

Colors in Web Pages

1.1. Human Color Perception

The human eye contains special cells called *rods* and *cones*. These cells are found in the retina at the back of the eye and contain pigments which absorb light over a range of frequencies.

Rod cells are much more abundant than cone cells. The pigment in rod cells, called *rhodopsin*, absorbs light in the blue-green range approximately in the middle of the visible spectrum, as shown in **Fig. 1** on the right. Rod cells are responsible for providing us with high-resolution black-and-white vision.

In contrast, we have fewer cone cells, but the cone cells come in three varieties that selectively absorb light in the red, blue, and green regions of the spectrum to provide us with the perception of color.

When our eyes absorb approximately equal amounts of light from the red, green, and blue regions of the spectrum, we perceive the light as being white. When our eyes absorb approximately equal amounts of light from just the red and green regions of the spectrum, we perceive the light as being yellow in color. The figure below illustrates this additive color model and shows how the light from three overlapping colored spotlights would appear to our eyes.

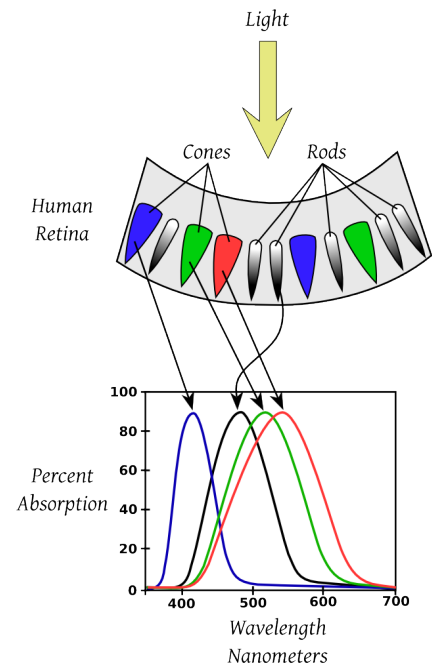
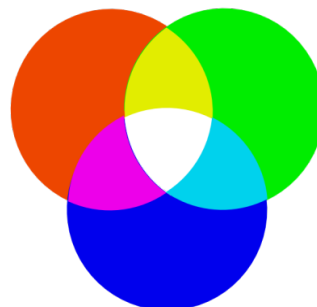


Fig. 1. The retina contains rod cells for black and white vision and cone cells for color vision.

Fig. 2. Equal amounts of light from overlapping red, green, and blue spotlights produce white.



1.2. Quantization of Red, Green, and Blue Color Components

In order for computer displays to reproduce the colors that we perceive, they need only to emit red, green, and blue light in different ratios. A computer can therefore describe any color of visible light using just three numbers -- one number to describe the amount of red light, another number to describe the amount of green light, and finally a third number to describe the amount of blue light.

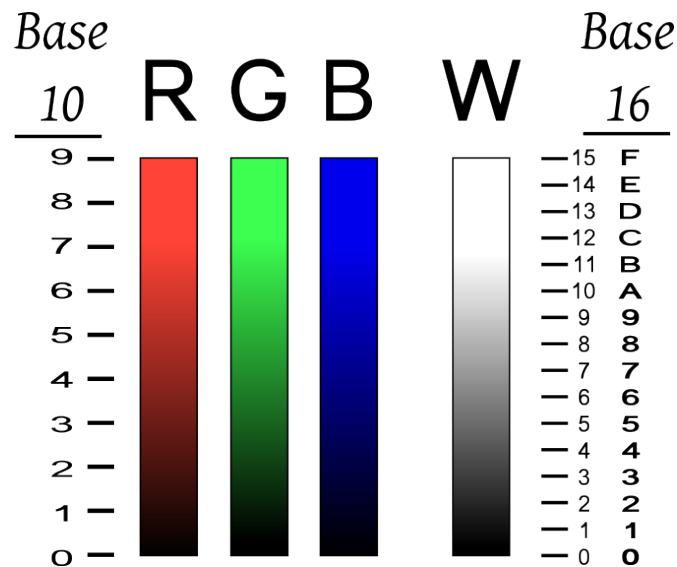


Fig. 3: The intensity of red, green, or blue can be described using different scales. A base 10 scale from 0 (no color) to 9 (full intensity) is convenient, but computer software commonly uses a base 16 scale as shown on the right.

As humans, we normally count and divide things by tens (because we have ten fingers!). So, looking at the scale to the left of the red bar above, we could say that zero represents the complete absence of red light --i.e., *black*-- while a 9 represents the brightest intensity of red that the computer display can display. Notice that there are in fact *ten* levels here because we started with zero rather than one. We can of course divide the green and blue bars in the same way as the red. We can now easily devise a notation to represent any color. For example, we could say that "**r0-g0-b0**" means "black" while "**r9-g9-b0**" means "yellow".

Dividing our color scales into ten parts is convenient, but arbitrary. We could just have easily divided our color scales into one hundred parts instead of just ten.

1.3. Binary Numbers

You might be surprised to learn that web browsers use neither ten nor one hundred as the basis of the three colors scales. Why? It might sound funny to say this, but the reason is that computers don't have ten fingers! Computers are therefore not restricted to counting by tens. Instead, computers count by twos. This is called *binary*.

Counting by binary is kind of boring, because there are only two digits, zero and one. Counting starts with zero, then proceeds to one. But one is the last digit! So after reaching 1, in order to get to what we would call the number two, you have to carry the 1 into the next column, giving "10" (one-zero). The next number after that, what we call three, is then "11" (one-one). But now we have run out of digits again, so we have to carry again just to get to the number four, "100" (one-zero-zero)!:

| Binary | Decimal |
|--------|---------|
| 0 | 0 |
| 1 | 1 |
| 10 | 2 |
| 11 | 3 |
| 100 | 4 |
| ... | ... |

Computers only recognize two states --"off" corresponding to zero, and "on" corresponding to one-- so this method of counting suits them quite well. But it doesn't suit humans very well. So, as a convenience, computer engineers decided that it was easier to count by *sixteens*. This is called *hexadecimal*.

1.4. Base 16 Numbers

Counting by sixteens is a compromise between what humans like to do --*count by tens or multiples of ten*-- and what computers like to do --*count by twos or multiples of two*. Since 16 is simply a multiple of 2 ($2 \times 2 \times 2 \times 2$, i.e., 2^4), it is trivial for a computer to convert base 16 numbers into base 2 binary numbers.

But how can humans count in base 16 when we only have 10 digits? One answer is to borrow the first five letters of the alphabet, **A**, **B**, **C**, **D**, **E**, and **F**, to represent the numbers 11, 12, 13, 14, and 15.




Now we can use the same notation we used earlier --but with base 16 numbers instead of base 10 numbers-- to describe colors: "**r0-g0-b0**" still represents "black" just as it did before. But now full intensity red would be "**rF-g0-b0**" while full intensity yellow would be "**rF-gF-b0**".





Fig. 4: Hexxa and Decima from planet Binary always count in base 16. It's just natural for them!

Since we can simply remember that the order of the colors is always red first, then green, and then blue, we can get rid of the letters "**r**", "**g**", and "**b**" and run all three numbers together. This is exactly what CSS allows us to do. The only

requirement that CSS imposes is that we prefix numeric colors with a hash sign, "#" to distinguish them from named colors. For example, the following are equivalent:

| | | | |
|----------------------------|---|--------------------------|---|
| <code>color:black;</code> | ↔ | <code>color:#000;</code> |  |
| <code>color:red;</code> | ↔ | <code>color:#f00;</code> |  |
| <code>color:yellow;</code> | ↔ | <code>color:#ff0;</code> |  |

Intermediate colors simply require numbers intermediate between **0** and **f**. For example, orange is just full red (**f**) with about half as much green (**8**), while a medium gray is just half way to white (**8**) for all three color components:

| | | | |
|----------------------------|---|--------------------------|---|
| <code>color:orange;</code> | ↔ | <code>color:#f80;</code> |  |
| <code>color:gray;</code> | ↔ | <code>color:#888;</code> |  |

1.5. 256 Color Levels

As we have seen, CSS conveniently permits defining colors using 16 shades of red, green, and blue. CSS and HTML also allow defining colors using 256 shades of each color component. 256 is simply 16^2 . Using 256 levels gives us much finer color control than just 16 levels. To achieve 256 color levels, we just keep counting beyond "f" by carrying over to a second column:

| Notes | Base 16 | Base 10 |
|---|---------|---------|
| | . . . | . . . |
| Counting up to f in base 16 requires only one column of digits → | d | 13 |
| | e | 14 |
| | f | 15 |
| Then we carry to get the (decimal) number 16 → | 10 | 16 |
| ... and keep going → | 11 | 17 |
| | 12 | 18 |
| | . . . | . . . |
| In base 16, we can count all the way up to decimal 255 using just two columns of digits → | fd | 253 |
| | fe | 254 |
| | ff | 255 |

Notice that the following colors are equivalent because "ff" is the brightest color in the 256-level notation, while "f" is the brightest in the 16-level notation, and likewise "88" is in the middle in the 256-level notation while "8" is in the middle in the 16-level notation.

| 16-level Notation | 256-level Notation |
|--------------------------|---------------------------|
| color:#f80; | color:#ff8800; |
| color:#888; | color:#888888; |

Now that you know how it works, you can try using a program like **Gimp** or **Photoshop** to pick web colors.

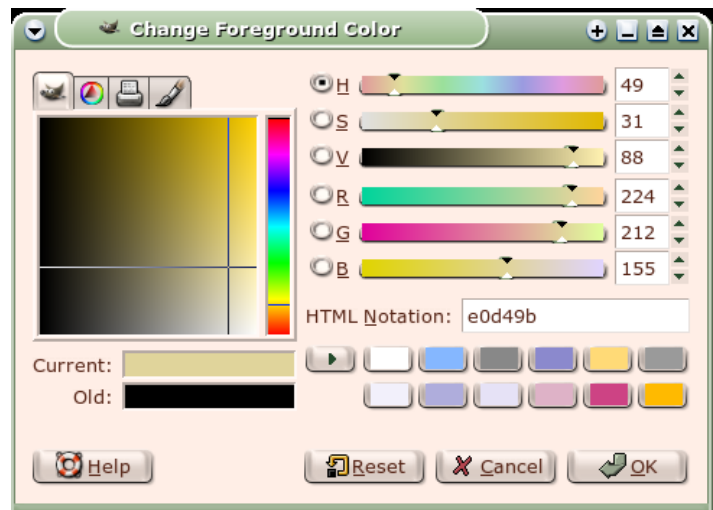


Fig. 5: Gimp color dialog. Using the color dialog from a graphics program like Gimp or Photoshop makes it easy to pick web colors.