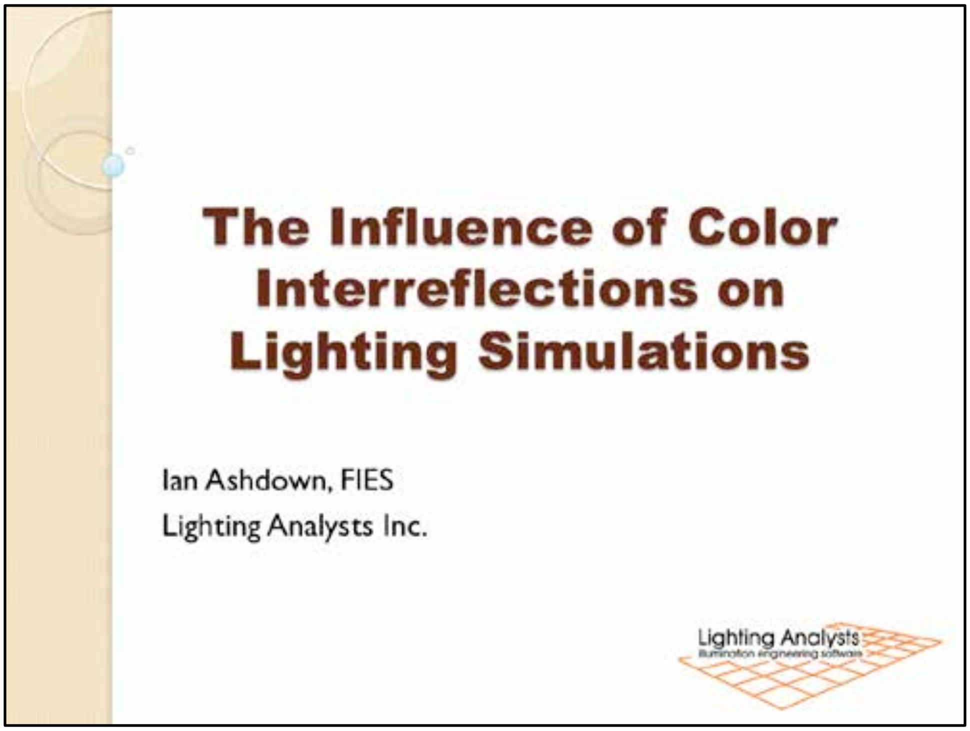
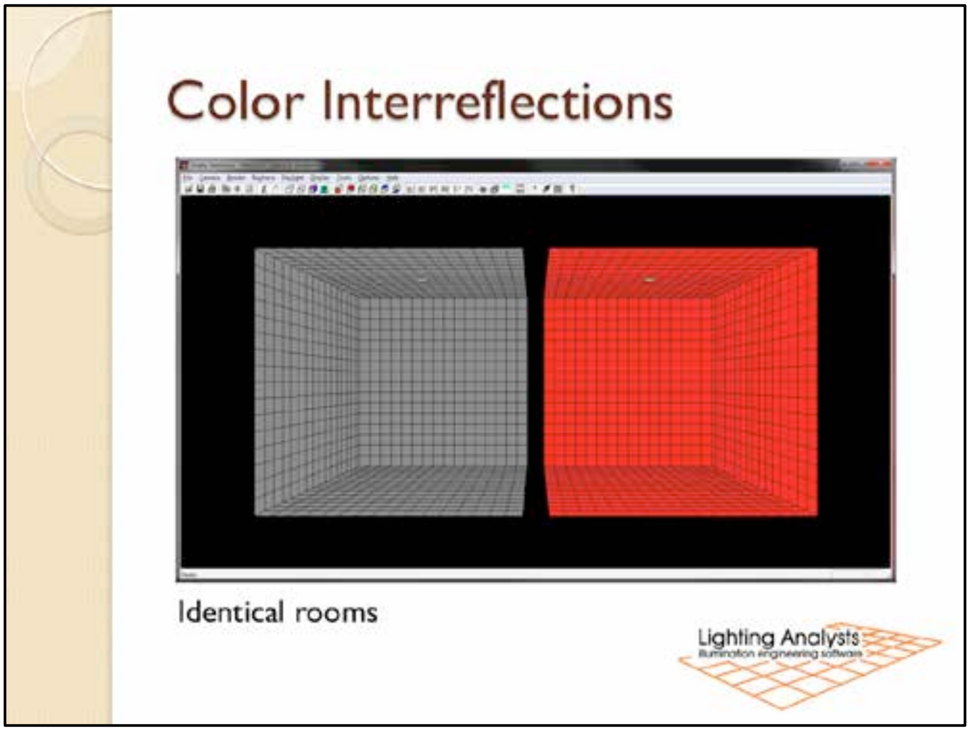
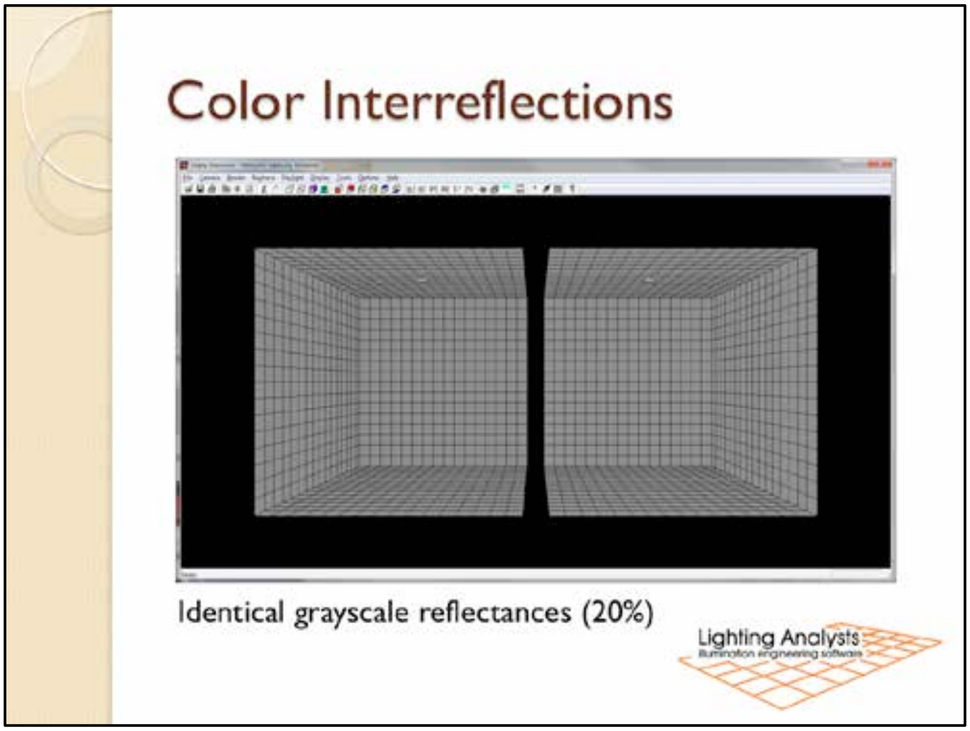



All commercial lighting simulation programs – *AGi32, Radiance, DIALux, Relux* and so forth – model color as red, green, and blue components. In the real world however, color is a continuum of wavelengths.

Any material that reflects light also has a continuous reflectance spectrum. We must therefore ask the question, how well does the RGB color model approximate multiple interreflections of light between material surfaces?

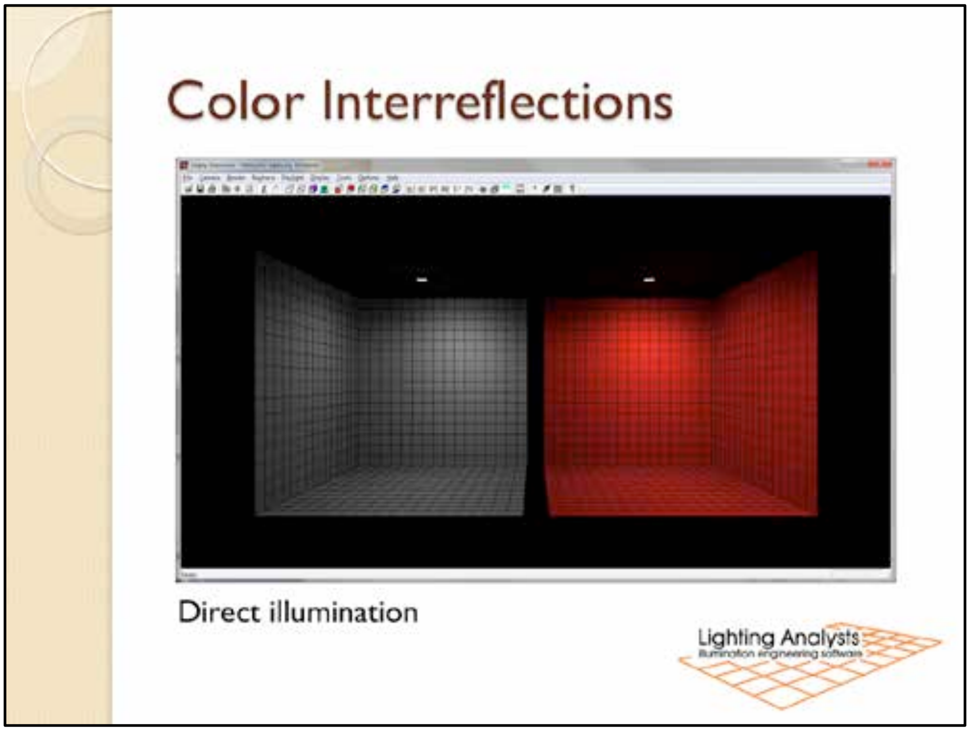



To illustrate the problem, consider two geometrically identical rooms with identical light sources. The only difference between them is that one room has gray surfaces that rdiffusely eflect 20% of the incident light, while ther other room has red surfaces that also reflect 20% of the incident light (as measured by a photometer).

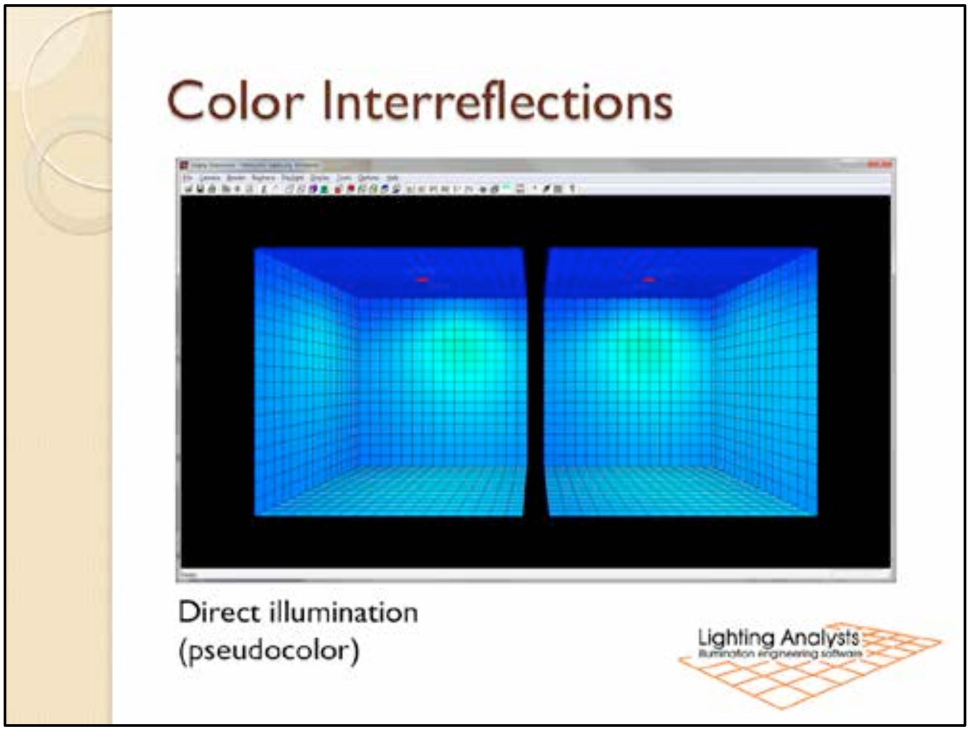



Here we see the two rooms rendered in monochrome. As you can see, they have identical grayscale reflectances.

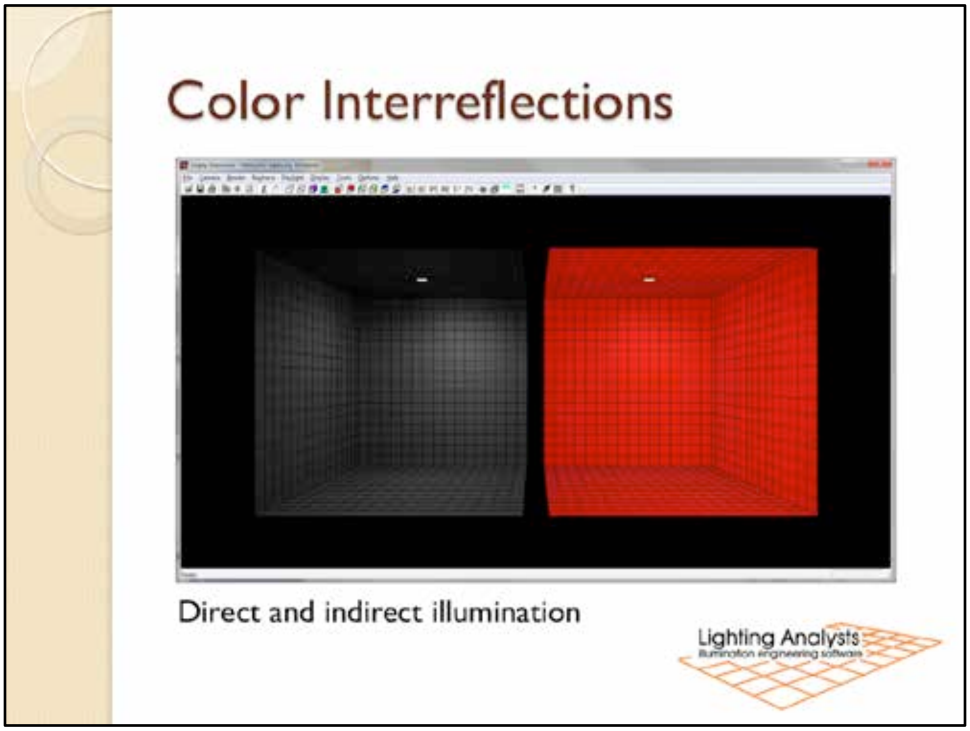
Now we ask the question: what happens when we turn on the lights?



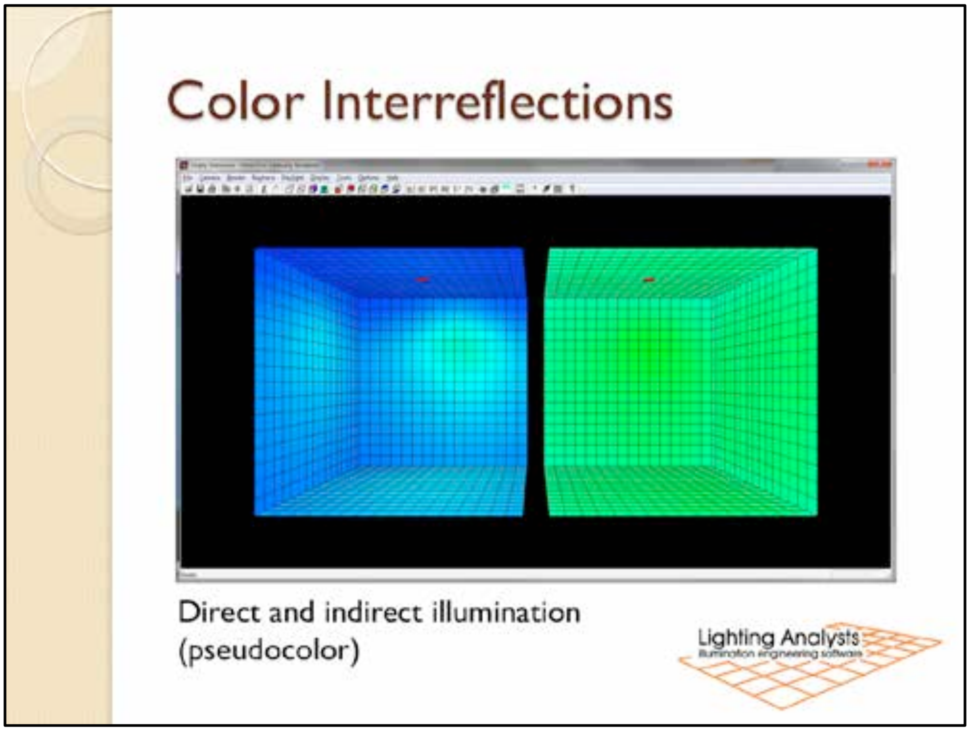

Here is what we see with the direct illumination. As we can see visually (and as we can measure with a photometer), the results are identical.




Here are the two rooms rendered in pseudocolor. As you can see, the surface luminance distributions for the direct illumination is identical.

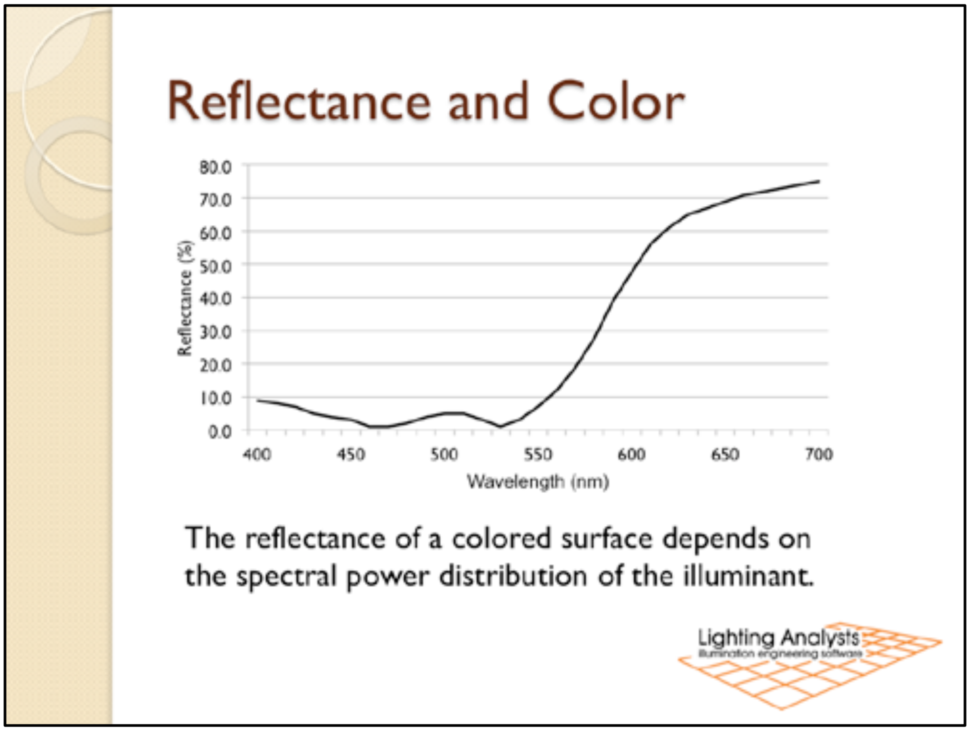



But now we add the indirect illumination due to the interrflection of light between the room surfaces. The red room appears much brighter than the gray room, and its luminance distribution is considerably "softer."




Viewing the room surface luminance distributions in pseudocolor confirms our visual observation – the red room is definitely brighter, and its range of luminances is much less pronounced than the gray room.

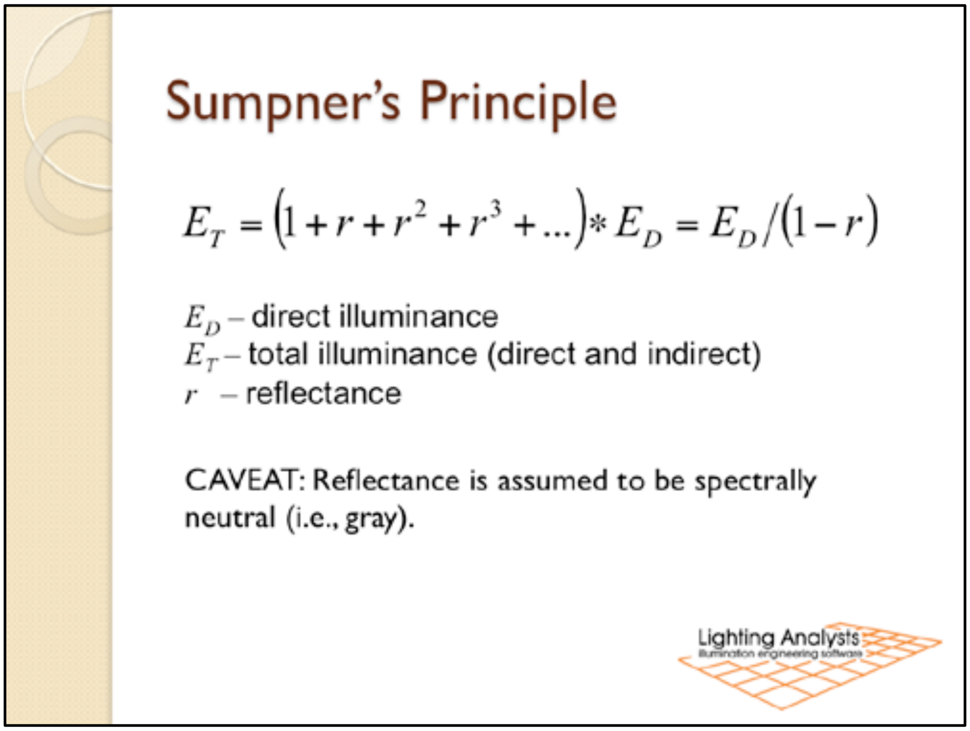
In fact, if we place a virtual photometer meter at the centre of the room at floor level, the red room is 2/3 brighter than the gray room.




The reason is that the reflectance of a colored surface depends on the spectral power distribution – the color – of the light source. When we say that the red surface has 20% reflectance, we are implicitly assuming a 6500 Kelvin daylight source. If we were to use a 650 nm red LED however, the reflectance would be 70 percent. Change this to a 460 nm blue LED however and it is less than one percent.

Even if we start with white light, the color of the reflected light in the red room is red – and it becomes successfully more red with every subsequent interreflection between surfaces.

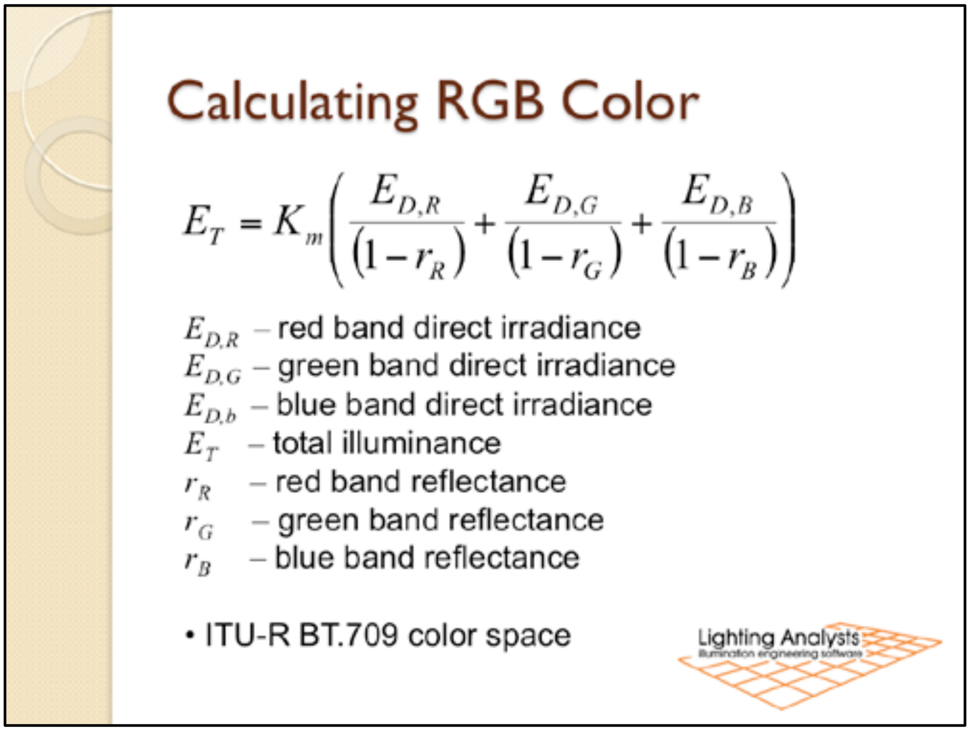
The problem is that there are an infinite number of reflection spectra that can be represented by an RGB color. This leads to the question: what sort of errors are we introducing into our lighting simulations by using only three colors?



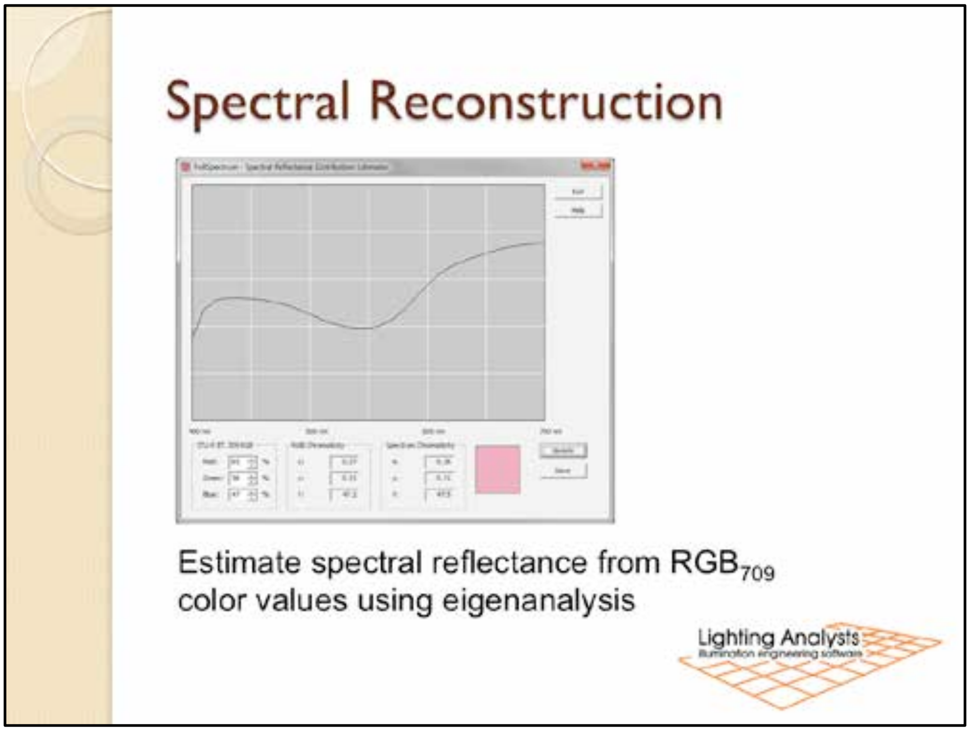

To answer this question, we need a simplified environment. The simplest possible environment is an infinitely wide room where the light bounces between the floor and ceiling until it is completely absorbed.

Starting with the direct illuminance, Sumpner's Principle says that the total illuminance due to the direct and indirect light is simply the direct illuminance divided by one minus the reflectance. The greater the reflectance, the greater the total illuminance.

The caveat is that Sumpner assumes a room with gray surfaces. This is not a problem however, as we can easily extend Sumpner's Principle to handle colored surfaces.




For RGB color, we simply separate the white light into equal amounts of red, green, and blue light before applying Sumpner's Principle to each color, then add and scale the results to obtain the total illuminance.




Now, we want to do the same without approximating the reflection spectra with three colors. Instead, we want to use the actual reflection spectra of natural and man-made materials commonly used in architectural spaces.

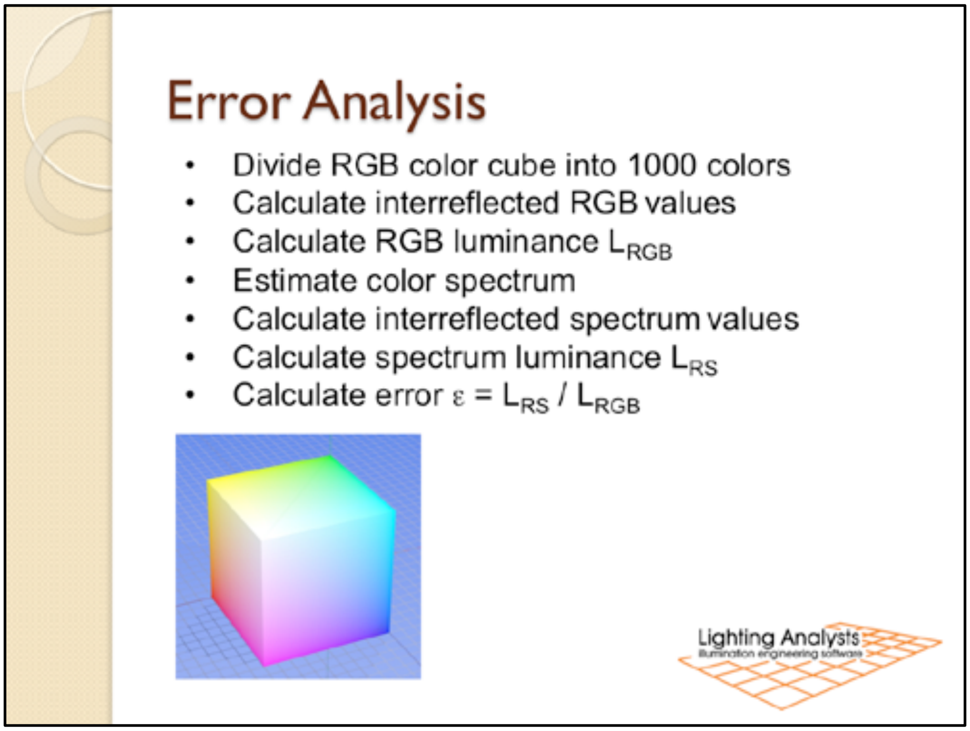
Fortunately, it is possible to estimate these reflection spectra to a high degree of accuracy, knowing only the RGB color values – the mathematical details are explained in the accompanying paper to this presentation. (For the record, the reflection spectra are representative of over 3,400 materials, including the entire Munsell Book of Color)

# Calculating Spectral Color

$$E_T = K_m \sum_{400}^{700} \left(E_{D,\lambda} / (1 - r_\lambda)\right) V(\lambda) \Delta\lambda$$

$E_{D,\lambda}$ – spectral band direct illuminance
$E_T$ – total illuminance
$r_\lambda$ – spectral band reflectance
$\Delta\lambda$ – spectral band increment (10 nm)

Having the reflection spectrum for any given RGB color, we can again apply Sumpner's Principle to calculate the total illuminance. This time however, we divide the spectrum into 31 separate color bands, not just red, green, and blue.




This gives everything we need to estimate the errors caused by modeling the reflection spectra of architectural materials using the RGB color model.

We take the RGB color cube and divide into 1000 colors, with ten divisions for each of the red, green, and blue axes.

We then use Sumpner's Principle to calculate the RGB luminance of an infinite room.

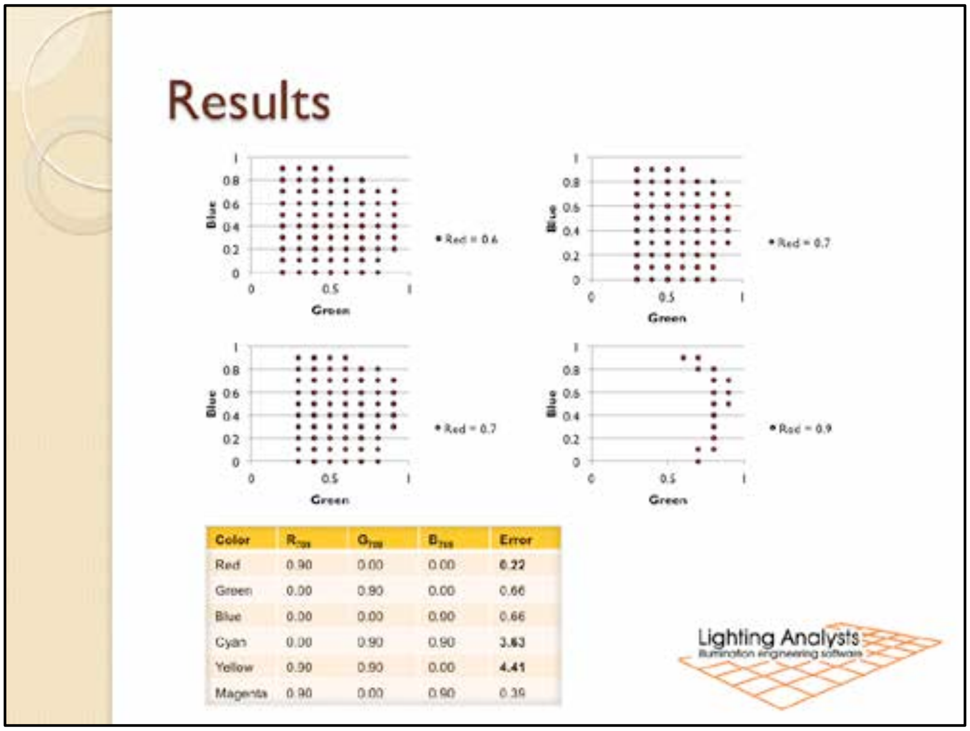
Having this, we estimate the reflection spectrum of the RGB color.

Again using Sumpner's Principle, we calculate the full-spectrum luminance of the room.

Finally, dividing the full-spectrum luminance by the RGB luminance gives us the error for the given color.


Here are the results, where each chart represents the RGB cube sliced at equally spaced intervals along the red axis from zero to 90 percent reflectance.

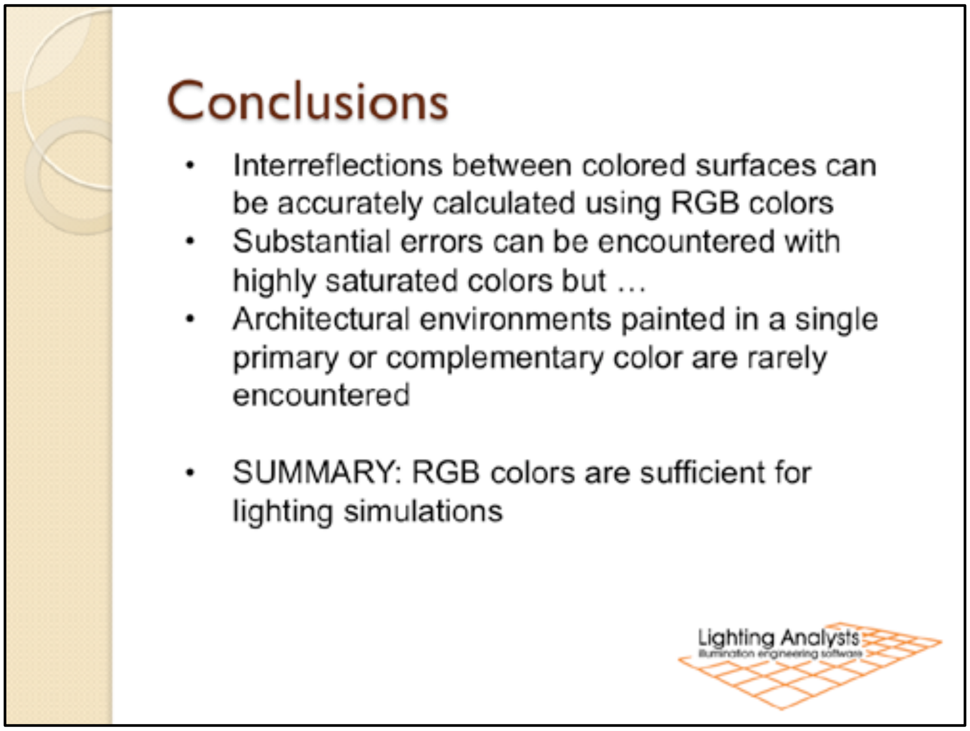
As a rule of thumb, interior lighting simulations are assumed to be accurate to within roughly ±20 percent. Therefore, each dot on the charts indicates that the expected error is less than this.




| Color | R | G | B | Error |
|---|---|---|---|---|
| Red | 0.90 | 0.00 | 0.00 | 0.22 |
| Green | 0.00 | 0.90 | 0.00 | 0.66 |
| Blue | 0.00 | 0.00 | 0.90 | 0.66 |
| Cyan | 0.00 | 0.90 | 0.90 | 3.63 |
| Yellow | 0.90 | 0.90 | 0.00 | 4.41 |
| Magenta | 0.90 | 0.00 | 0.90 | 0.39 |

Here we see the remainder of the results. We also see that the errors become unacceptable for really saturated colors.

As we can see from table, the primary and complementary colors are the worst. Fully saturated yellow, for example, result in an underestimation of the surface luminance by over three times, while fully saturated red results in an overestimation by roughly the same amount.




The good news is that most RGB colors yield acceptable errors. Altogether, they cover most commonly used architectural colors and some 60 percent of the RGB color gamut.

We do see substantial and even unacceptable errors for highly saturated colors, but it is highly unlikely that an architectural environment will be painted in a single primary or complementary color.

In summary then, RGB colors are sufficient for lighting simulations. After thirty years of using the RGB color in commercial lighting design software, this is comforting to know.