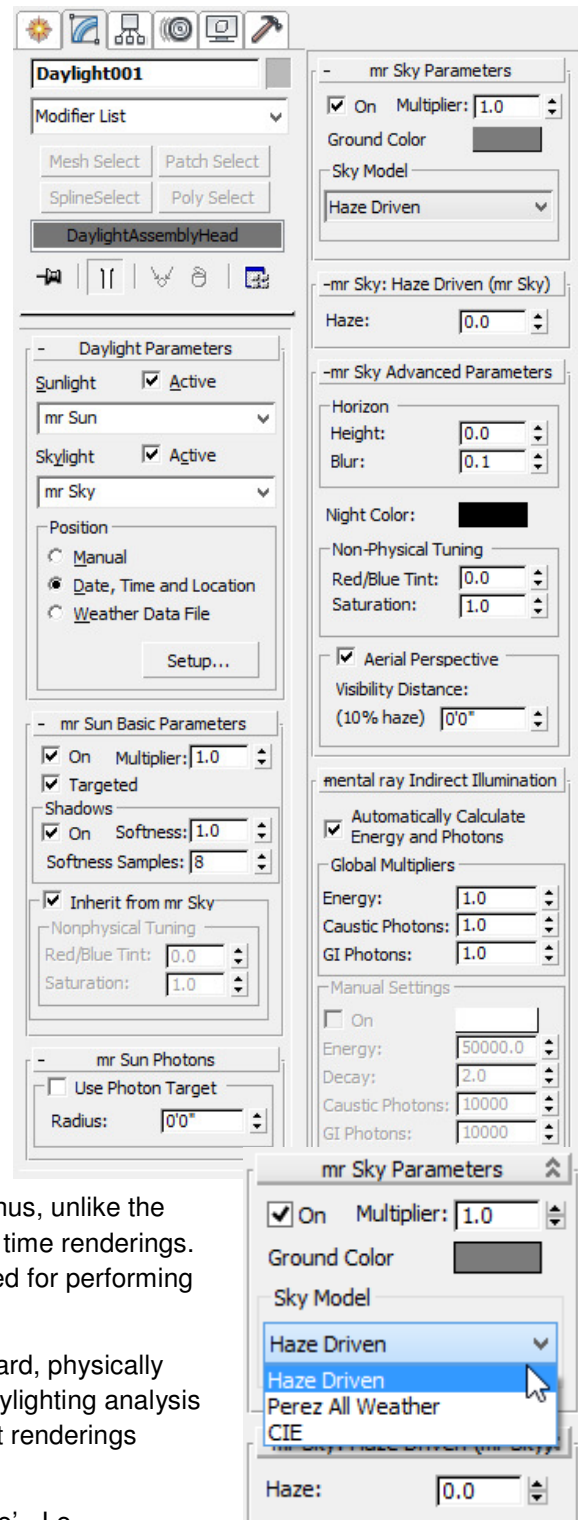
The Daylight System supports three different sky models. A sky model is the way the skylight provides its direct illumination. Each has different characteristics and is used in different situations.

The three sky models are:

Haze Driven - this model is set by default in new Daylight Systems and creates the nice blue sky background. It's very good for general purpose architectural renderings, for both exterior and interior scenes, because it supports a 24-hour time range and thus, unlike the other two sky models, can be used for twilight and night time renderings. However, it is not physically accurate and cannot be used for performing Daylighting analysis.

Perez All Weather - This sky model is an industry standard, physically accurate model used for daytime renderings and the Daylighting analysis tools. However, it cannot be used for dawn / dusk / night renderings because it is daylight-only.

CIE - The CIE ('Commission Internationale de l'Eclairage' - i.e. 'International Commission on Illumination') sky model is also an industry standard, physically accurate sky model that again does not work for sunrise/sunset or night time renderings.



Important mr Sky Settings

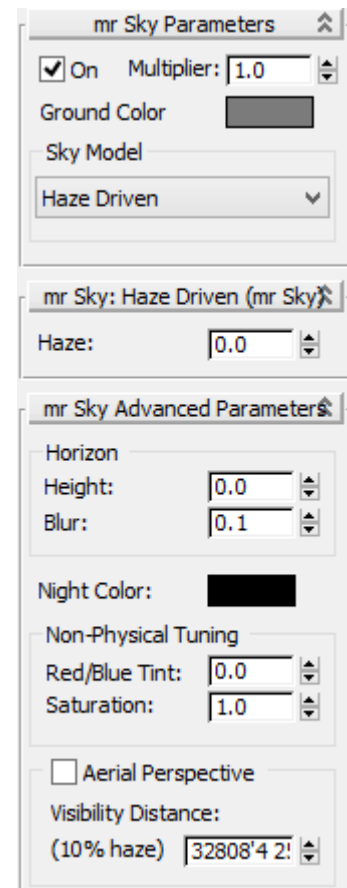
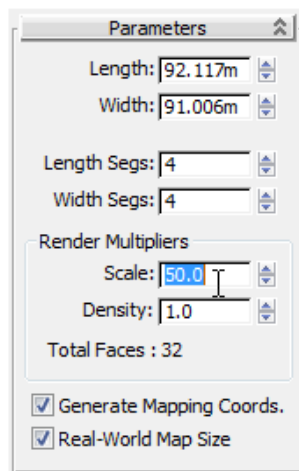
In a new, blank model, the standard Daylight System with all default values looks like this:



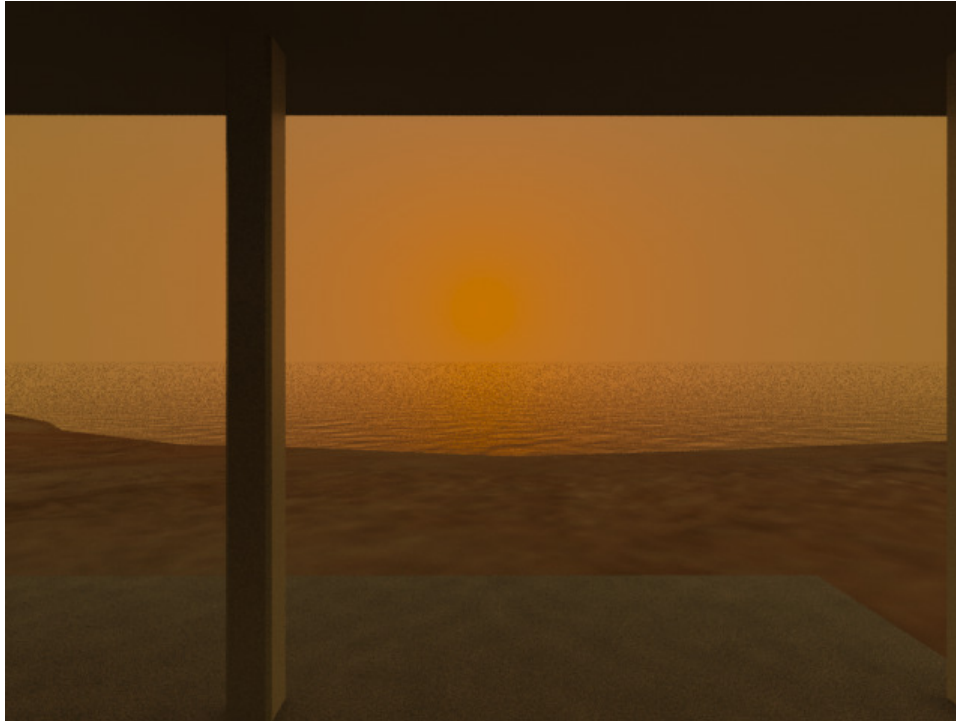
Which by all accounts is a little blah. As mentioned, the mr Physical Sky inherits its properties from the mr Sky component of the Daylight System. The important mr Sky properties that affect your renderings (using the default Haze Driven sky model) are the ground color, the Haze amount, the horizon height and blur, and the setting for the Aerial Perspective.

The Ground Color is the color of the virtual ground plane and should typically be set to the average color of your desired ground plane. It will reflect the illumination and can thus affect the lighting and color of the scene. It can be visible in the scene if you don't have a physical modeled ground plane.

Tip: If you do model a ground plane that is to extend indefinitely, as the water example in the beach house image above, a good tip is to set the ground plane object's Parameters > Render Multipliers > Scale to some larger value that allows it to appear edgeless without modeling an overly large plane.



The Haze amount ranges from 0.0 (a clear day) to 15 (extremely hazy). This value influences the color and intensity of the sun, the background sky, and horizon. Use 0.0 for clear days. Use 15 if your scene is in a sandstorm in the Sahara or on the surface of Mars.



Haze = 15.0

The horizon Height will raise or lower the horizon line; typically you might want to lower it a little to keep it from overpowering your scene. The Blur value blurs the horizon line, making it even more subtle.

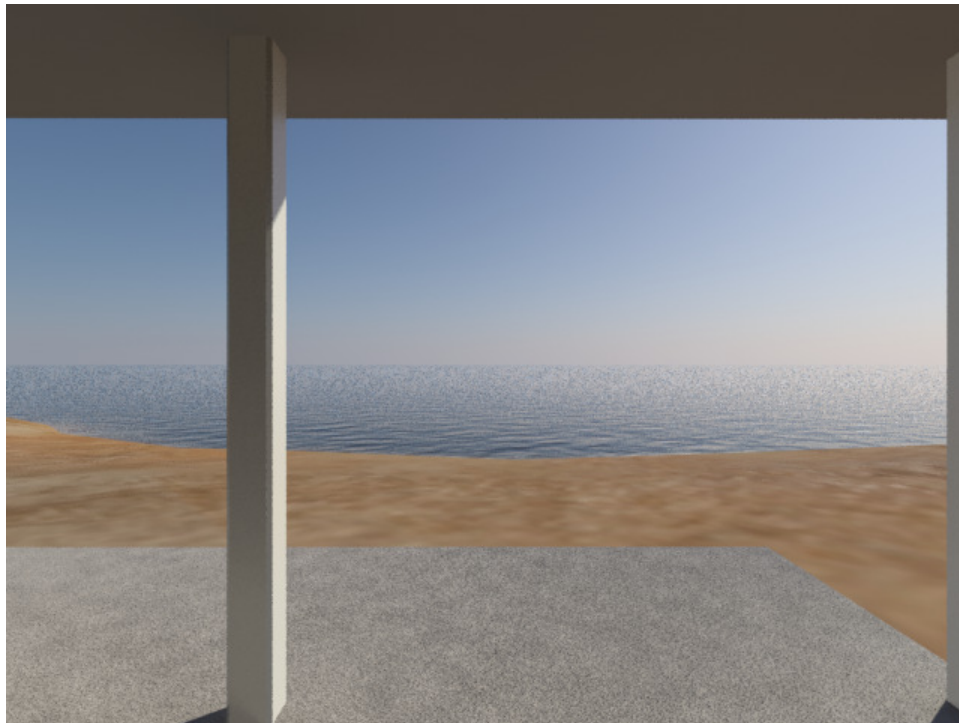


The Aerial Perspective toggle enables the Visibility Distance setting which is a haze effect where background objects begin to tint towards blue and fade away with distance. The value sets the distance at which approximately 10% of haze is visible at a Haze level of 0.0. With nothing in the background it is barely noticeable. With modeled objects in the background the effect can substantially help the overall feel of the scene as it imparts a real-world simulation on them. If you have a bitmap for the background, the effect is less forgiving and can look fake.

mr Physical Sky Environment

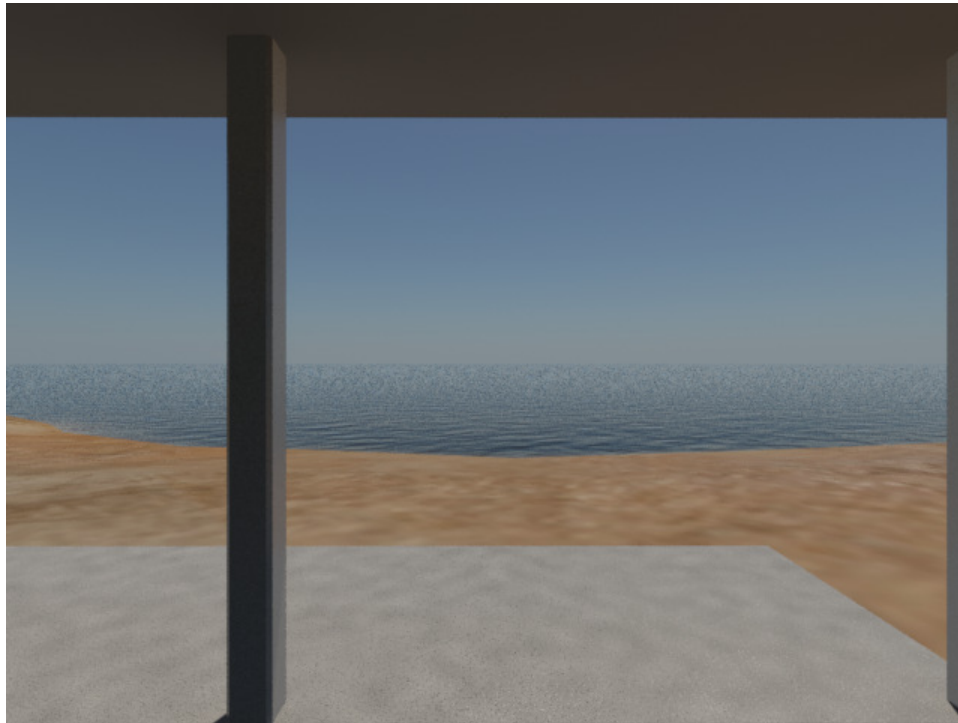
Now that we understand the idea of a Daylight System, we need to combine it with a proper background in the environment map channel for the scene. The environment map channel is simply a mechanism for providing a background to your scene. You can load a static image material into the Environment Map channel, or you can use the mr Physical Sky environment map which will create a spherical map procedurally, complete with ground, sky, and glowing sun disk keyed to the accurate positioning of the mr Sun, using the settings for the time of day, location of the scene on the surface of the Earth, and other real-world conditionals that help achieve accuracy.

The mr Physical Sky environment map provides a gradient background that changes depends on the time of day. In the morning you would get a reddish gradient, at noon it will be blue, and at night it will be dark bluish-purplish. Here's the same scene as on Page 26, only at 12 noon. The Haze amount in all images is 0.0.



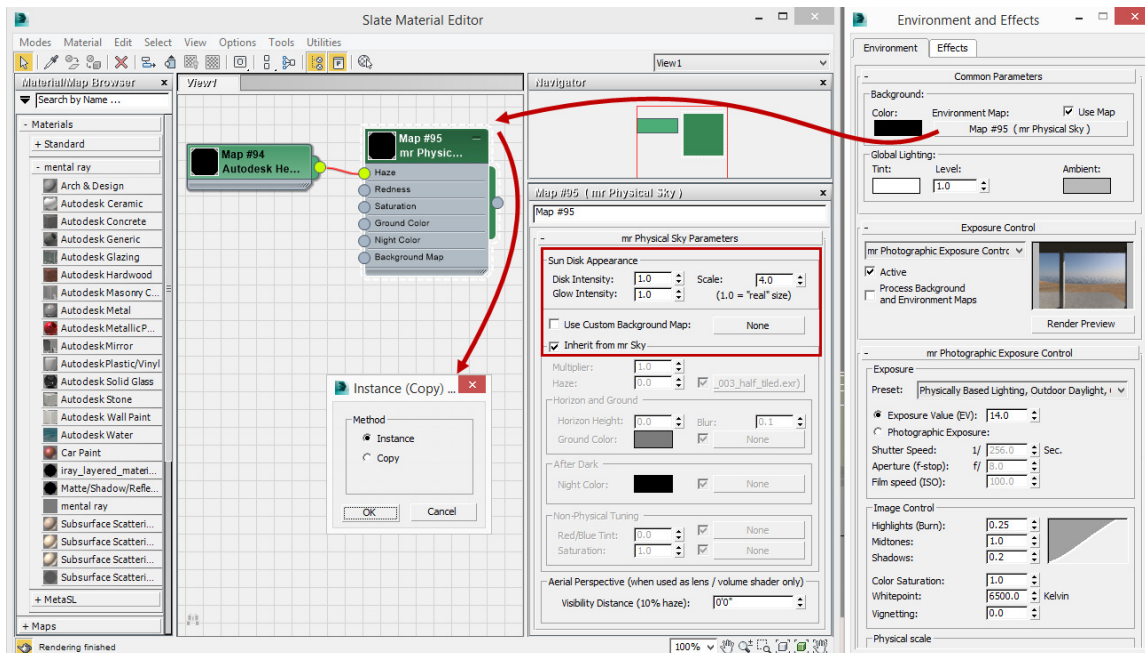
Note how the sky is much more blue but is still rather pale and the horizon is pretty hazy.

Change the time of year to June 1st at noon, and you get this:



Which is much more summer like.

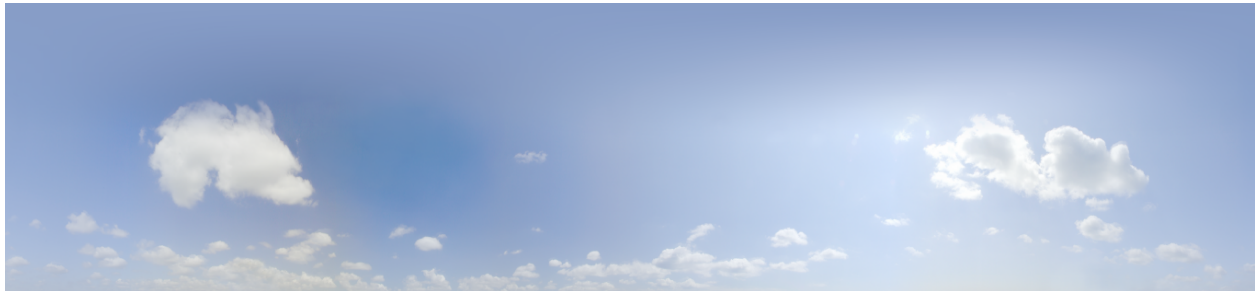
Typically you don't have to tweak the settings for the mr Physical Sky very often - you kind of set it and forget it. The settings are by default inherited from the mr Sky. To edit the mr Physical Sky you need to instance it into the Material Editor by dragging it from the Environment dialog box.



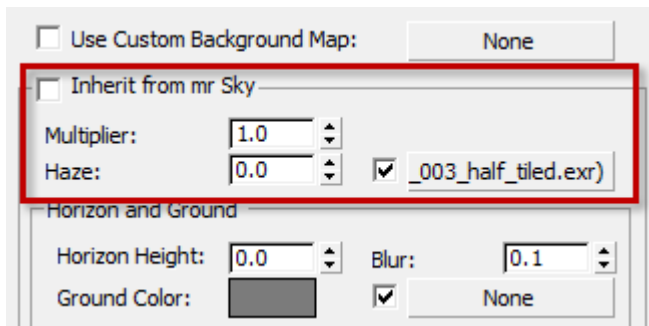
When to tweak the mr Physical Sky

The mr Physical Sky environment map is supposed to be a purely a cosmetic effect used to provide a sky-like gradient background and ground plane. By itself it does not alter the lighting levels of the scene, since those are calculated by the Skylight (mr Sun) object. By default the majority of its properties are inherited from the mr Sky, but as you can see from the properties above you can alter the disk and glow intensity as well as the actual size of the disk in the sky. The blue background, clouds, and other mr Sky-centric things will affect reflections in your renderings.

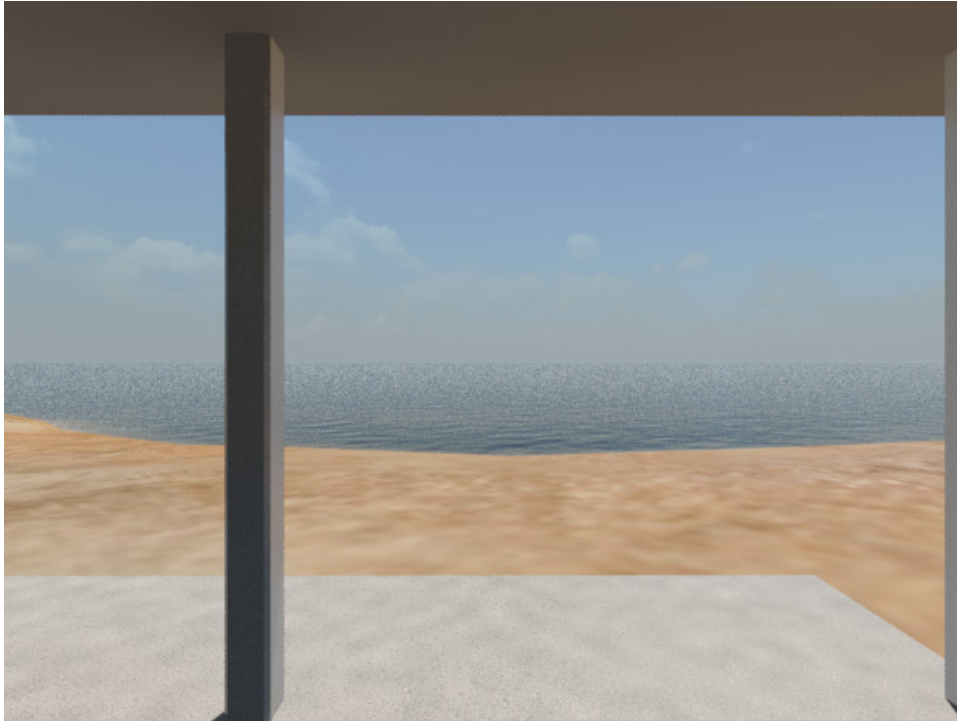
The mr Physical Sky's properties include maps for Haze, Redness, Saturation, Ground Color, Night Color, and Background Map. When "Inherit from mr Sky" is enabled, none of these maps (if any are assigned) will be enabled in your renders. Note the Map #94 that is assigned to the Haze map - it's actually an Autodesk Hemispherical map that uses an EXR file (OpenEXR is an extended HDR image format developed by ILM). This file is located in C:\Program Files (x86)\Common Files\Autodesk Shared\Materials\Textures\Environments\SunAndSky\Presets\5. This particular image is a sky with clouds:



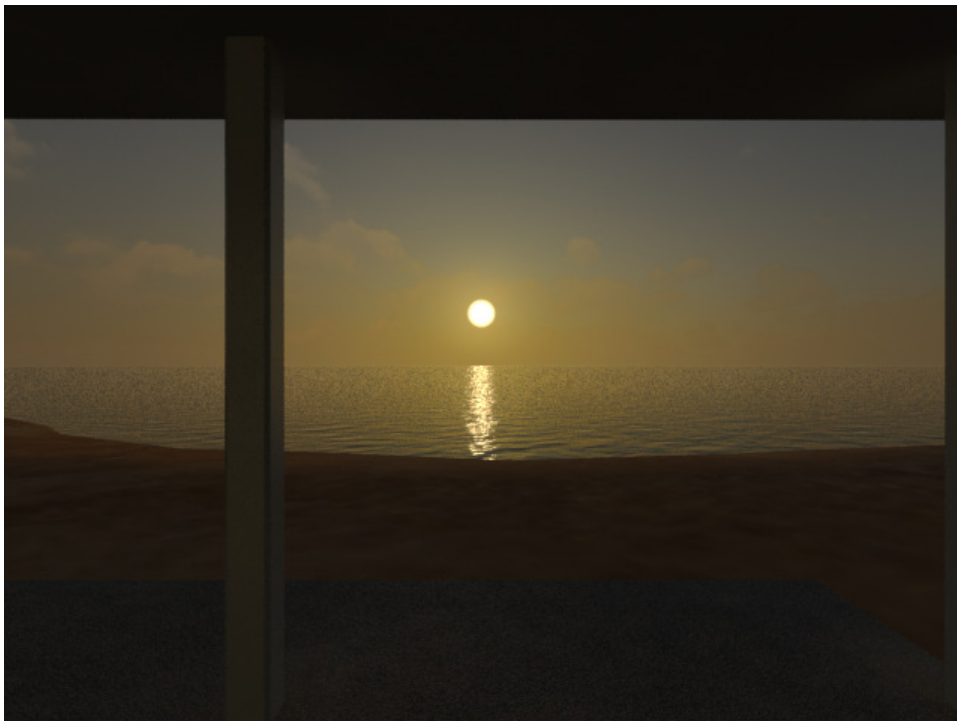
Thus, if we disable the "Inherit from mr Sky" option, we can put clouds in the background:



And get this (at 12PM on June 1):

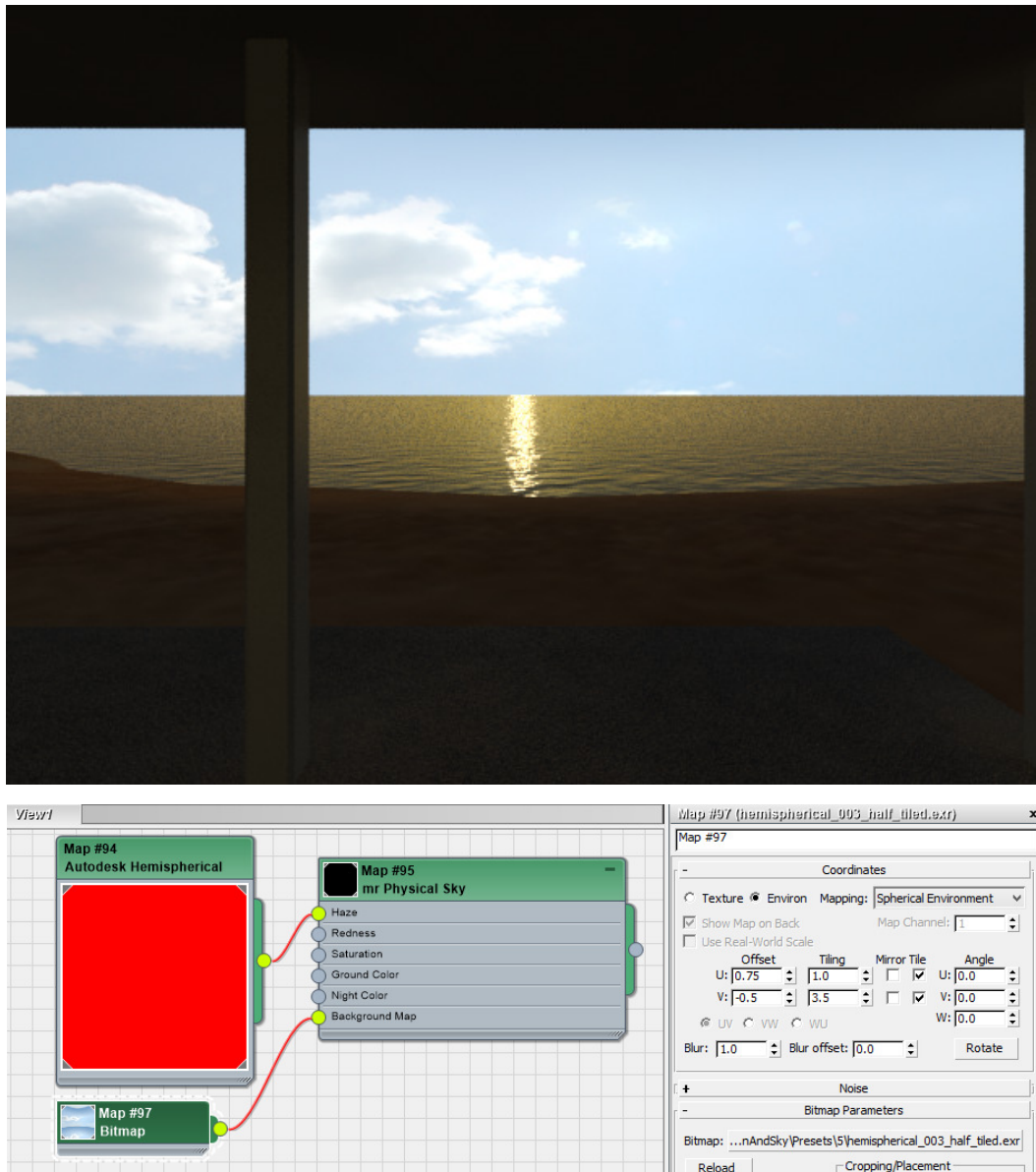


And this at 8AM on November 21:



Notice how the Autodesk Spherical map in the Haze channel doesn't block the sun disk or mr Sky contribution, but the map works with the sun settings to provide a realistic sky for that time of day.

Note: Do not put a map in the "Use Custom Background Map" slot. This completely blocks the illumination contribution of the mr Sky and you get no sun disk. For example, if I put the same background EXR as a standard bitmap applied to the Background Map channel (set as an Environment map using Spherical mapping) with the time set to 8AM on November 21, you get this unnatural image:



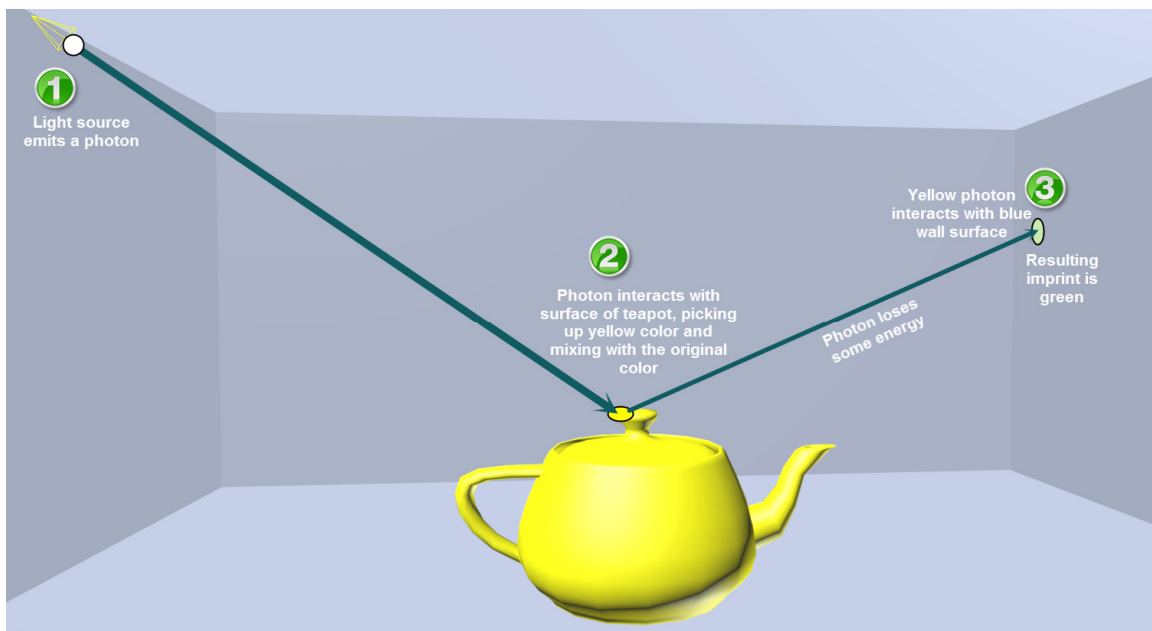
Other reasons to tweak the mr Physical Sky:

One reported issue is that if the sun disk that is created by the mr Physical Sky is in front of the camera, it can be picked up by portal lights and Final Gather. This can result in overly bright spots in the rendering, particularly if the disk is behind the portal lights. For more on this issue, see Jeff Patton's blog article about it here: <http://jeffpatton.net/2011/11/mental-ray-physical-sky-tips-for-architectural-interiors/>

Global illumination (Photon Mapping)

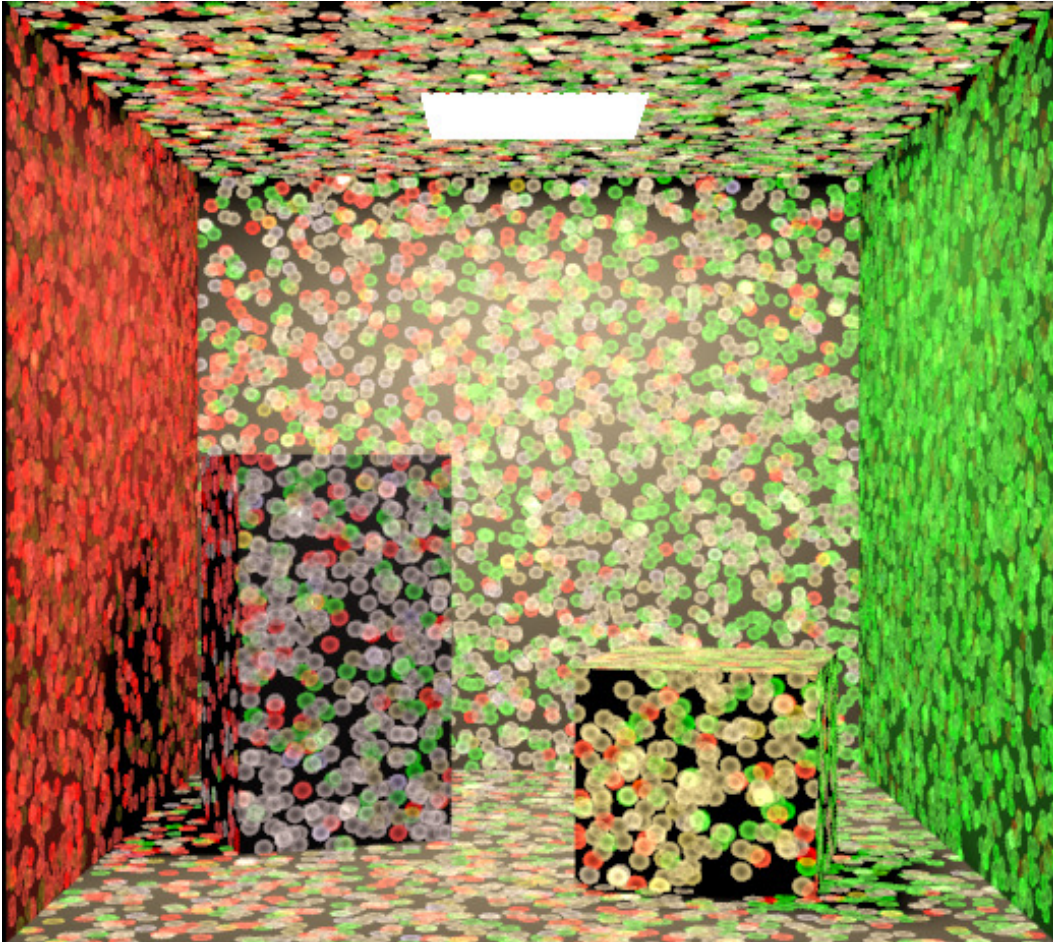
Global Illumination, also referred to as GI or Photon Mapping, is a specific technique used for adding indirect illumination to your scene by emulating the physical properties of light. In some CG circles the term “Global Illumination” is used in place of Indirect Illumination, that is, all of the bounced light in the scene environment. In 3ds Max Design, the term is the formal name for the photon mapping technique of providing indirect illumination, so both terms are used interchangeably.

As mentioned previously in the section on Indirect Illumination, real world lights emit infinite numbers of photons that interact with the environment, is absorbed by and/or bounced off of surfaces depending on the material, imparting their light on them. In turn it picks up color information as well, and this repeats itself as the photon bounces around. Light naturally decays using the inverse square law, so this continues on indefinitely. This is what GI emulates in software. However, unlike real life, in software we can control how many photons a light source will emit, how much energy the photon will have initially, what color it is, how it will decay, and how it will interact with materials.



When you use GI to spray the scene with photons, the photon layout is view independent; they are sprayed from the light sources and if you aren't changing your lights or GI properties, the arrangement of photons - called a “photon map” - should be static. Furthermore, once we “dial in” our photon map, we can save it to disk to be recalled later, even if our view changes. This ability to reuse photon maps allows you to work more efficiently and save valuable time on final renders.

Looking at our Cornell Box again with low values for GI photon emissions, you can see the above concept in action:



Here you can see where photons, emitted from the light above, are sprayed onto the scene and reflected around, picking up the colors of the objects they interact with and imprinting them on the walls.

A Global Illumination-only solution gets a bad rap because you need to tweak the settings or you get the splotchy “disco ball” effects on the walls that needs fixing. A GI-only solution requires adding photons (perhaps over a million), and/or tweaking the sampling settings until you start to get smoother results:

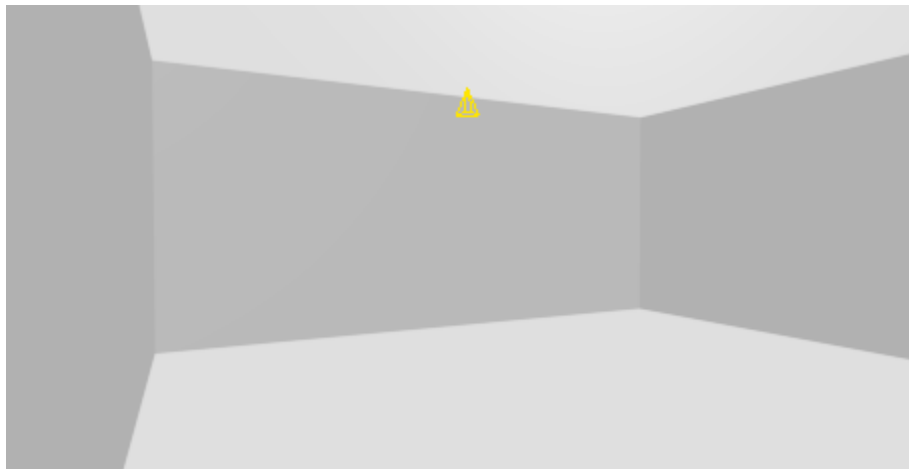


Global Illumination can produce a good image on its own, but it needs help. That was originally the primary function of Final Gather (FG), which was designed to clean up the GI photon splotchies so you did not have to spray so many photons into the space to get clean results. FG has since morphed into being almost an all-in-one indirect illumination solution that doesn't need to rely on GI to function and function well. However, the combination of GI + FG in interior renderings is quite a powerful combination.

A Simple GI Tutorial

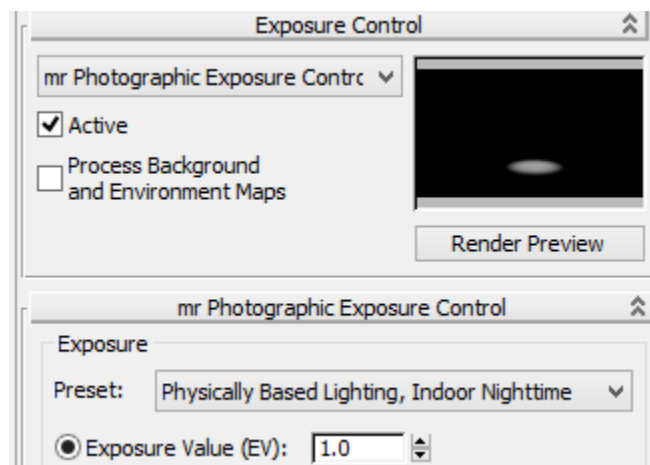
This is a simple tutorial to illustrate how Global Illumination works in 3ds Max Design. I like this tutorial quite a bit because it isn't concerned with getting an exquisite image. Rather, it exemplifies in real terms how you should learn the rest of mental ray: Take a single subject, create a very simple model to test that subject, and tweak each knob to find out what it does and what the acceptable values are.

1. Open the GI_Box.max file in the project \Scenes folder. This is a simple 20'x20'x9' box with a single spot light near the ceiling, pointing straight down. There are no materials applied to the geometry, and no openings to allow light to escape.

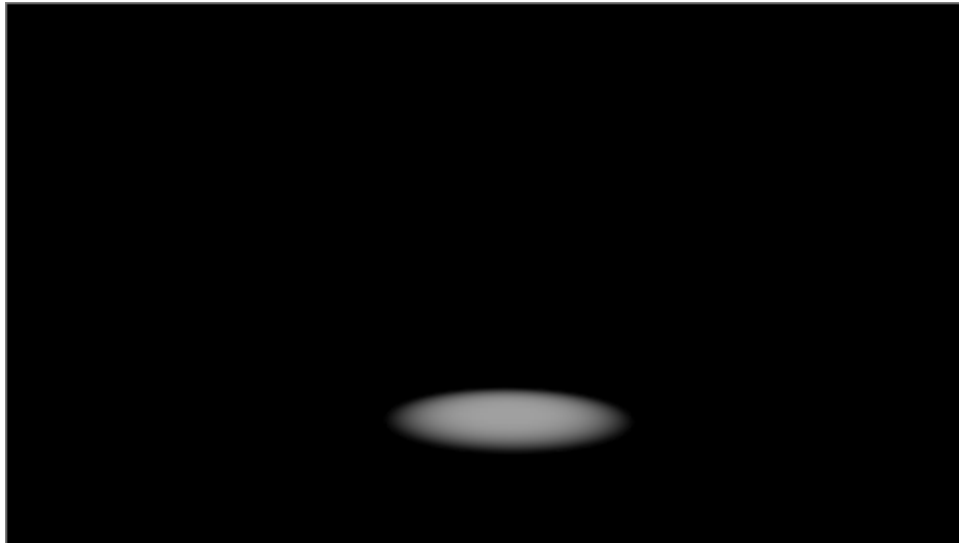


2. Open the Render Setup dialog and go to the Global Illumination tab and open the Final Gathering (FG) rollout. Uncheck “Enable Final Gather” as we are not using it for this tutorial. Open the Caustics and Photon Mapping (GI) rollout and ensure Photon Mapping (GI) is also unchecked. This in effect disables all indirect illumination. Leave the Render Setup dialog open.

3. Before we render, we should test our exposure. We are rendering an enclosed box with no exterior light sources or indirect lighting, so exposure control won’t really affect much right now. But we should at least set this right now to see how the scene will render out. Go to the Render > Exposure control (or hit the 8 key) and set the Exposure Control to use mr Photographic Exposure Control. Set the Exposure Control (EV) to 1.0. Hit the Render Preview. You can leave this dialog open as well.

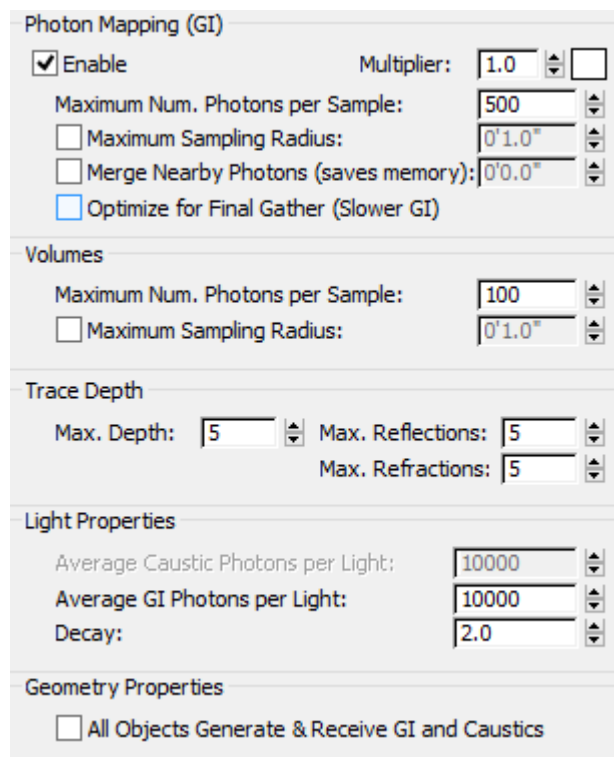


Hit the Render button and you will see this:



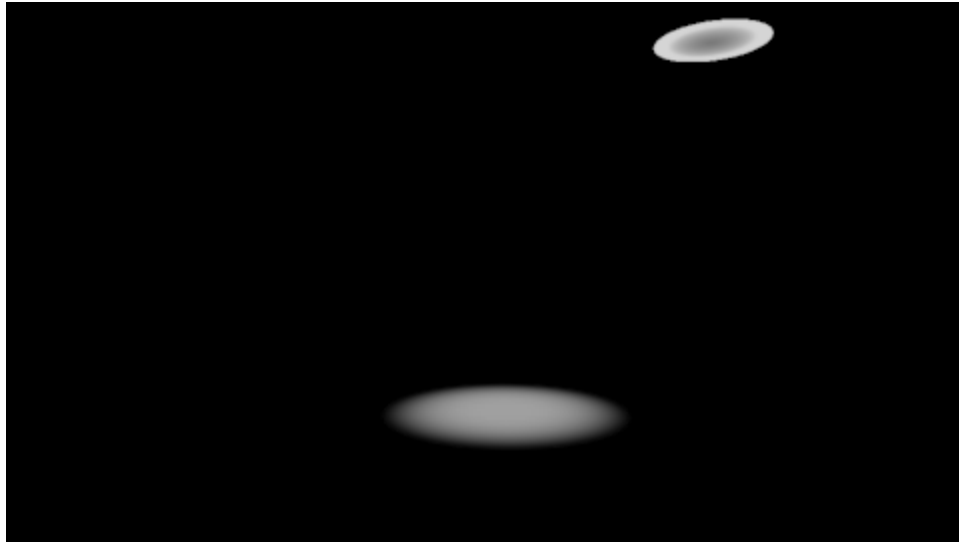
The spotlight is generating a pale pool of direct light on the floor as expected, but does not light any other part of the scene because we have disabled all indirect illumination.

4. Back in the Render dialog > Global Illumination panel, enable Photon Mapping (GI).



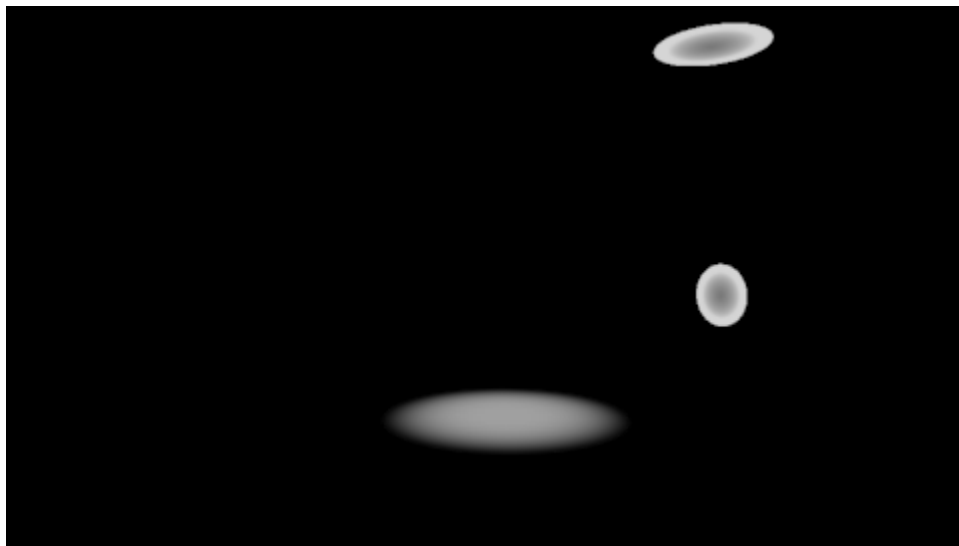
5. Set all the Trace Depth parameters to 1 and the Average GI Photons per Light to 1. This tells mental ray that we only want an average of 1 photon contributed by any single light in the scene.

6. Render Camera01. The result should look like this:



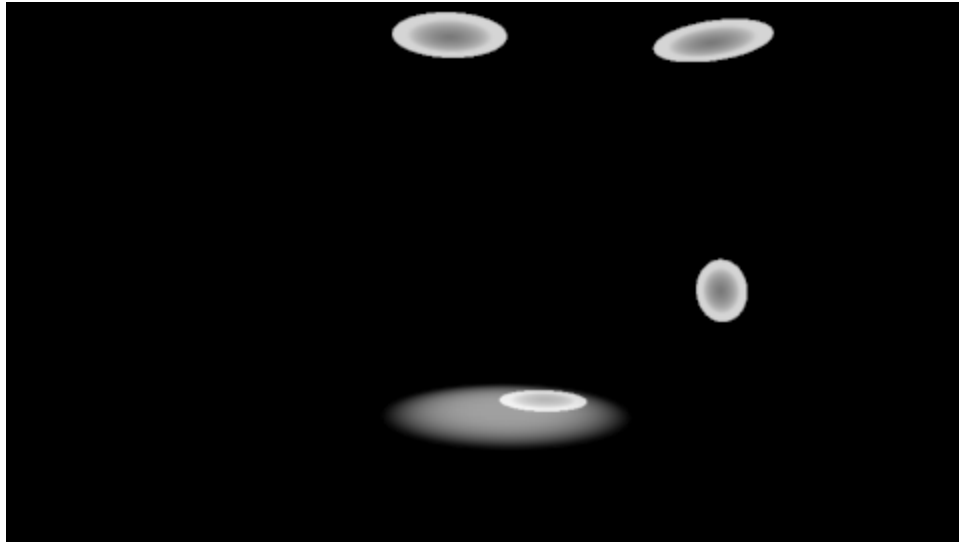
Here we get the same direct lighting on the floor. The new puddle of light on the ceiling that resembles a flashlight beam is the depiction of a photon that is being stored in this area. The photon was shot from the light source, bounced off the floor, and hit the ceiling where it stopped. Because we set our Trace Depth to the lowest setting of 1, the photon was allowed only that single bounce.

7. Set all the parameters in the Trace Depth group to 4 and render again.

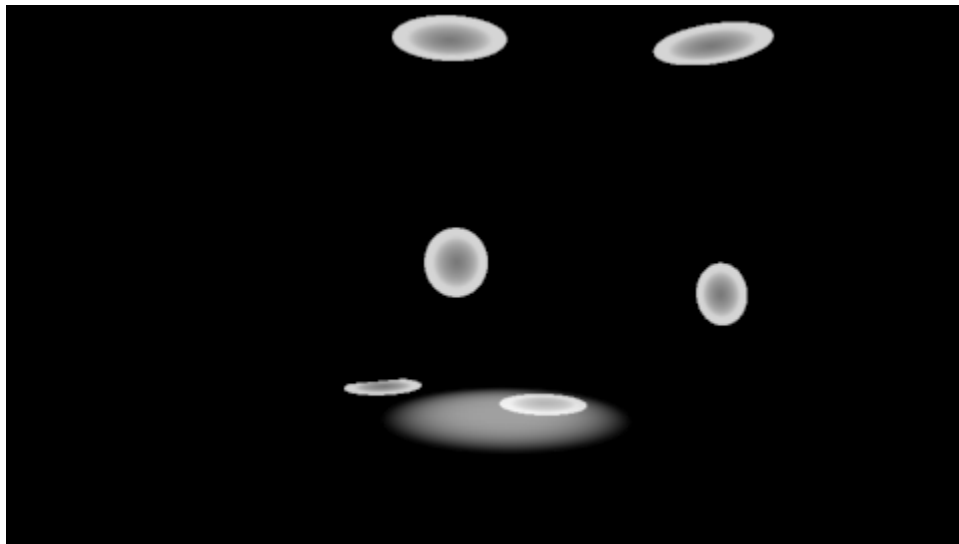


Here we get two photons; the rest are behind the camera.

8. Increase all the Trace Depth values to 6 and render again.

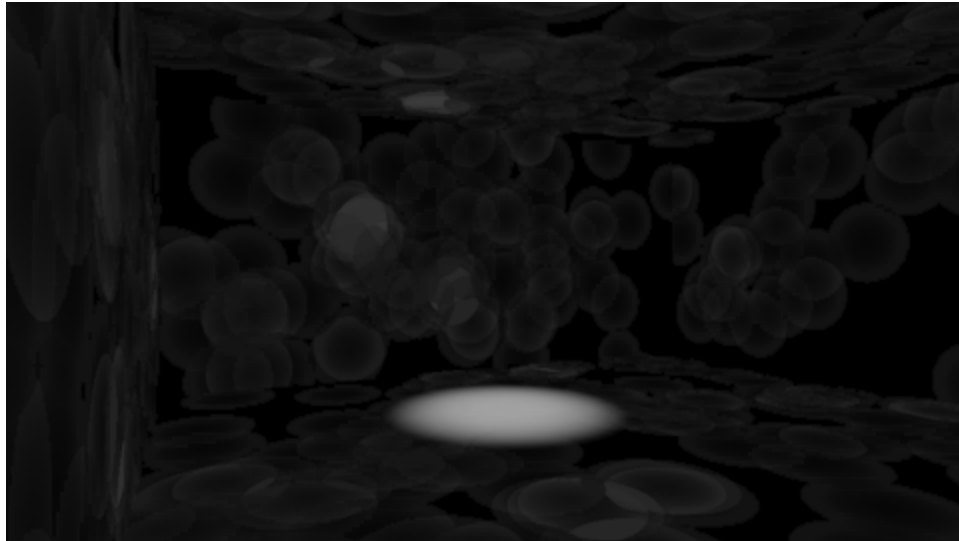


9. Increase all the Trace Depth values back to the default value of 10 and render again.



10. Set the Trace Depth parameters back to 5. The Maximum Depth number limits the combination of reflection and refractions. If Max. Depth is 3 and the trace depths are each 2, a photon can be reflected twice and refracted once, or vice versa. Generally speaking you can keep the Max. Depth number between 5 and 7 for most scenes, as you need enough bounces for things to reflect well but too many just takes more time. Materials tend to reflect light much more often than refract light (water, glass, plastics). Increase it from 7 if you have many transparent objects that are subject to refraction.

11. Increase the Average GI Photons per Light to 500 and render again:



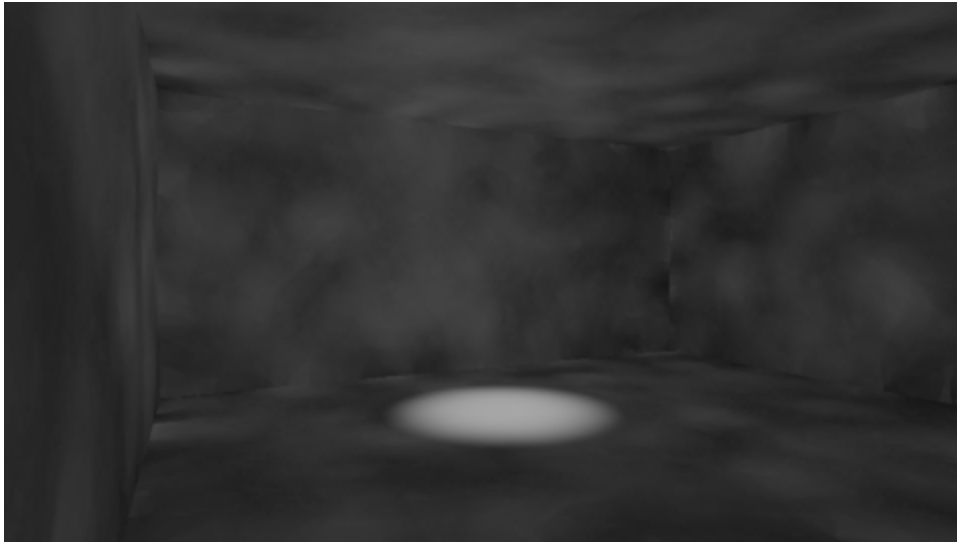
We now have 500 photons being emitted, but they are all darker. This is because all of the photons are sharing the same light energy from the single light source (remember we changed the Average GI Photons Per Light value). Adding more photons would simply dim the image further.

By default, these energy and photon settings apply to all lights in a scene, and all objects are set to initially set to receive global illumination. You can change the photon settings per light and GI settings per object in their respective properties. Note the setting at the bottom: All Objects Generate & Receive GI and Caustics. When turned on, all objects in the scene will now generate and receive caustics and global illumination, regardless of their local object properties settings. This setting does not alter the object's local object properties settings for mental ray. When off (the default), an object's local object properties determine whether it generates or receives caustics or global illumination. Turning this on is an easy way to ensure that caustics and global illumination are generated in one fell swoop.

12. Increase the Average GI Photons per Light to 10,000 (the default) and render. The result should look like a much darker version of the previous render with many more photons dispersed around the scene.

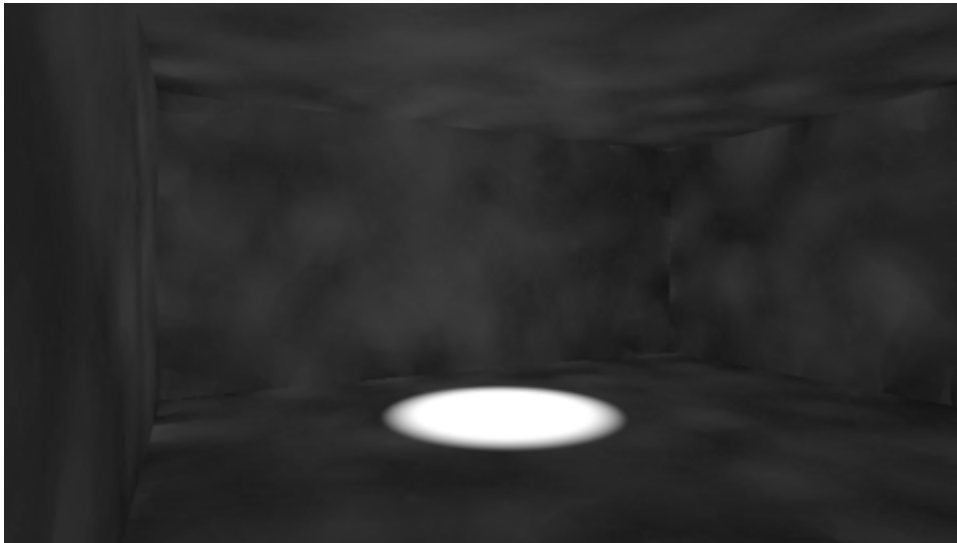
To increase the light level, we can either increase the GI multiplier to a higher value, which will increase the photon energy, or alter the exposure.

13. Increase the GI Multiplier to 10.0 and render again.



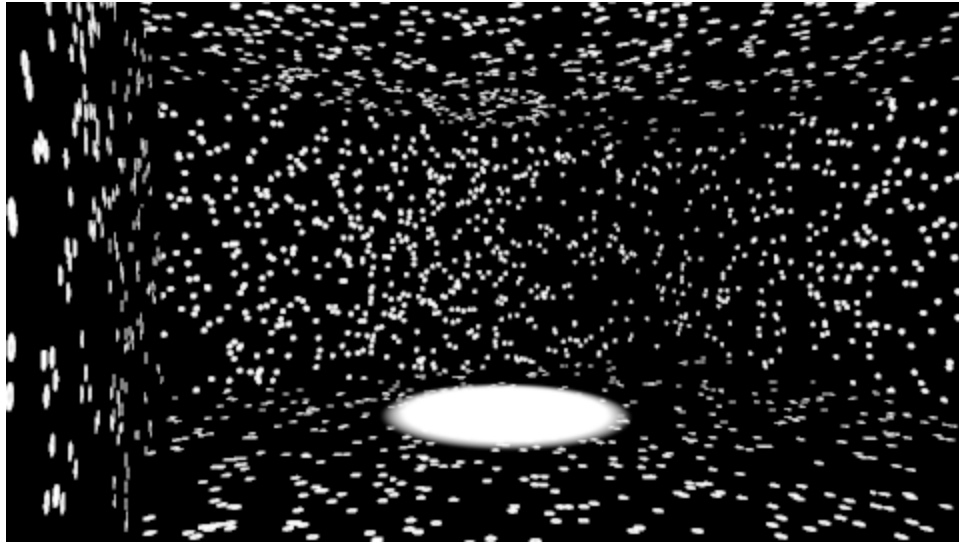
14. Turn the GI multiplier back to 1.0. You typically want to keep it at 1.0; consider the multiplier a cheat.

15. In the Environments and Effects dialog, turn down the EV value while you watch the Preview Render. The image will become visible near a value of -1.0; set it to -3.0 and render.

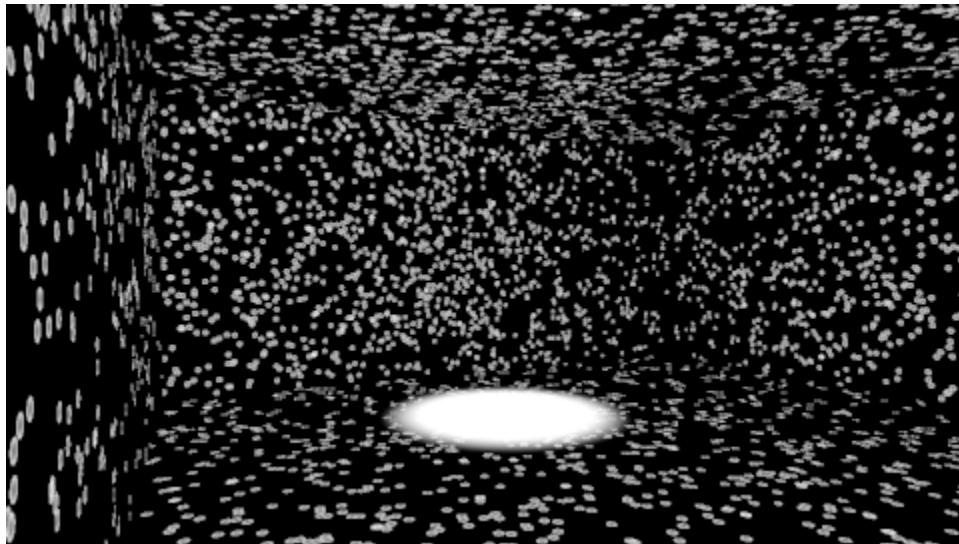


17. Note the light disk got brighter as well.

18. Back in the Render Setup > Global Illumination > Caustics & Photon Mapping (GI) rollout, set the Average GI Photons per Light to 5000, and enable the Maximum Sampling Radius (it defaults to 0'-1"). Render again.

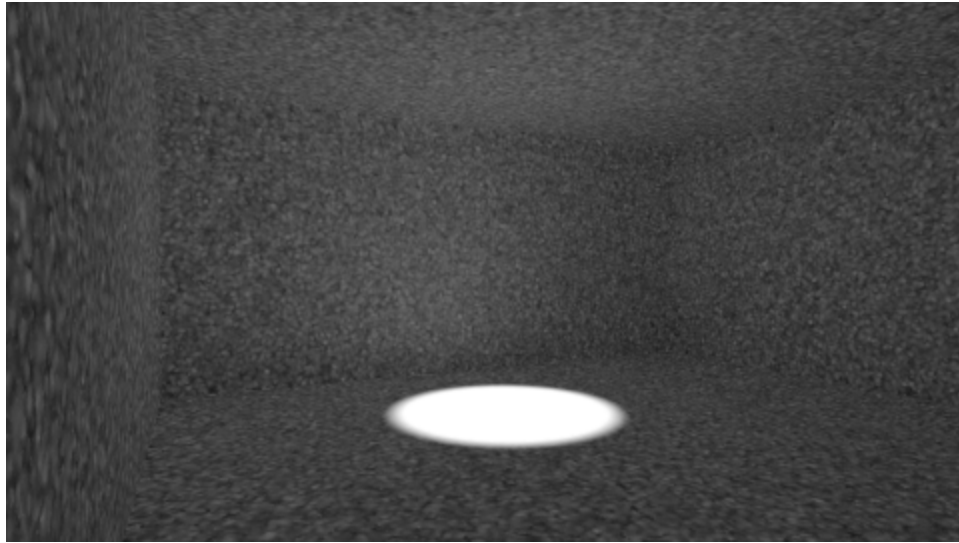


Here we start to get the “disco ball” effect that GI is famous for. Increase the Maximum Photons per Light to 10000 and render again:

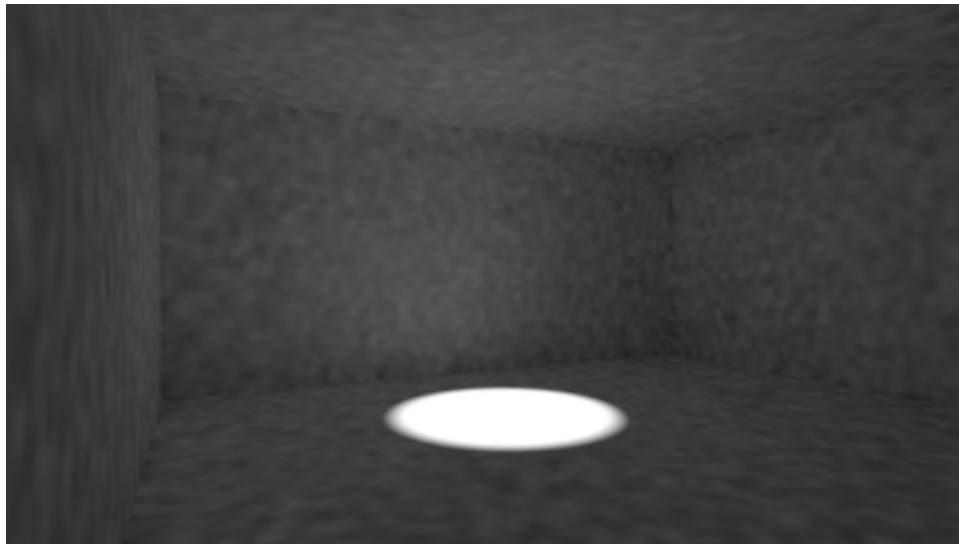


With the settings used here, the Maximum Sampling Radius effectively sets the size of the individual photon imprints, so these are all 2” across. (This is not actually the case all the time, as we will see later). When you make the photon imprints smaller, they still have the same energy so they appear brighter. When the Maximum Sampling Radius is unchecked, the size defaults to 1/10 of the overall scene dimensions. Since our room is 20’x20’, the default radius would be 2’-0” or 4’-0” across. The default value (unchecked) is a good starting point for when we use GI in conjunction with Final Gather, which is the vast majority of the time you will use GI, but as you will see in the Interior scene section there are some critical settings to make here.

19. Change the Average GI Photons per Light to 1,000,000 and render again. With so many photons every part of the scene is covered by a sample, but it’s still very grainy. Increasing the number of photons by itself clearly isn’t the answer.



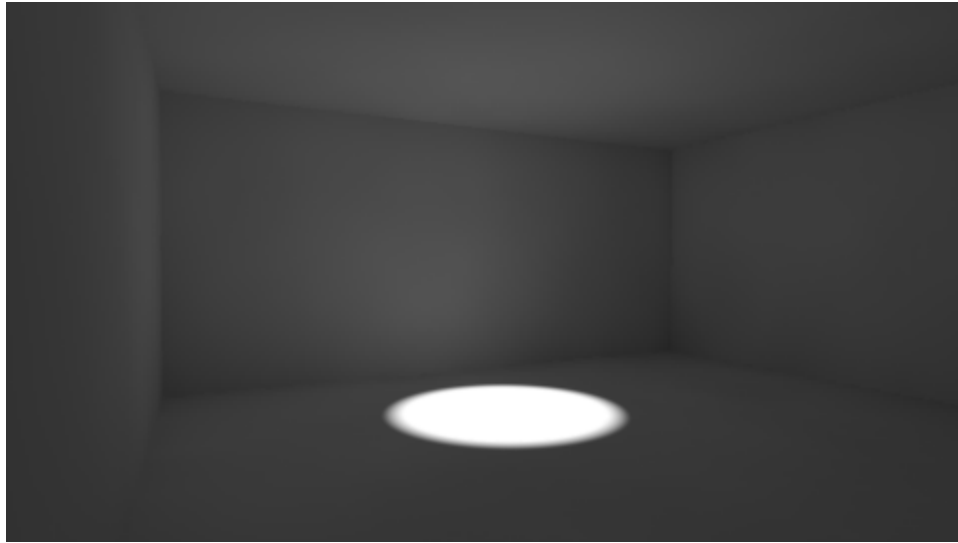
20. Change the Maximum Sampling Radius to 3" and render again. Increasing the sampling radius starts to fill the spaces between the photons so that they overlap.



21. Change the Maximum Number of Photons per Sample to 6000 and then render. It will look very much like the same as before... for now.

The Maximum Num. Photons per Sample is the number of photons collected together at render time around a particular rendered sample; these collected photons are averaged out to give a final GI value to that rendered sample (the sub-pixel point that is evaluated to create the final raster image), in effect computing the intensity of the GI solution. For this case with a high density of photons, the smaller the number, the noisier the image and the sharper the photons as they aren't combined together as much. The larger the number, the more they are combined and averaged out, and the less noisy the image. However, detail will start to get lost.

22. We set the number to use 6000 photons per sample, but we still have a small sampling radius of 3". Increase the radius to 1'-6" and render again:



Now we're getting somewhere. The photons are smoother but the image is certainly blurrier and less defined.

The Maximum Number of Photons per Sample depends on both photon density and sampling radius. With only 10000 average GI Photons per light - a low number - no setting for Maximum Num. Photons per Sample will improve anything while the radius remains low because they aren't close enough together to mix. We also need a large enough sampling radius to collect enough photons to smooth out.

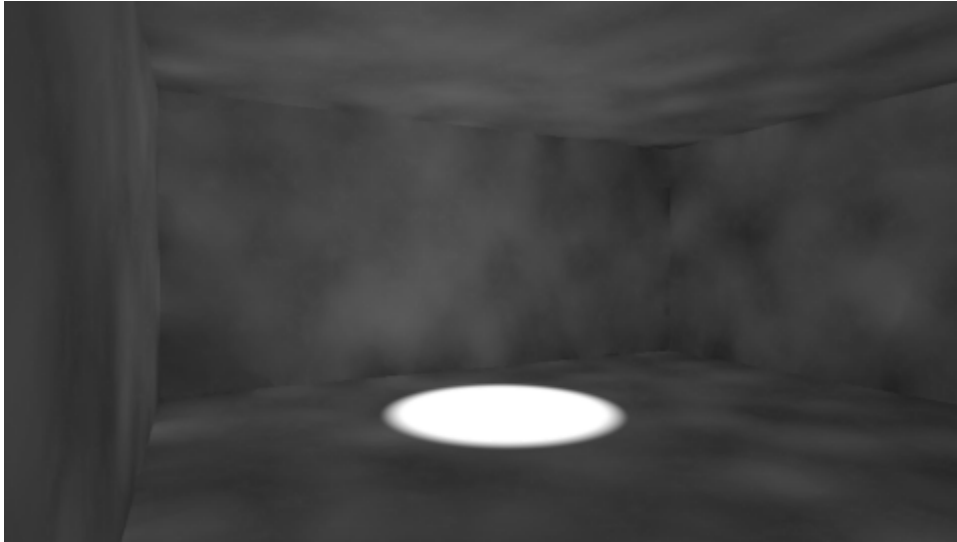
These three values - Maximum Num. Photons per Sample, Maximum Sampling Radius, and Average GI Photons per Light - all work together. For a GI only solution you need a lot of GI photons at a small enough radius to increase illumination at each point, and therefore need a higher Maximum Num. Photons per Sample to smooth out the noisy artifacts.

Remember the comment about the Maximum Sampling Radius setting the effective size of the photon? It is true when there are too few photons, because that is its area of their influence. With only 5000 photons in step 18, the radius of 1" produced the spotted effect. Where there are dense regions of photons, mental ray will gather together photons in an expanding radius around the current sample until either the Maximum Number of Photons value is reached or the Maximum Sampling Radius is reached. The area of influence for a single photon varies depending on the photon density in that area. Where there are few photons - as in our 5000 photon example above - mental ray will stop collecting photons when the Maximum Sampling Radius is reached and won't have the chance to merge with other photons because they are too far away.

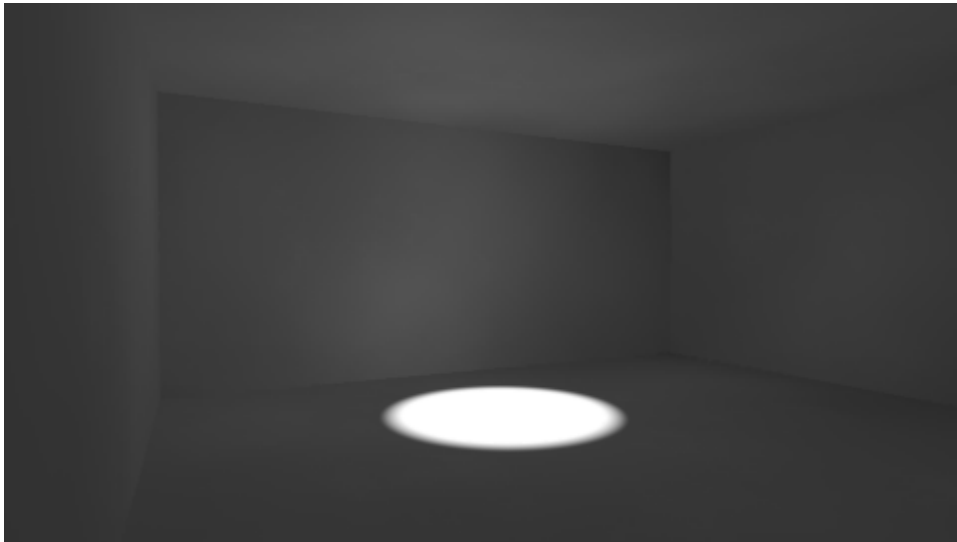
There are two routes to getting a decent GI solution. The one we have seen so far is to keep the radius small, increase the Average GI Photons per Light to very high numbers, and use high numbers for Maximum Num. Photons per Sample. This gives you a very smooth result, as seen in step 21 above, but can take considerable time to calculate.

The other option is to keep the Maximum Num. Photons per Sample low, at its default of 500, use a smaller number of GI Photons per light, and specify a larger radius - large enough that the photons touch and can mix together.

23. Change the Maximum Number of Photons per Sample back to the default 500. Change the Average GI Photons per Light to 20,000, and uncheck the the Maximum Sampling Radius to use the default (about 2'):



24. Change the Maximum Sampling Radius to 5' and render again:



Here the large sampling radius allows the low photon density to smooth itself out without losing a lot of detail; compare the difference in sharpness of this image to that in step 22, particularly along the corners of the room.

Let us now compare rendering times:

Step	22	24
Average GI Photons per Light	1,000,000	20,000
Maximum Number Photons per Sample	6,000	500
Maximum Sampling Radius	1'-6"	5'-0"
Render Time	5 seconds	1 second

Clearly, very high values the Average GI Photons per Light and for Max. Num. Photons per Sample can kill your render times.

As mentioned previously, we can save and reuse a photon map and reuse it no matter where our camera is.

25. Expand the Reuse (FG and GI Disk Caching) rollout, and in the Caustics and Global Illumination Photon Map section, change the menu from Off to Read/Write Photons to Photon Map files. It will prompt you with a save dialog box to store the photon map to a location you determine. It typically goes into the project's .\sceneassets\renderassets folder. Give it the name "GI Box 24 Photonmap.pmap" to save the photon map.

26. Render the scene or click the "Generate Photon Map File Now" button below and it will create the .pmap (photon map) file. With a saved .pmap file, you won't have to go through the GI calculation stage every time you render. If you change your GI settings or move lights around, you will have to save another photon map.

27. The above file is about 411KB on disk, but this is a very small model; these .pmap files can get to be quite large on real scenes. Set the values back to as they are in Step 22 (1,000,000 / 6000 / 1'-6") and save another map; the new file is 20.5MB.

To help with this, mental ray has a tool that will merge nearby photons. Once enabled we can set the radius that will be used to merge nearby photons and optimize the photon map.

28. With the values still at Step 22 settings (1,000,000 / 6000 / 1'-6"), enable Enable Merge Nearby Photons (saves memory), and enter a value of 1'. Select Read/Write Photons to Photon Map and click the three ellipses button to browse to the folder and save a new map under a new name. Generate the new file - it's now only 24KB. The larger the value the smaller the .pmap file, but the grainier the image will be. The smaller the size the better the image but the larger the .pmap file. However, it should still be orders of magnitude smaller than the original file.

29. Set the Photon Map group button to "Read Photons Only from Existing Photon Map Files" and make sure the new optimized file is selected. Hit the Render button and the new rendering completes almost instantaneously.

Conclusion:

As with all mental ray features, the trick is to examine Global Illumination in detail enough to understand what it does and how the controls affect render quality, render speed, and overall efficiency. Global Illumination is a great tool for interior renderings, usually in combination with Final Gather. Remember that Global Illumination needs photons to be able to bounce among at least two surfaces. Therefore, it is typically not used for exterior renderings, because the photons don't have much to bounce off of before they simply shoot out into space, and won't contribute to the indirect illumination. For exterior scenes you want to use Final Gather.

Final Gather

Final Gather can be considered to be the opposite of GI. Instead of photons shooting from light sources into the scene, rays are shot from the camera into the scene to sample the contribution of light on an object's surface. Unlike GI, Final Gather is view dependent and a new round of Final Gather calculations would need to be performed for every camera and/or change in view. Thus, special additional consideration needs to be made if you are creating animations or rendering out many images of a single scene.

Because each ray is sampling the geometry to understand how much illumination it receives from its surroundings, we can use all sorts of techniques to illuminate the space. HDRIs, which contain the full lighting information, can be used not only as high quality backplates but also sources of light which will be picked up by FG. Objects with self-illuminated materials now become light sources. The contribution of the mr Physical Sky environment can provide FG indirect illumination.

Final Gather is actually a three-pass system where a low resolution rendering is created that gathers up the indirect illumination information, then is added to the direct illumination and surface properties during the final rendering ('beauty') pass.

You will see this when you render a Final Gather scene, as the first passes are very pixelated and get refined as each pass performs more work. This visible pass system allows you to evaluate the scene lighting and overall feel quickly, allowing you to cancel it out if things need adjustment.

How Final Gather Works

mental ray starts by spraying the scene with Final Gather rays from the camera. The number of Final Gather rays sent into the scene is determined by the Final Gather Density value. Each ray, called an eye-ray, places a Final Gather point where it hits a piece of geometry in the scene. The FG point samples the direct illumination on that point. From this Final Gather point, additional rays are shot randomly into the scene to sample indirect illumination at the point where they hit other surfaces in the scene. The number of additional rays is specified by the Rays per FG Point value. Those rays will then reflect, sample, and propagate through the scene until the Diffuse Bounces value is reached.

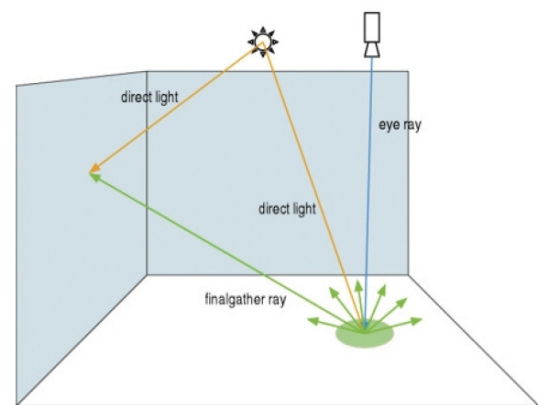


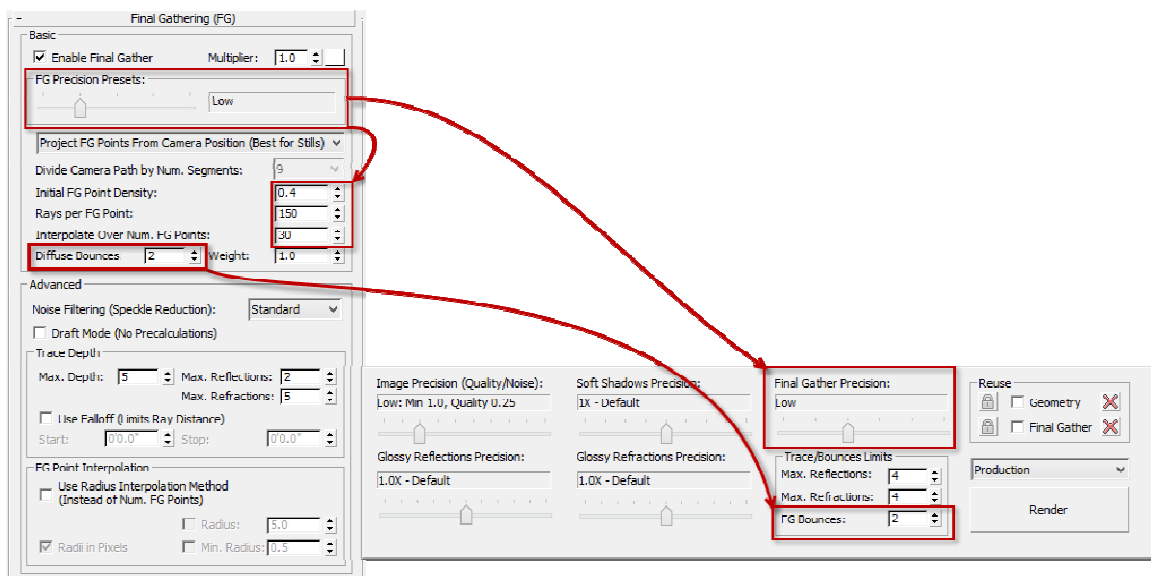
Image courtesy Paolo Berto, mental images

As Final Gather rays propagate through the scene, the rays either reflect off of surfaces, are absorbed by them, or are refracted by them based on the surface material. With each bounce, ray energy decays over distance using the physically correct inverse-square law, so each subsequent ray interaction is less and less. Once the maximum number of bounces is made, the rays' cumulative indirect light intensity and color are stored in the original Final Gather point.

During the final render pass, mental ray calculates the average illumination of a number of the nearest Final Gather points that fall within a radius around each rendered sample. The number of points averaged together is the Interpolate Over Num. FG Points and is by default 30. This indirect summation of Final Gather points is then added to the direct illumination value and surface color to produce the final sample. The higher the Final Gather point density and the more rays are shot from each Final Gather point, the more accurate the final rendering will be.

Final Gather Settings

The number of settings for Final Gather isn't large but each one is important. Some of the important Final Gather settings are also found in the Rendered Frame Window as explained below.



The Multiplier setting scales the overall contribution of Final Gather, and the color swatch will tint the Final Gather points. As with GI, the multiplier is a cheat. The default multiplier of 1.0 at pure white provides physically accurate results.

Presets

We've already discussed the four primary settings important for Final Gather - Initial Final Gather Point Density, Rays per FG Point, Diffuse Bounces, and Interpolate over Num. FG Points. Together those determine the number of FG points sprayed onto the geometry, how many additional rays emanate from those points, how many times those rays are allowed to bounce around the scene, and how many resultant FG points are averaged together to produce the final brightness and color of a rendered sample.

The Final Gather Preset / Final Gather Precision slider in the Rendered Frame Window is a single value that is a combination of these four specific settings. There are five presets:

	Initial FG Point Density	Rays per FG Point	Interpolate over Num. FG Points	Notes
Draft	0.1	50	30	Not intended for production; good for check renderings and scene evaluation
Low	0.4	150	30	Better refinement over Draft, also good for check renders with other lighting effects (AO, GI)
Medium	0.8	250	30	Most popular setting; Increase render times over Low; Better shadow definitions & contrast.
High	1.5	500	30	Smoother along flat surfaces; 7x longer rendering time over Draft, 3x longer than Medium
Very High	4.0	10,000	100	Extremely long render times (10x+ over Medium)

Note too that in the Rendered Frame Window you can disable Final Gather by sliding the Final Gather Precision slider all the way to the left.

Other settings to note:

Use Radius Interpolation Method (Instead of Num. FG Points): This setting modifies the combination stage to use a fixed radius around the sample point to determine the FG points which will be averaged together.

Weight: The Weight adjusts the contribution of Diffuse Bounces to the FG points. For example, adding more Diffuse Bounces will brighten the scene too much; the Weight setting can help tone this additional brightness while still giving you the smoothness that additional Diffuse Bounces provide.

Noise Filtering (Speckle Reduction): Final Gather works by averaging the Diffuse Bounces back to the FG points and averaging the FG points together. If a FG ray hits a particularly bright spot - which, given the randomness of the ray propagation from the FG point, is a sure thing - the result will be an overly bright FG ray and a blotchy result. The Noise Filtering option provides none to extremely high filtering out of overly bright FG rays and helps smooth out your FG results at some expense of overall brightness.

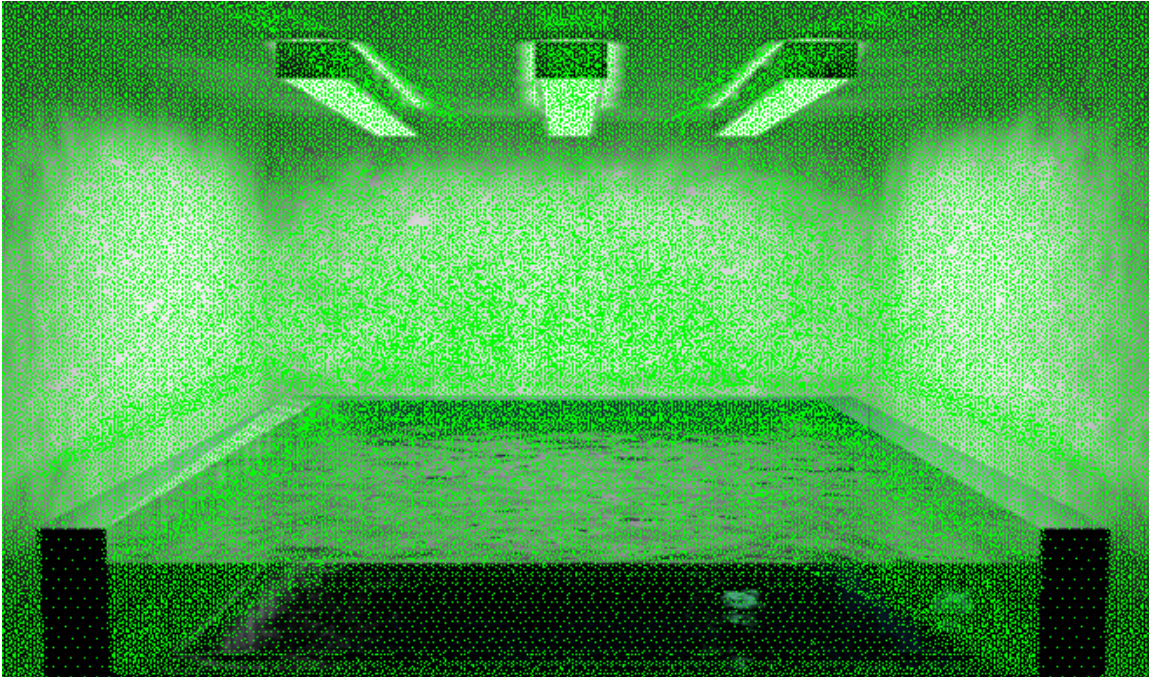
Use Falloff (Limits Ray Distance): Pretty self-explanatory. This setting increases the decay at which FG rays travel, allowing you to limit how far an FG ray will travel before it stops and returns the environment color. This is particularly effective for exterior scenes where the chances of FG rays bouncing off into infinity is much greater. Use Falloff has a Start and End value; the Start tells mental ray when to start the additional attenuation, and the End is the FG Ray cutoff point.

Using Diagnostic Mode

Mental ray includes a very handy Diagnostic tool that allows you to visually see how various aspects of the mental ray renderer are functioning under the hood with a color representation of the renderer's internal data. Probably the most popular diagnostic tool is the Final Gather visual diagnostic, which displays the point cloud of green dots which represent the Final Gather points that were placed in the pre-

processing phase. Each green dot represents a point where mental ray sees a change in contrast and has determined the need for additional Final Gather points.

To enable it, go to the Render Setup dialog > Processing panel > Diagnostic rollout, enable the Visual mode, and select Final Gather. Render the scene and you will see the FG density map appear.



Final Gather Tutorial

With the current project set to C:\AV2742 Mental Ray in 3ds Max Design, open .\scenes\AV 2742 Beachhouse_Start.max. Go to Camera Interior 02.

Select the Daylight system and set the time for 12PM on June 1, 2013. Ensure Daylight Savings Time is enabled. The location should be set to Las Vegas, NV. The beach house scene has a few interior lights, but they are turned off. They look like they are on because they have a self-illuminating material on them, but they cast no actual light. All of the interior illumination is from the Daylight System coming through the front window wall glazing.

Initial Final Gather Setup:

In the Render Setup dialog, Common tab, ensure the resolution is Set the Resolution is 640x360, which is the same aspect ratio as HDTV (1.778). It's high enough to evaluate the effectiveness of our settings but low enough not to kill rendering times.

Sampling Mode is Unified with a Quality setting of 0.25 (Low)

Global Illumination rollout → Enable Final Gather. Set the FG Preset to Draft and Diffuse Bounces to 1.

Set all Trace Depths for all settings to the default of 5.

Caustics and Photon Mapping (GI) should be disabled.

Go to the Environment and Effects dialog and test the exposure. By default it is set to 15 which is fine for an outdoor scene, but will leave an interior rendering underexposed. Hit the Render Preview button and watch as it lightens as you lower the Exposure Value (EV) to 11.0. The trick is to get it low enough to lighten the interior, but not too low that it blows out the glazing.

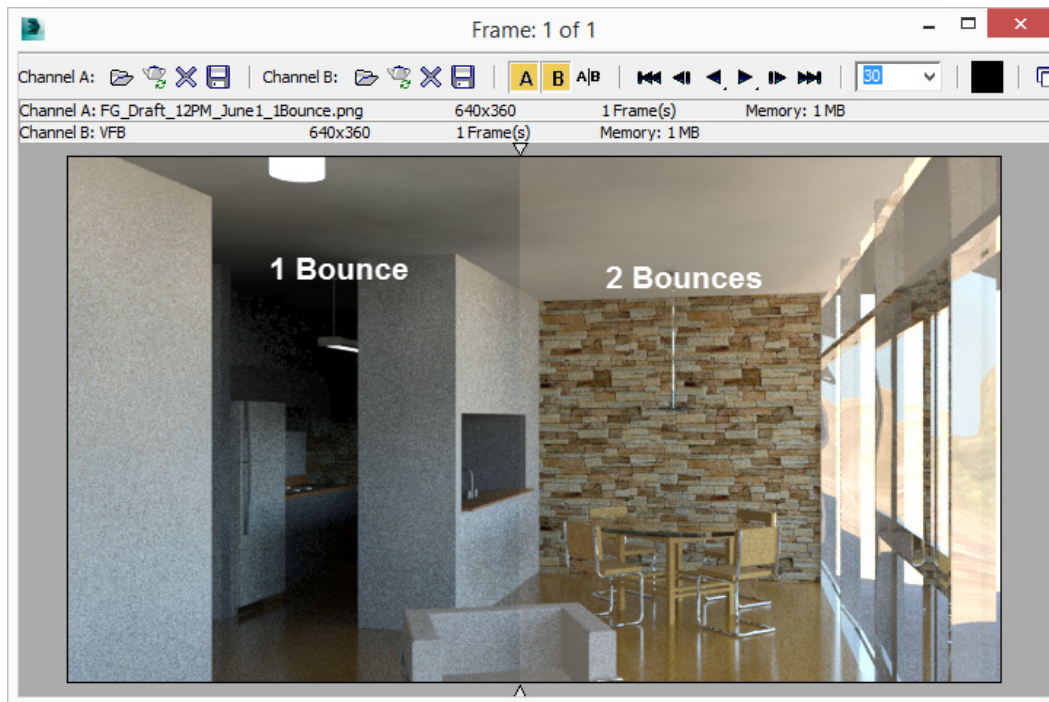
Render the scene:



The exposure is fine, but it is very grainy, the ceiling is kind of blotchy, and the exterior light is not reaching into the interior very well, particularly in the kitchen. Increasing the Diffuse (FG) Bounces will lighten the scene somewhat as rays cast from the FG points will bounce off of additional surfaces, but with an increase in render times. Set the FG Bounces to 2 and render again:



You can see the difference when you load both renders into the RAM Player:



In general, keep your bounces as low as possible; 1 is great for test renderings, 2 is fine for many final renderings, but don't go above 4 or 5 unless you really need to.

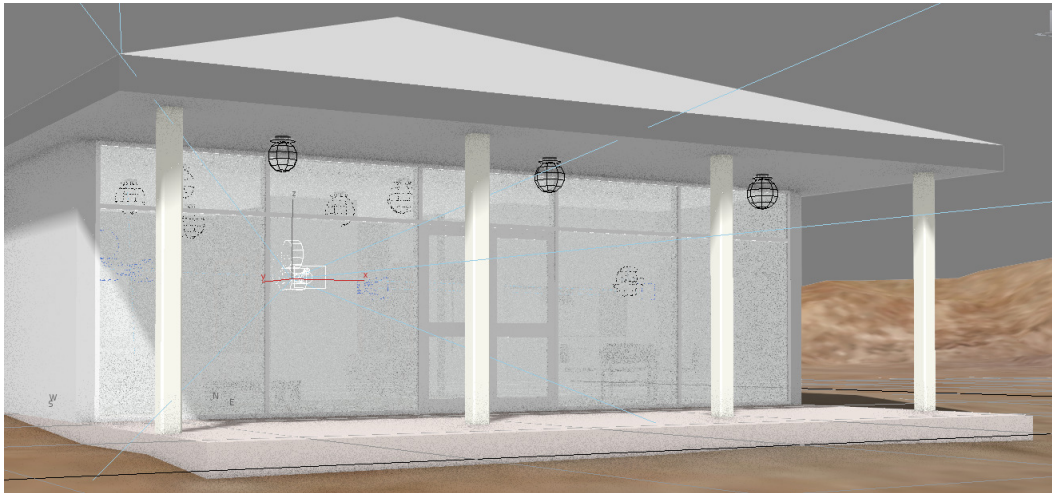
In this case, the ceiling blotchiness is improved with 2 bounces, but the image is still too noisy. This can only be fixed somewhat by playing with Soft Shadows Precision, Image Precision, Shadow Sample Softness in the mr Sun properties, etc. The answer to getting a better image as well as increasing the contribution of the exterior light is to use a mr Sky Portal.

Adding an mr Sky Portal

The mr Sky Portal is a special mental ray light type that is specifically intended for interior daytime renderings where you need to pull additional exterior skylight into the scene without requiring excessively high Final Gather or Global Illumination settings. Each portal that you add over windows and doors acts like an area light that gets its brightness and coloring from the environment. Using mr Sky Portals is pretty easy:

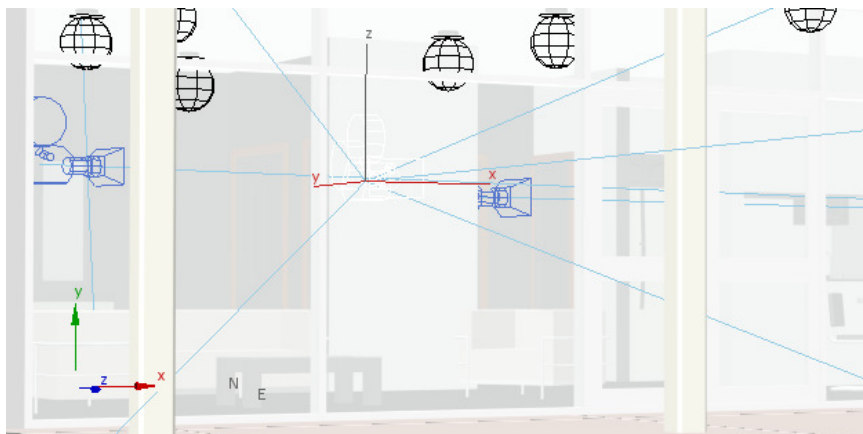
From the project's .\scenes folder open the AV2742 Beachhouse_Start.max file, or continue from the previous tutorial.

Go to a Top view the enable Perspective. Orbit so you see the front of the beach house



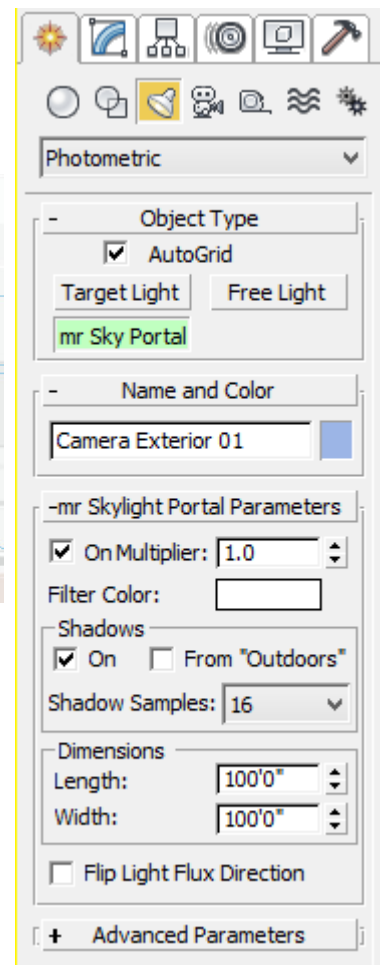
On the Create panel, click (Lights). On the Object Type rollout, click “mr Sky Portal,” then turn on AutoGrid so you can create the Sky Portal directly on a surface. When you position the “mr Sky Portal” on an object, ensure the Z axis is perpendicular to the surface.

Position the cursor at the bottom-right corner of the bungalow curtain window (the object name is Glazed), making sure the Z axis indicator is perpendicular to the surface.

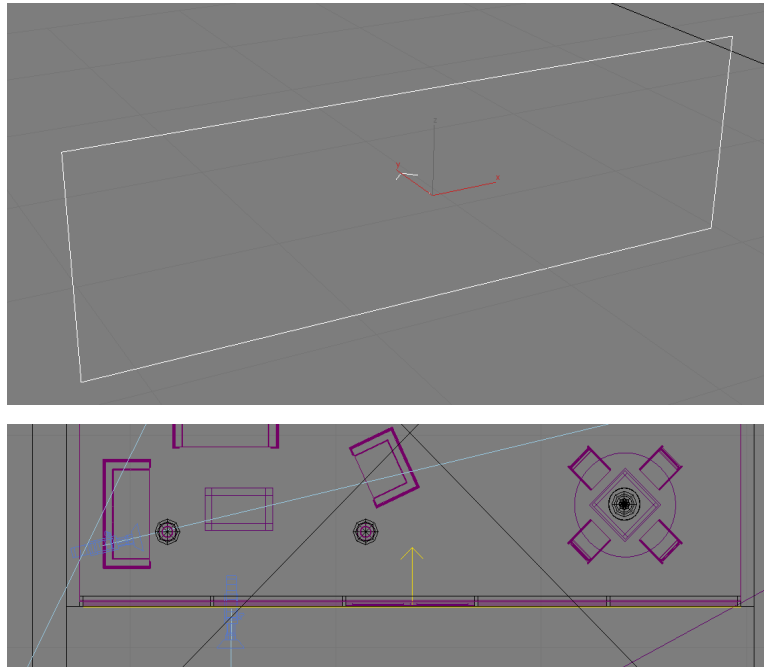


Create the mr Sky Portal by dragging diagonally from the lower-left corner to the upper-right corner, until the portal covers the entire area, then release the mouse. Right-click to complete Sky Portal creation.

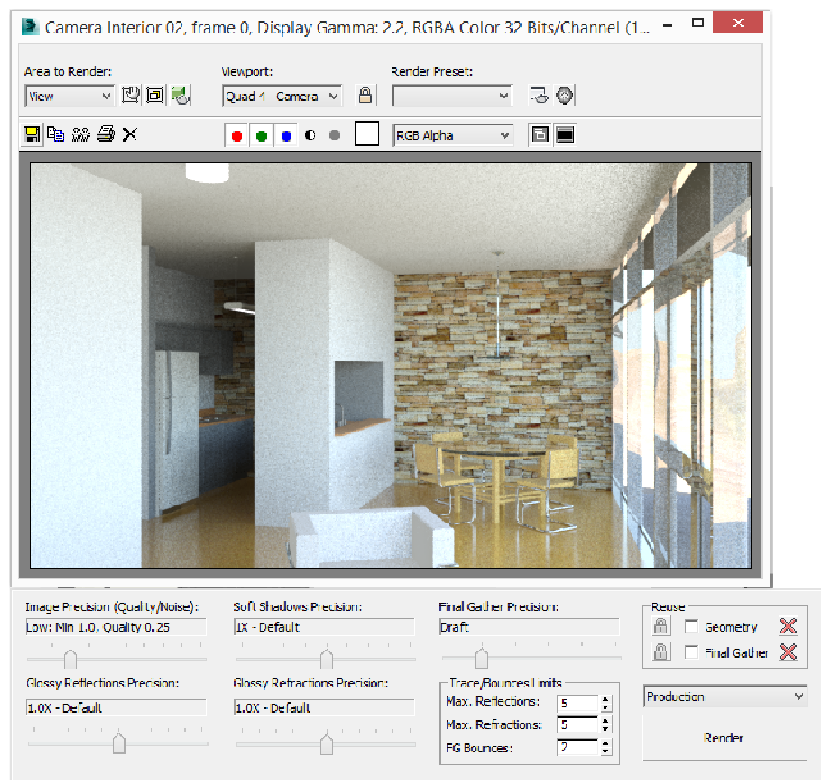
Typically you would create a separate mr Sky Portal for every window and glass door in the model. In this case, a single large portal covering the entire front of the building is fine.



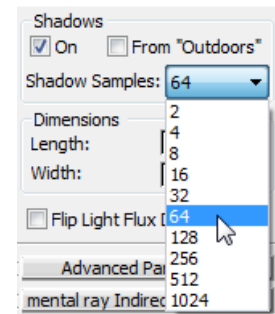
Right-click on the new mr Sky Portal, and select “Hide Unselected” to isolate it. Note the direction of the arrow - it should be pointing inwards to the interior of the beach house. You can also go to a Top view and enable Wireframe (F3) and check it there as well.



Go back to Camera Interior 02 and render again with the same settings:



That's much better and render times were kept in check. We can clean up the noise by increasing the shadow samples in the mr Sky Portal to 64.



Finally, render the scene using the following settings:

Image Precision (Quality/Noise): Medium: Min 1.0, Quality 1.0 	Soft Shadows Precision: 1X - Default 	Final Gather Precision: Medium 	Reuse <input checked="" type="checkbox"/> Geometry <input checked="" type="checkbox"/> Final Gather
Glossy Reflections Precision: 1.0X - Default 	Glossy Refractions Precision: 1.0X - Default 	Trace/Bounces Limits Max. Reflections: 4 Max. Refractions: 6 FG Bounces: 2	Production



Saving a FG Solution for Faster Renders

Computing the Final Gather points is a very expensive task for computers to handle, and is the primary reason renderings take so long. However, once you have your FG solution dialed in, the lights are not going to change, your camera views are set, and you are ready to render your final images, you can pre-calculate and save your Final Gather map - the "point cloud" of Final Gather points - and call it back again when you need to re-render.

Better still, you can pre-calculate and save (cache) the Final Gather points at a lower image resolution, then reuse that lower resolution FG solution for the higher-resolution final image. This saves a lot of render time and lowers memory consumption. The process goes like this:

1. Set the render resolution to 1/2 that of your final intended resolution. It is recommended that this be in some even multiple of the final image resolution; half is usually best.
2. Under Final Gather > Reuse (FG and GI Disk Caching) rollout, set the Final Gather Map to “Incrementally Add FG Points to Map Files.”
3. Specify a folder / file name for the FG map.
4. Select Generate the Final Gather Map File Now
5. Set the cache to be Read-Only for use when rendering the final image.
6. Render the scene at the final image resolution. If a cache file exists and is set to Read-Only, mental ray reads the data from disk and skips the FG calculation process completely, completing the rendering much faster.

Additional FG Tutorial

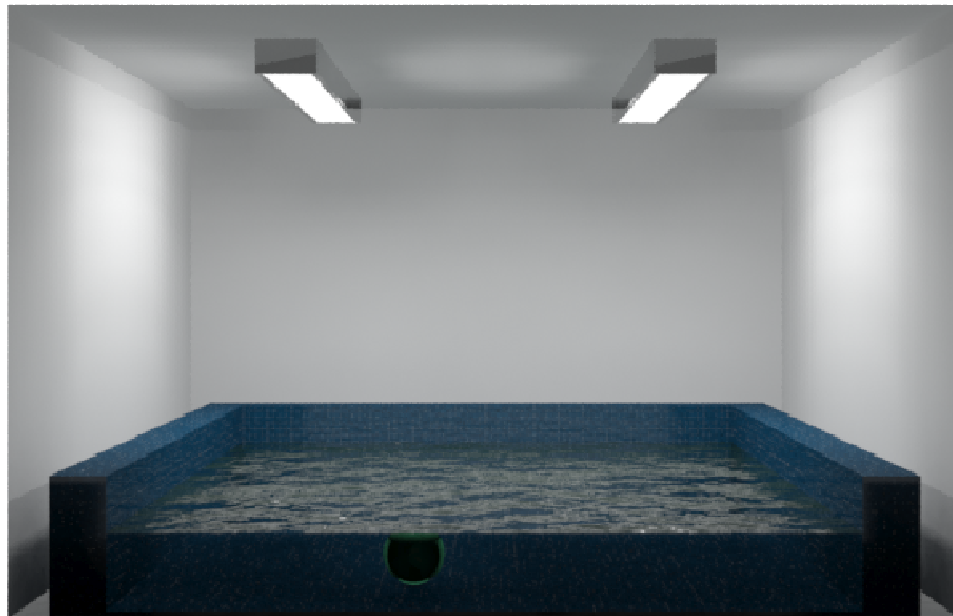
Open the project file FG_Pool.max. This is a simple 20'x20' box with a pool modeled in the center. We will use this file later when working with Caustics.

Initial Lighting Setup:

There are two photometric rectangular area lights placed in the scene, using the “4ft Pendant Fluorescent” template. They are set to use Ray Traced Shadows, the rectangle dimension is 8'x1', color is D65 Illuminant (6500 Kelvin), and the Dimming was unchecked with a resulting intensity of 3200 lm.

Next, open the Environment and Effects dialog and under mr Photometric Exposure control, set the EV value to 6. Render a preview to confirm the exposure setting will work.

Render the image:



Wow, not bad. Render time was 1:25 (mm:ss) The lighting is very even with no splotchiness. The low quality setting used in the Unified Sampling section makes it a little noisy in the pool, but that's an easy fix. We will take care of the water later when we talk about Caustics.

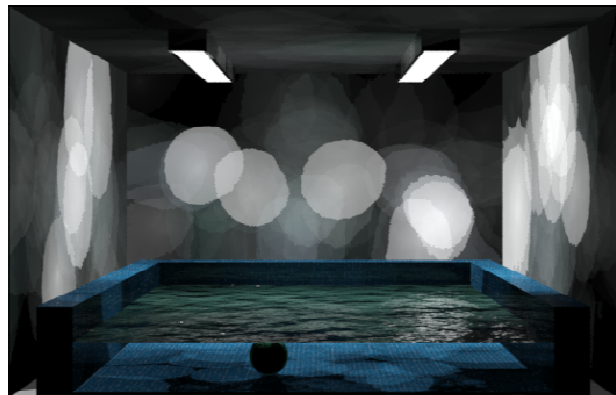
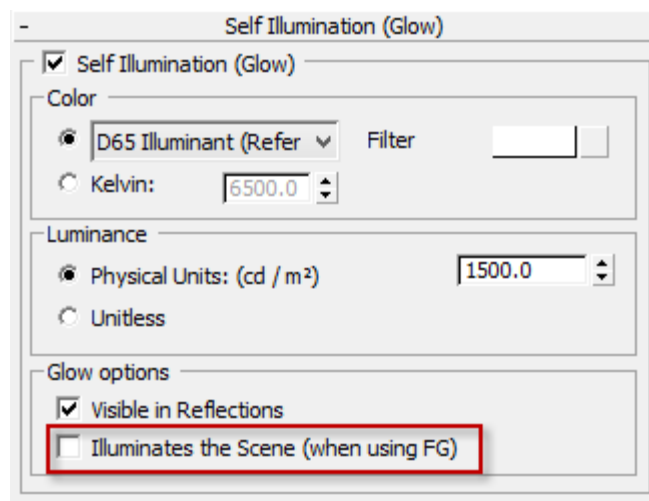
Self Illuminated Materials:

Self-illuminated materials can add illumination to the scene when using Final Gather, but because it is not direct illumination they will not cast shadows. Typically they are used to simulate the illuminated lens inside a light fixture, as otherwise the light would be cast into the scene, but the fixture itself would remain dark. This is the case you see with out of the box Revit light fixtures.

The two light fixture boxes have an Arch & Design material applied to the bottom face. The material uses the Frosted Glass template, with Self Illumination turned on. The color is set to D65 Illuminant, and Luminance set to Physical Units of 1500cd/m². Illuminate the Scene (with FG) is unchecked.

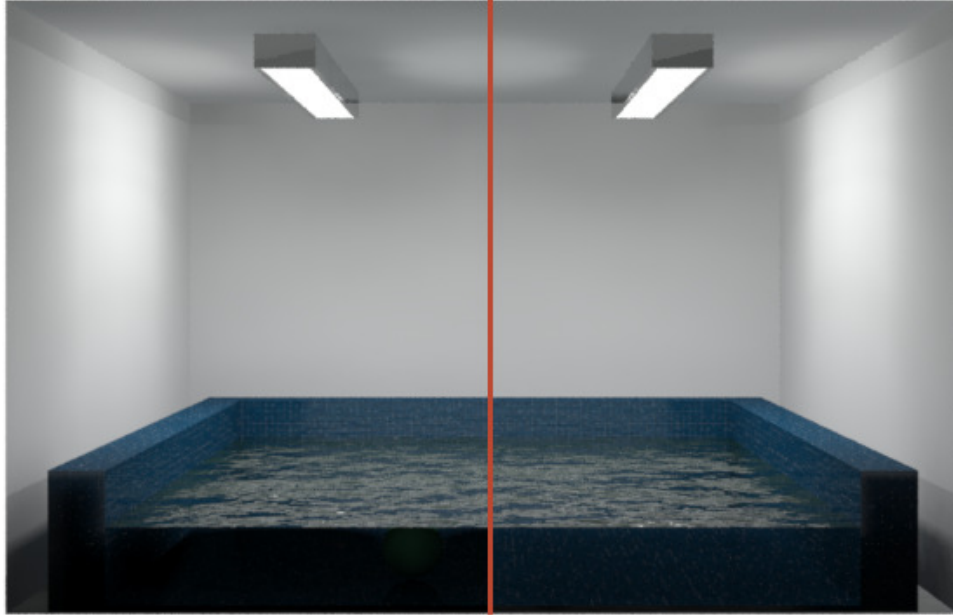
Go the Light Listed and turn off the photometric area lights. If you render the scene, you'll just see the two glowing rectangles, but no light will be transmitted to the room itself. (Small reflections may appear in the water, which is to be expected). If you check the Illuminate the Scene (with FG) you will see splotchy indirect illumination cast across the room that will need cleaning up, possibly with high settings that could impact render times. Because this can interfere with the actual light sources, let's keep this turned off to avoid the chance of over-lighting the space. Self-illumination with FG contribution works great for things like neon signs.

In the following images all of the photometric lights were disabled. On the left side, the "Illuminates the Scene (with FG)" was disabled. On the right, this setting was checked.



Low, 1 Bounce:

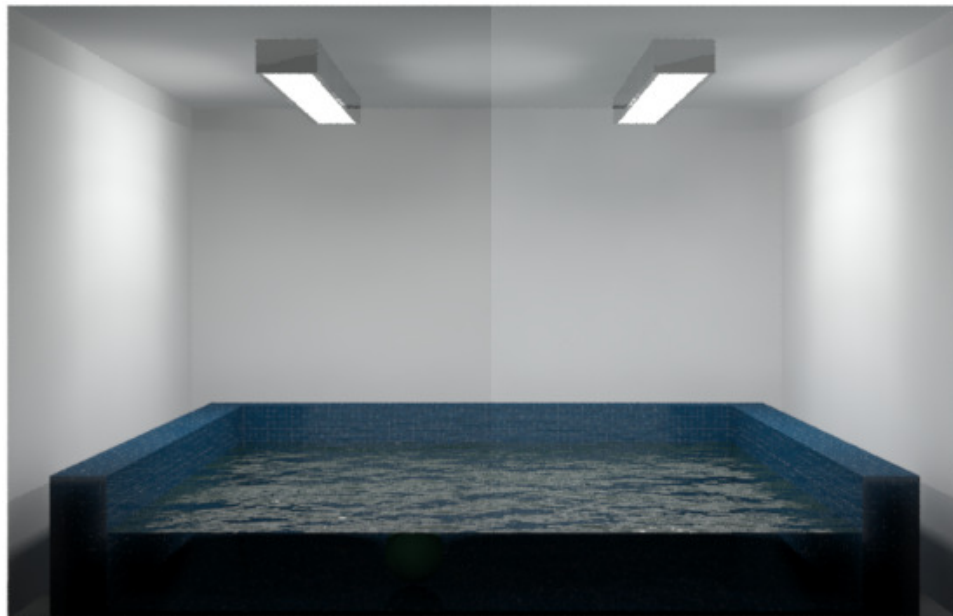
Although the Draft was pretty good by itself, let's try the Low preset, keeping Bounces at 1:



Render time grew to 1:28, and the overall image improved slightly. On the left is Low, on the right is Draft. The Low image has slightly more diffuse lighting, more spread out. The water contrast increased as well. The darkness of the water is a material issue and one we will fix in the next section on caustics.

Low, 2 Bounces

Let's try the Low setting again with two Diffuse Bounces:



Left: Low, 1 Diffuse Bounce. Right: Low, 2 Bounces.

As expected, the additional bounce brightened the image somewhat. Overall the lighting is pretty good, so let's ramp up the sampling quality to get rid of some of the noise. Render time increased to 2:32, a fairly big jump.

Low, 2 Bounces, Quality = 1.0

In the Renderer tab, set the Sampling Quality to 1.0



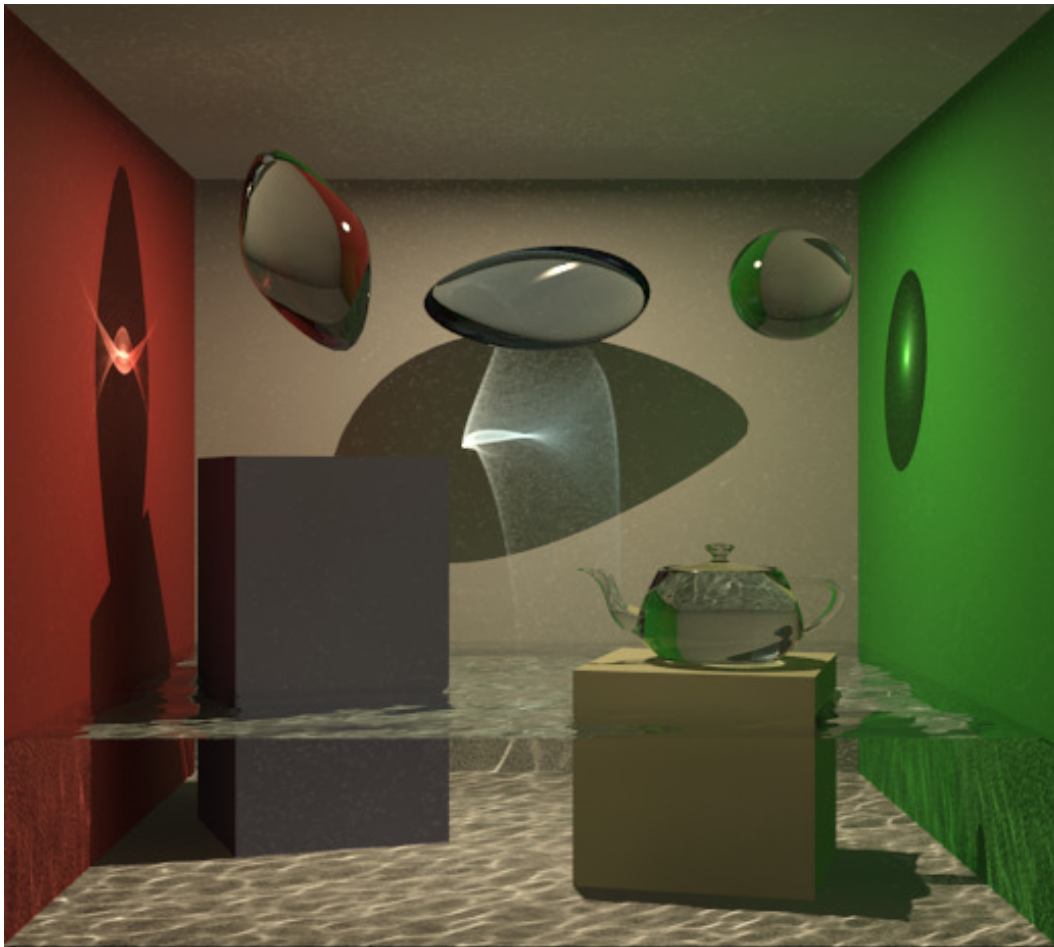
It's perhaps difficult to see at this low resolution, but the higher Quality setting improved anti-aliasing, particularly along the edges of the light fixture. Render times shot up to 5:13.

Because we only have two lights, with no contribution from a Daylight system, it's probably not worth the effort to bump up to a Medium preset. Instead we should look at the small details to make the image really pop: Caustics and Ambient Occlusion.

Caustics

Caustic indirect illumination effects are the result of concentrations of light energy as they pass through or reflect off a transparent surface such as water, glass, or plastic. Photons become focused as they pass through materials with different Index of Refractions (IOR) which causes bright spots to appear on the various surfaces in the image.

Below is the Cornell Box with several caustics generators - the water plane and the glass orbs. The photometric light was changed to a Point light to focus the light energy even more.



Model source: Jennifer O'Connell, *Mastering mental ray: Rendering Techniques for 3D and CAD Professionals*.

The decision to use caustics is one that should not be taken lightly. First of all, it can become computationally expensive and drive render times up. The path to the desired effect is not an easy thing to predetermine before you do a lot of test rendering. But more importantly, like any trendy effect, it can be overdone in many cases. Used tastefully it should enhance the quality of the rendering without looking cheesy.

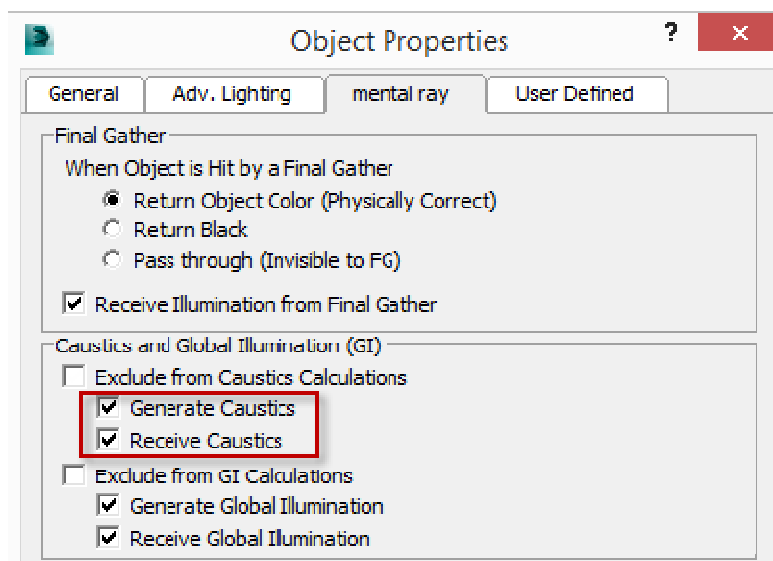
Caustics use photon mapping, which is why the Global Illumination panel groups Caustics and Photon Mapping (GI) together into a single rollout. The controls are few and easy enough to understand, as the values and terminology are very similar to Global Illumination settings.

Typical Caustics Preparation Steps

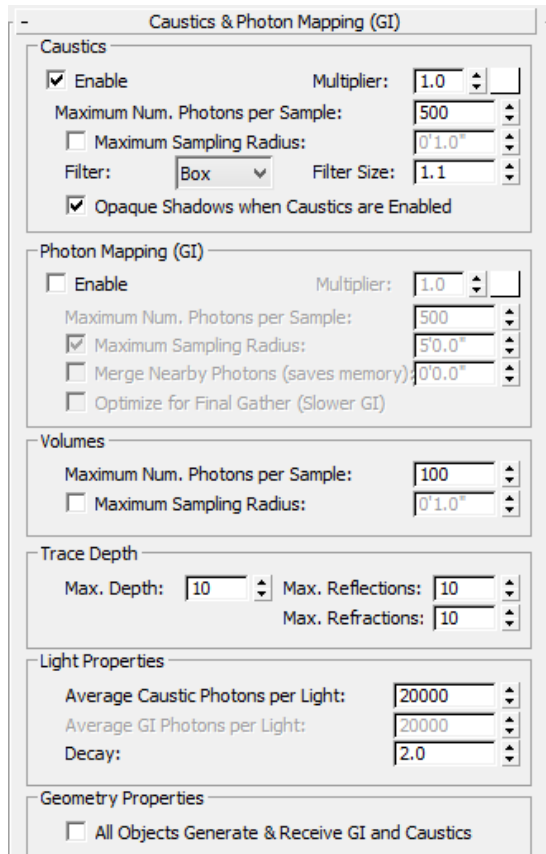
The first step to working with caustics is to specify three things: what light objects create caustics, what renderable elements can generate caustics, and which renderable elements can receive caustics. These are object-specific properties found in the mental ray tab. Access them by right-clicking on an object and selecting Object Properties.

Because of the special-effect nature of caustics you need to in effect cheat and explicitly tell mental ray where the effect is going to occur. While you can set a global option to set all objects to receive and cast caustics, performance will be better if you enable these on an object by object basis. By default, objects are set up to receive caustics, but you have to specify what generates them.

Much of the success in caustic generation depends on the lighting and materials used to generate the caustic effects. Often the lights used to illuminate the scene can be too far away or too diffuse to provide enough concentrated photons to result in the caustic effect you are looking for. In those times it is usually easier to create a caustic-only generator light source, and disable caustics generation from the normal scene lights. We will look at this later in this section.



Caustics Rollout Settings



The Caustics and Global Illumination (GI) rollout with default values

First, in the Caustics & Photon Mapping (GI) rollout, enable Caustics. The multiplier and color swatches allow you to increase the caustic effect as well as tint the caustic photons. The Maximum Number of Photons per Sample (default: 500) determines the sharpness of the caustics; smaller values are sharper, larger values are blurrier. The Maximum Sampling Radius value is similar to that of photon mapping, except by default (unchecked) it is set to 1/100th of the scene size, not 1/10th as in GI. A specified smaller radius can produce a tighter caustic effect.

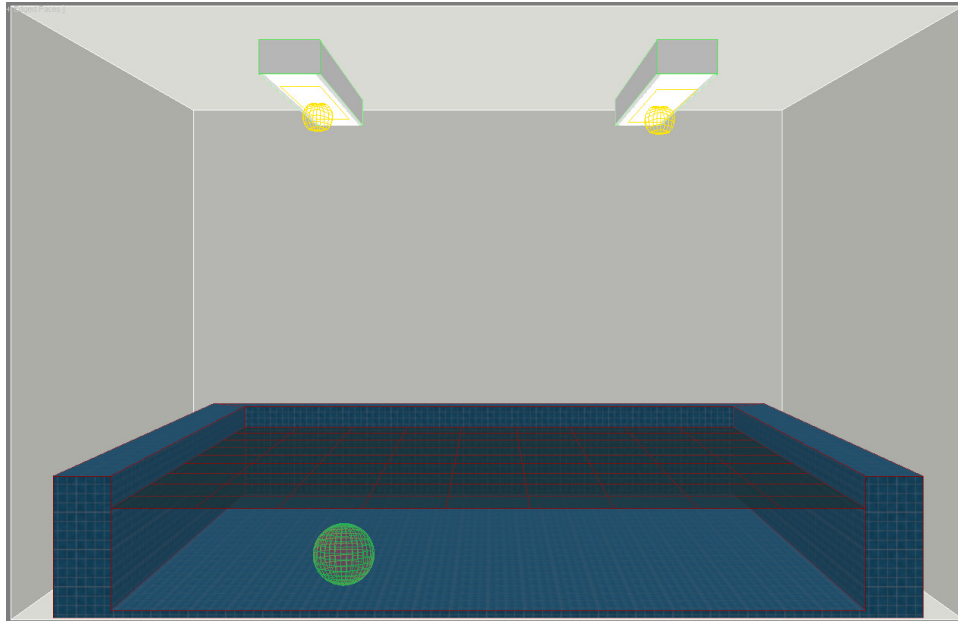
The Filter setting can be Box (default), Cone, or Gauss. Default is Box. All other things being equal, the Box filter is fast and good enough for draft purposes. The Cone filter produces a sharper result, and the Gauss filter provides a slightly blurrier result. Usually a filter size of 1.1 is fine; the effect can be subtle.

Opaque Shadows when Caustics are Enabled generates faster opaque shadows; unchecked it will produce partially transparent shadows. Default is checked.

By far the most important value to work with is under the Lighting group, Average Caustic Photons per Light. The default value is 20,000, but you often will need to set this to 500,000 or higher (a million photons is not atypical) to achieve the proper effect.

Caustics Tutorial

With the current project set to C:\AV2742 Mental Ray in 3ds Max Design, open .\scenes\Caustics_pool_start.max. If prompted, accept the target file's Units. This scene is similar to the one from the FG tutorial, but has some of the materials updated.



Render the scene using a resolution of 640x360 (an HD aspect ratio of 1.78) with no photon mapping, just Final Gather on the Draft preset with 2 diffuse bounces:

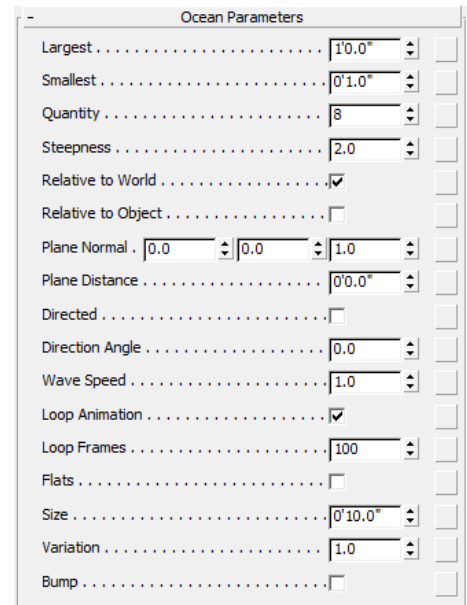


Overall the scene illuminates fine except the pool is too dark and unrealistic, given the amount of light.

First a word about the water material itself. Open the Material Editor (M on the keyboard) and double click on the Water material. It was created by starting with an Arch & Design material and selecting the “Water, Reflective Surface” template. This fires off a script that configures the material to look and act like ocean water. It does this by using a mental ray Ocean shader applied in the Bump map slot.

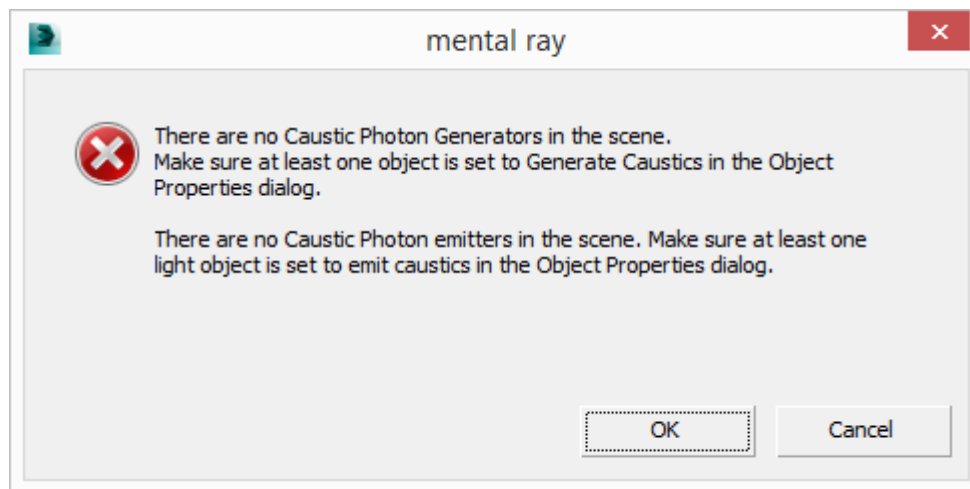
However, it’s usually better to apply this in the Displacement Map slot instead, because the Bump slot won’t show the waves along the edges, belying the realism. In the case of this file, I changed the Ocean map to the Diffuse channel and set the Displacement value to 0.7. In the Ocean map parameters, unchecking the “Bump” option is required to make the effect come alive when used as a Displacement Map.

Note: The displacement value of the waves in the water has no effect on the caustic effects. The purpose here is solely to make believable looking water.

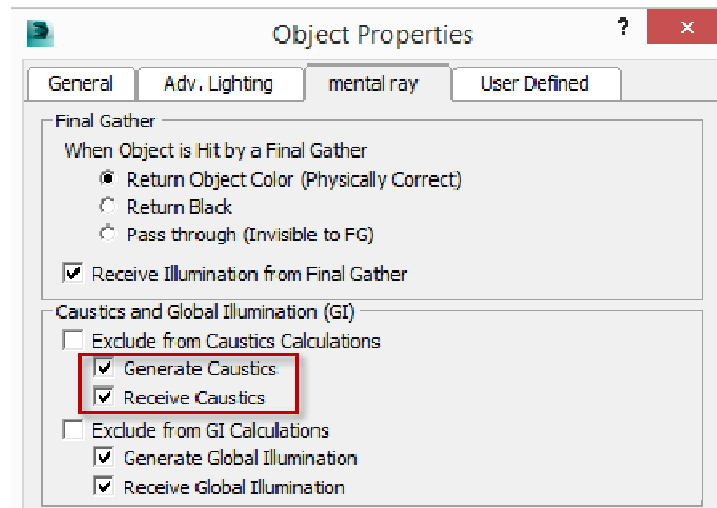


Caustics Settings

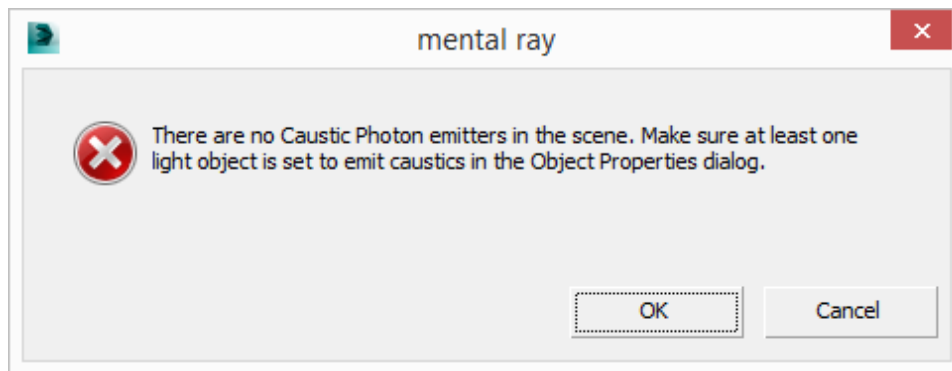
In the Caustics & Photon Mapping (GI) rollout, enable caustics and get things going. If you render now, you’ll get this error because you have not specified a caustics generator.



Cancel the rendering. Right-click on the Water object, and select Object Properties. In the mental ray tab, check Generate Caustics. Do the same for the red sphere in the pool. All other objects in the scene are already set to receive caustics.



If you render now, you'll get this error because you haven't specified a caustics emitter, the light source that will generate the effect.



Right-click on one of the light objects > Object Properties > mental ray tab, and check Generate Caustics. Even though the lights are instanced, the Caustics properties are not copied between them. Manually change the other light properties as well.

Render the scene using the default settings, and you will see just a very subtle caustic effect, because the default caustic photons per light number is very low. Also, the blue tile material makes it difficult to observe, particularly in low-resolution test renders, how the effect changes as you tweak the dials.

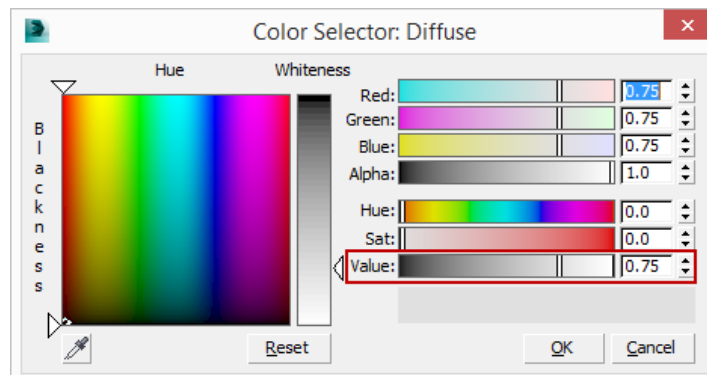


To make it easier to resolve the caustic effects, we should use a very important tool in the mental ray arsenal: Material Override.

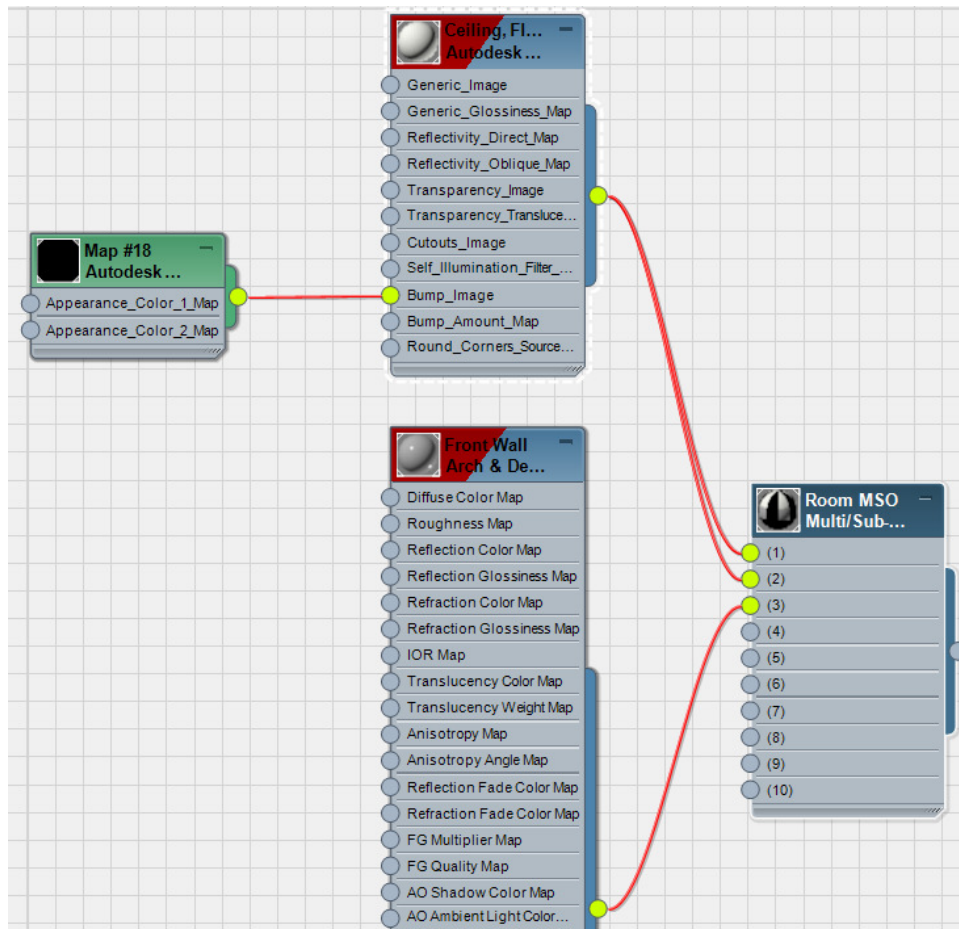
Overriding Materials to Evaluate Lighting

When you are preparing the lighting setup for any scene, it's best to work on lights in isolation. Work on each light separately, turning the others off so you can tweak and evaluate each one on their own. However, it's also quite useful to take materials out of the equation as well, as they impart additional contrast and can hide details that need addressed. That's where Material Override comes in handy. With it we can replace all of the materials in the scene with a 75% gray, non-reflective matte material perfect for evaluating the overall lighting, as well as caustics, ambient occlusion, and rounded corners. With only one material, the number of variables goes way down in addressing render issues.

Go to the render Setup dialog, Processing panel, Material Override group, and enable it. Select the Arch & Design material from the Material / Map Browser to create a new material. Open the Material Editor and drag an instance of the new material into the View area. In the new material, set the Reflection value to 0 and the Diffuse color to a 75% gray. This is easiest done by setting the RGB and Value to 0.75

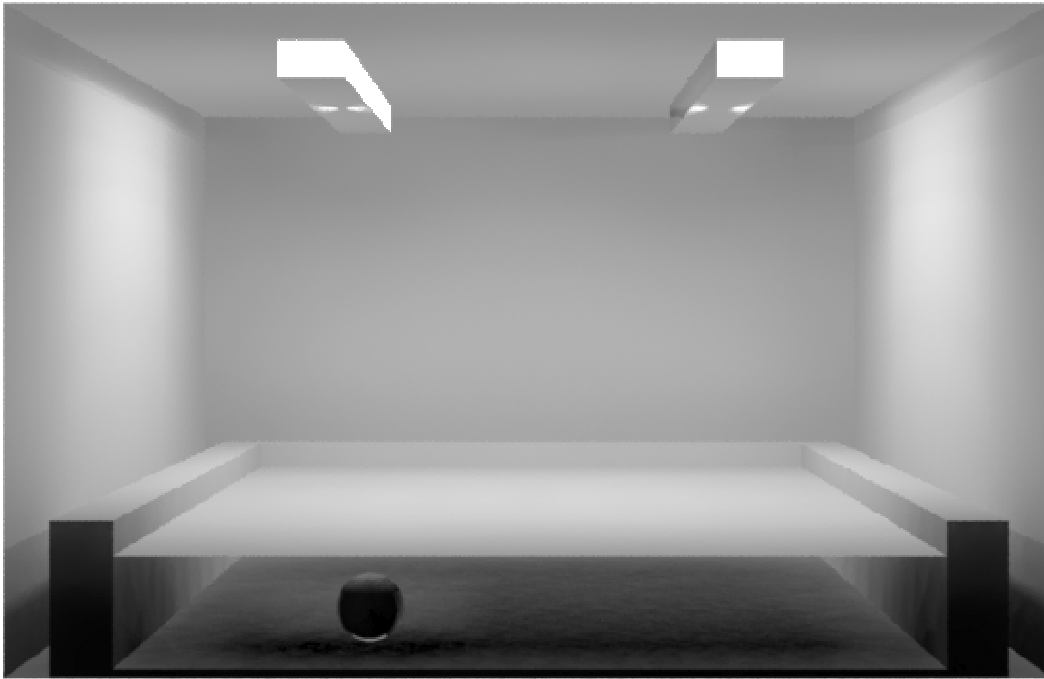


However, there is a problem - possibly two. First, the “box” that makes up the walls and floors is situated beyond the camera. The box polygons have their normals pointing into the scene. The original material applied to the box is a multi-subobject material that has three slots: One for the ceiling & floor, one for the 3 walls you see in the rendering, and another for the fourth wall. The polygons for the box have Material IDs that correspond to these materials. This arrangement allows flexibility, so you to easily change just the materials of the walls, for example.

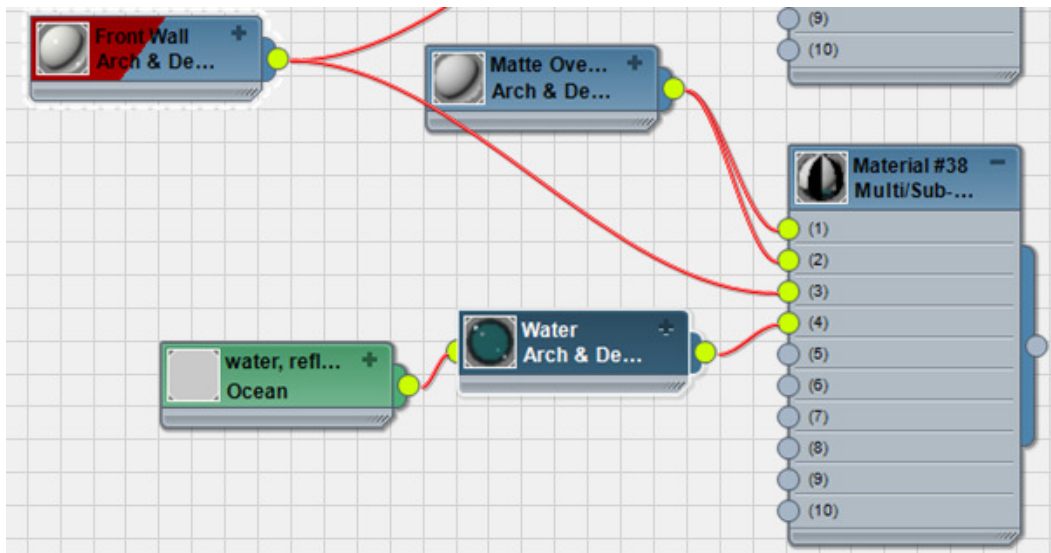


The ceiling & floor (Material ID 1) and the three walls (Material ID 2) have an Autodesk material applied to them. This is the problem because Autodesk materials are always 2-sided, so the front of the room - the non-normal face pointing to the camera - is unexposed to lighting and thus you get a black box in the render.

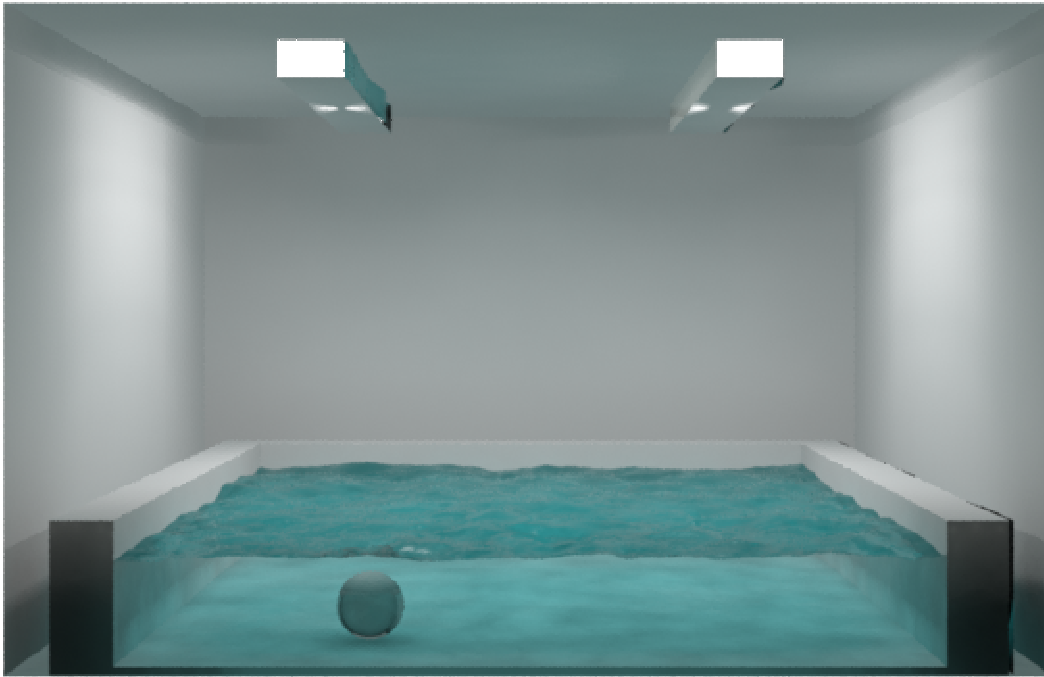
Therefore, the fourth wall polygon needs to have an Arch & Design material assigned to it that has the “Back Face Culling” option enabled. This allows the face to be invisible when facing the non-normal side. The Autodesk materials, with their simplified interfaces, do not have this valuable option exposed, and this is a classic case where the Autodesk materials - which render very quickly and are easy to use - have a critical missing feature and we need to resort to an A&D Material to get the job done.



As you can see, the water is generating caustics even though the material is not transparent, but this only projects caustic effects onto the floor. Let's assign the output of the Water material to Slot #4 of the override MSO material, and change the polygons in the water object to Material ID 4.



Render again:

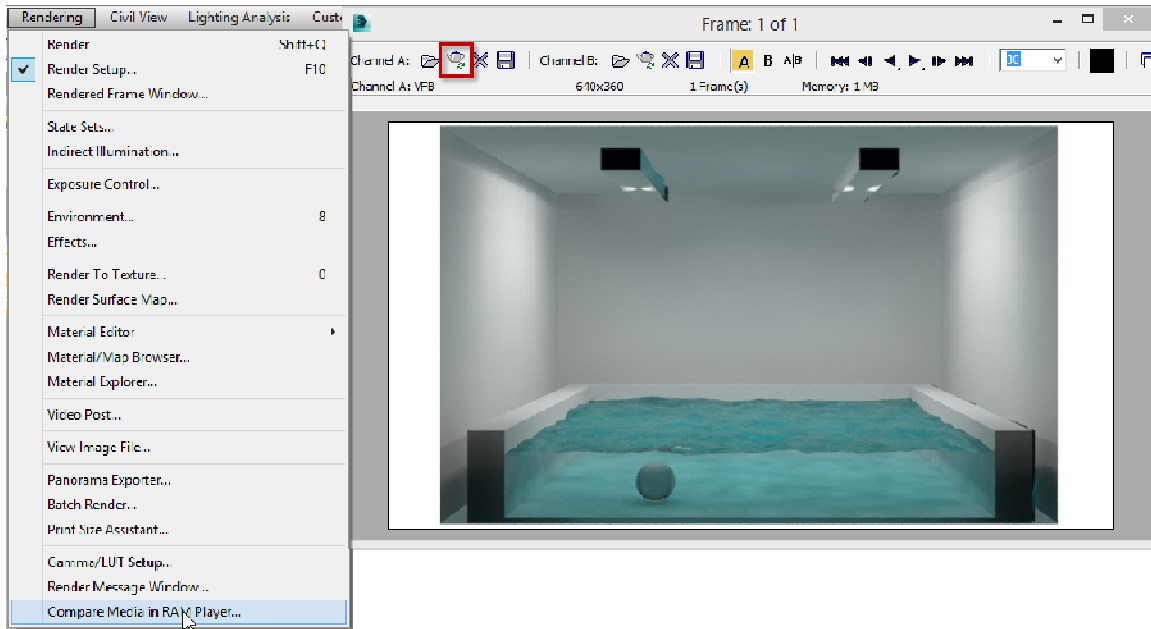


Much better, as we clearly see the caustics and also see the influence of the water onto the ceiling.

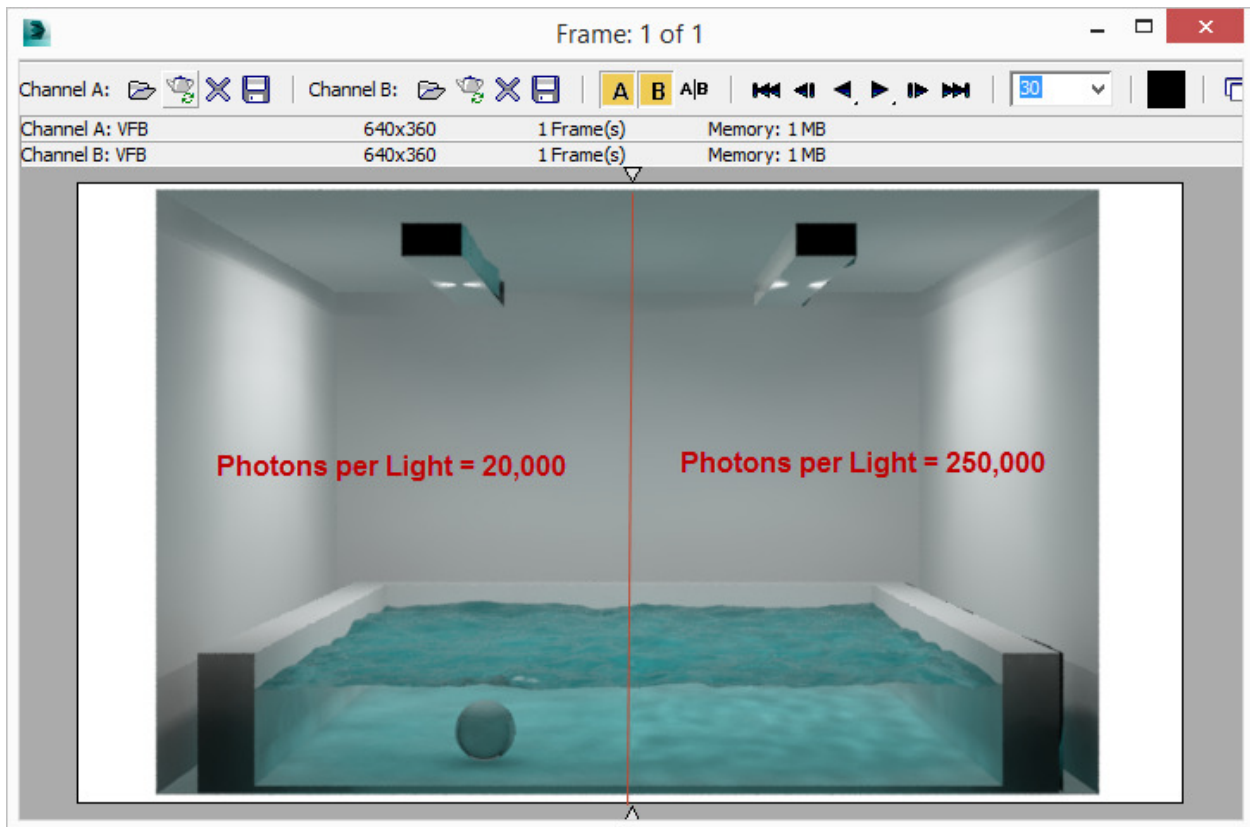
However, it brings up a solid point about using the Material Override when evaluating your lighting. It's an all or nothing affair; that is, it will take all surfaces, transparent or not, and make them opaque and gray. If you have glazing that lets light from the outside in, you will need to either hide those elements to test your renders or resort to an MSO material where you can keep certain things from going gray. For now let's concentrate on the caustic variables.

When making slight tweaks to a rendering setting, it's valuable to fire up the RAM player and load your renderings into it for quick A|B comparisons.

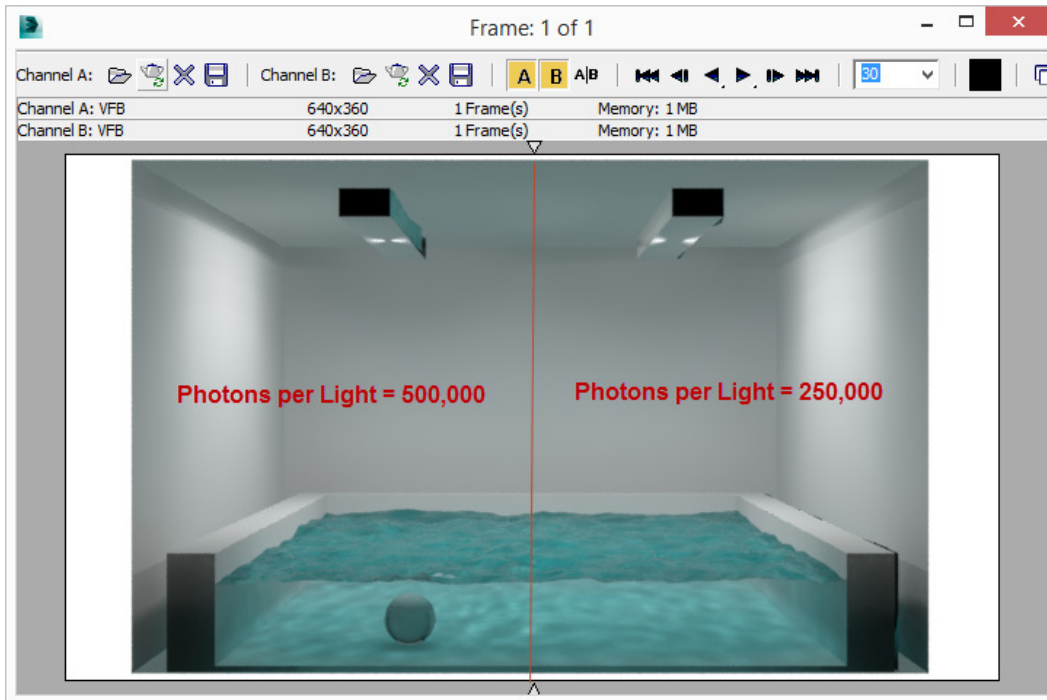
Go to the Rendering pull down > Compare Media in RAM Player, and load the most recent rendering into channel A. With each successive rendering, load it into alternating channels so you can see exactly what the effect of your latest change is from the previous render.



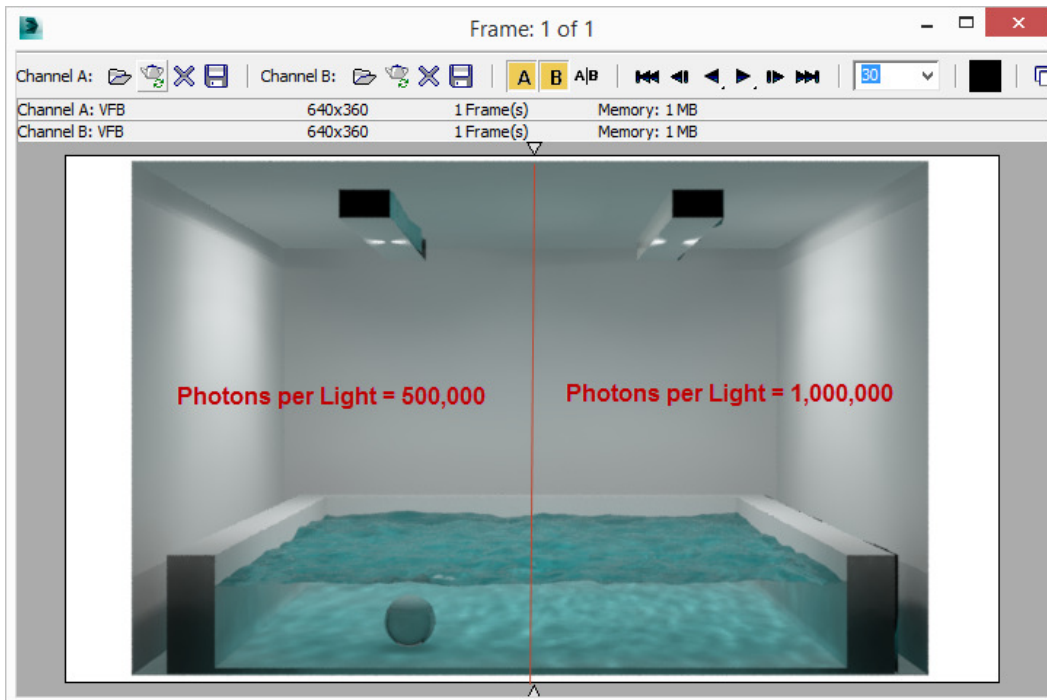
In the Caustics rollout, change the Average Caustics Photons per Light to 250,000 and render again (uncheck the “Open on error” box in the mental ray dialog). Notice the Photon Emission portion of the rendering now takes considerably longer. As you can see, the caustics are noticeably brighter.



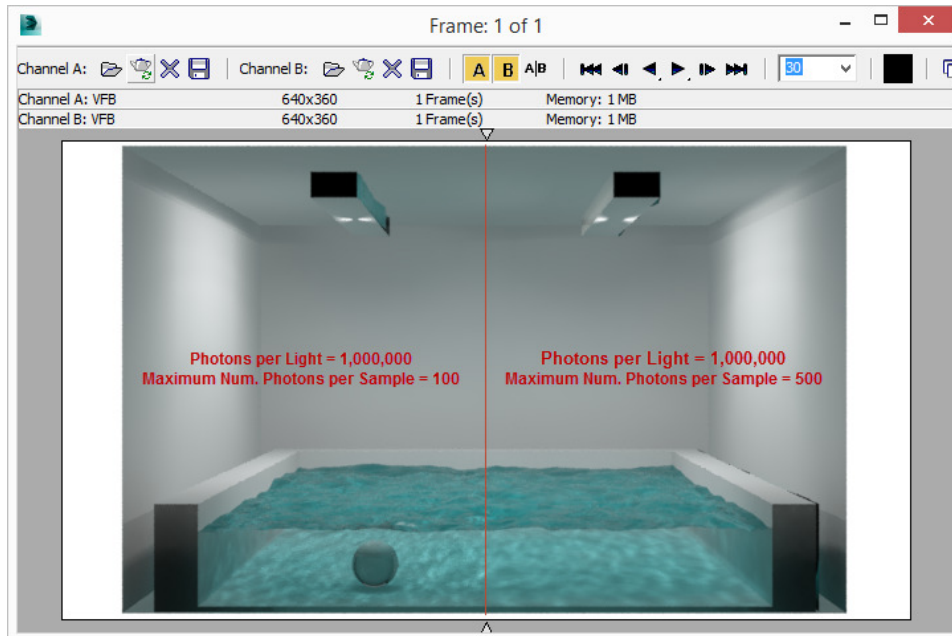
Change this value to 500,000 and render again and note the brighter highlights. This is another valuable technique that we used in the GI tutorial: Take a single setting and push it to its maximum and minimums to see the overall impact on the image.



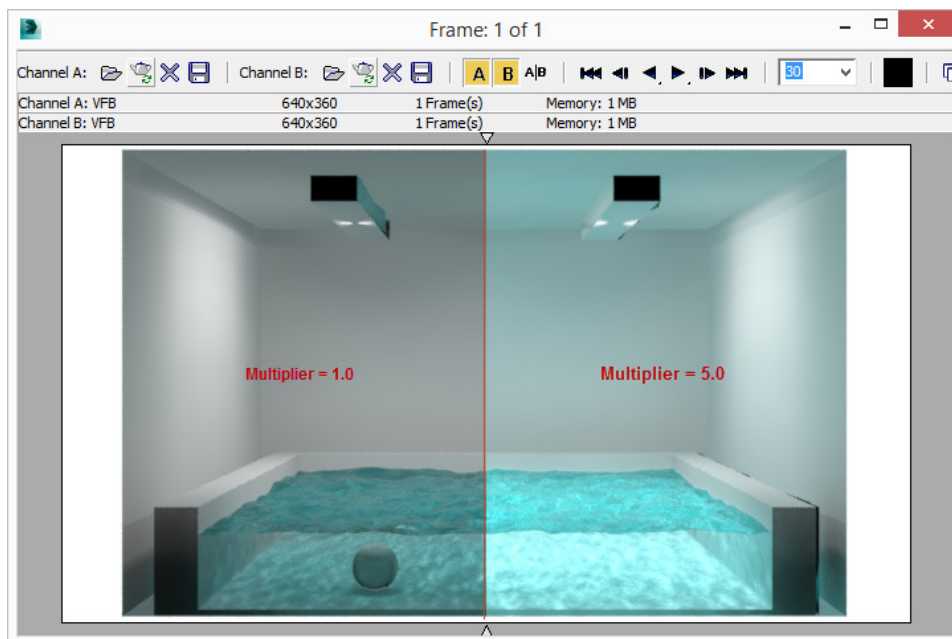
Finally, let's shoot the works as they say in the trade, and set it to 1,000,000:



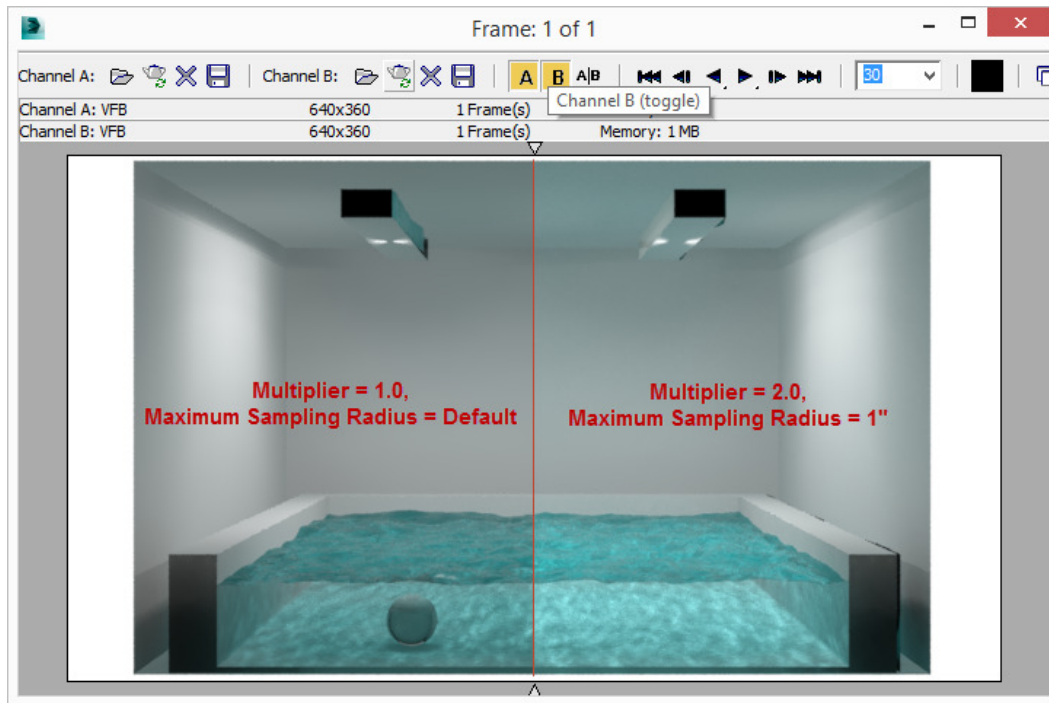
This value works great - we get nice bright caustics. They aren't too sharp, however, so let's see if we can fix that. We're looking for nice tight lines of light on the pool bottom as in the first Cornell Box image in this section. Change the Maximum Number of Photons per Sample from the default of 500 to 100:



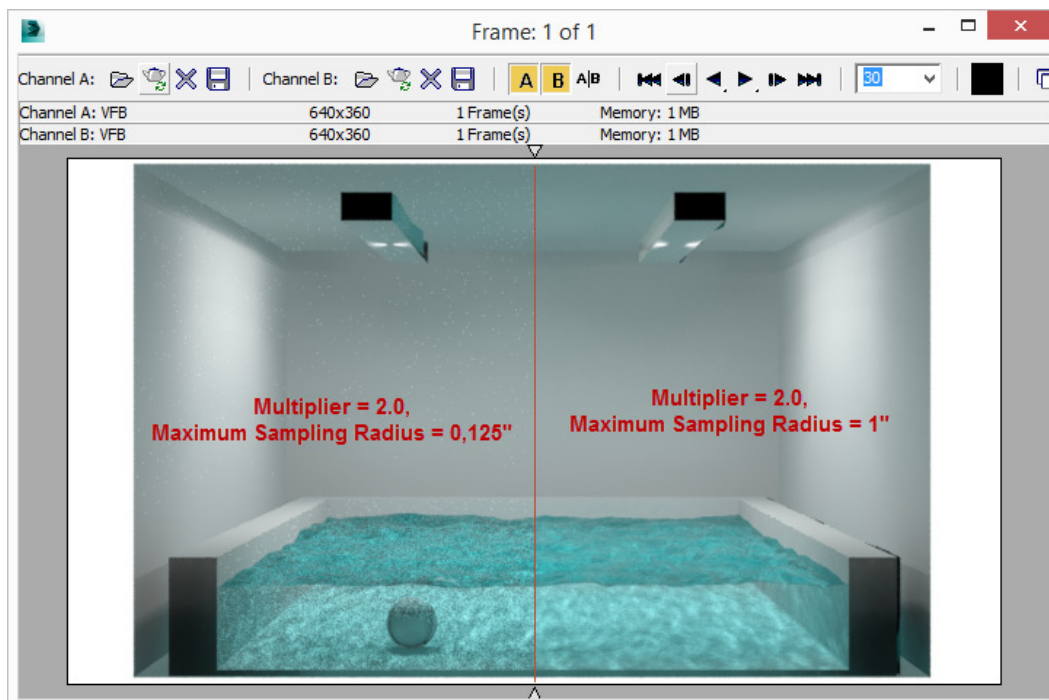
Now we're starting to hone in on tighter caustics as you would expect in a pool. As a new control point, bring the number of photons per sample down to 75 so we can concentrate on another variable: Multiplier. Render this and put it into the A channel of the RAM player. Set the Multiplier to 5.0, render, and put it into the B channel in the RAM player.



Yow, now it's something out of Half Life 2. Take the Multiplier back down to 2, and check the box for Maximum Sampling Radius and set it to 1"



Much better than the default, so let's take the Sampling Radius to 1/2". You won't find much difference at this level, but further down you will see the caustics break up into small disks. If we take it down to 1/8", and compare apples to apples, we get this:



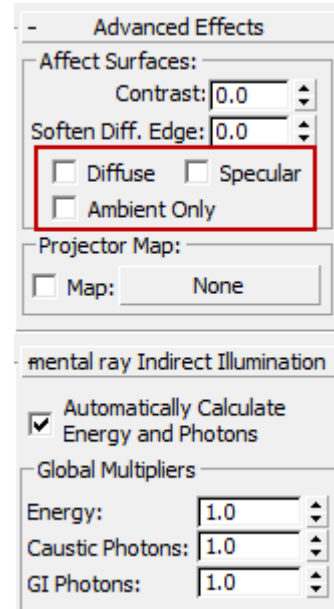
The sample radius is too small and we start getting disco flecks on the wall and pool. Going in the other direction doesn't really do much from having it at 1", so let's stop here; uncheck the box to use the scene defaults.

Adding Caustic-Only Lights

Notice we aren't getting caustics on the ceiling or walls, when we should be. This is most likely caused by these area lights being high up and very directional (they are using a Photometric Web which points most of the photons downward), so the walls and ceiling are receiving little actual light and are mostly illuminated with indirect light. To help solve this let's set the two lights to not generate caustics and create a new light dedicated to only creating caustics. Simply select each light, Object Properties > mental ray > uncheck Generate Caustics.

In this case I'll create a new Photometric light (or copy an existing one) and place it in the center of the room and put it about 5' high. Set its Light Distribution (Type) to Uniform Spherical, and change the target distance to 20'. In the Advanced Effects rollout, deselect the boxes for Specular and Diffuse. This ensures this new light does not cast illumination on scene surfaces.

When working with caustic-generating lights, experimentation between the caustic light properties and the caustic properties themselves can keep you entertained for some time. The intensity of the light source has a direct impact on the look of the caustics. For this scene I could take it way down to only 20cd.



Ambient Occlusion and Rounded Corners

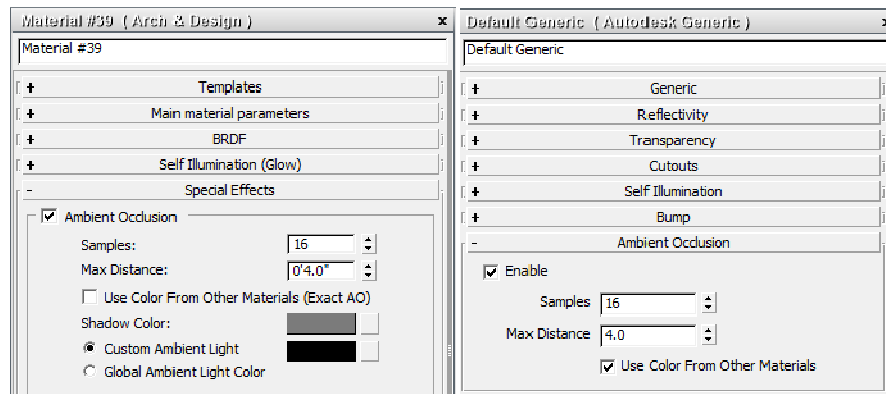
mental ray's Arch & Design and Autodesk materials feature certain "special effects" capabilities that can enhance your renderings and save valuable modeling time.

Part of the problem with most renders is that they are instantly identified as CGI. Why? Because some of the most basic things are missing, such as the legs of a chair not looking like they actually touch the floor.

As mentioned previously, Ambient Occlusion is a technical feature first developed by the film industry that enhances small details by measuring the distance between two close surfaces and darkening the space between them. It creates "contact shadows" between the objects and darkens corners, further simulating the natural effects of light in these areas.

It does this by ray tracing, naturally; it sends out a specific number of random AO rays from every rendered sample into the scene, and detects how many rays hit something close by - those which are "occluded" from traveling on. The rays emanating from the sample point are only allowed to travel a small distance (otherwise they would not be "contact shadows"). The more rays that hit something close by, the darker the sample is made. The fewer rays that are occluded, the less the sample is affected.

Setting up Ambient Occlusion is actually pretty easy compared to other effects like caustics. They are material specific, so activate it in Arch & Design materials under the Special Effects rollout. In the Autodesk materials there is a specific Ambient Occlusion rollout.



The settings for Ambient Occlusion are simple:

Samples: This is the number of rays cast out into a scene from a rendered sample. 16 rays is the default which works well for most circumstance. You can go up to 64 where close-ups of fine details are required. The higher number of rays the longer the render time. AO sends rays per sample across the entire visible surface of objects that contain the AO-enabled material. Rendered samples may be groups of pixels (under sampled), pixels (1:1 sampling), or fractional pixels (supersampling). If you have a higher sampling Quality / Image Precision / Samples Per Pixel setting, you may be able to get away with lower AO values and still get good results.

Max Distance: The distance each ray will emanate from each sample to look for an occlusion. A too high value will result in a darker region that looks more fake, because the contact points between two surfaces could be further away. Too small and you get a tiny pencil line of darkening if at all.

Use Color From Other Mats (Exact AO): This checkbox will add slight bleeding of color from one surface to the other. Ensure this checkbox is used for self-illuminating materials, because they do not impart actual illumination on nearby objects. Any illumination is picked up by FG and/or GI and probably won't be realized at very close contact point distances. This option will bleed the self-illuminated color onto the adjacent surface, giving the impression the glowing object is actually casting light. Otherwise, AO will simply darken the pixels together, instantly negating the believability of the illuminated object.

Overall, Ambient Occlusion is a great way to add that little bit of added believability in the scene, and most people won't understand why. Although it should be used selectively (as it does increase render time) it is always worth it for the final renders.

Round Corners

Another way images can look fake is due to unnaturally sharp corners. In the real world almost nothing has a perfectly sharp edge; they are difficult to build / fabricate without breaking, they aren't necessary, and can hurt you. Instead, corners are "broken" to make them more durable and comfortable.

In a rendering it's very evident, because beveled or rounded corners will pick up specular highlights from the surrounding lights. Indeed, that's the one thing that makes them visible. A perfectly sharp corner doesn't pick up that edge and looks weird to your eye. Broken corners also allow materials to meet without looking overly odd.

mental ray answers this in the Arch & Design and Autodesk materials with the round corner special effect. Round Corners, is a render-time effect that will do exactly what it says - it will round the corner of an edge to provide a highlight area to pick up specular highlights