TIP and Color Blindness

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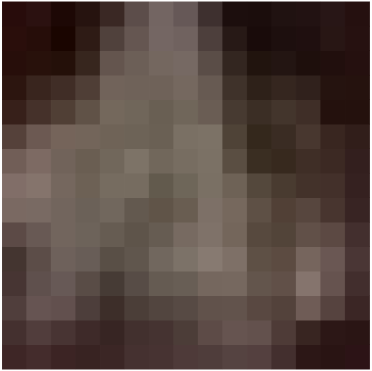
Digital Representation of Images

- The standard digital representation of colored images is simple, conceptually.
- The pixels form a 2-dimensional matrix, whose entries are the coordinates in some (normally) 3-dimensional color space, RGB.
- It's important to realize that the R, G, B used in practical work are not spectral red, green and blue - far from it (as you will measure).

Digital Representation of Images

500x380 pixels



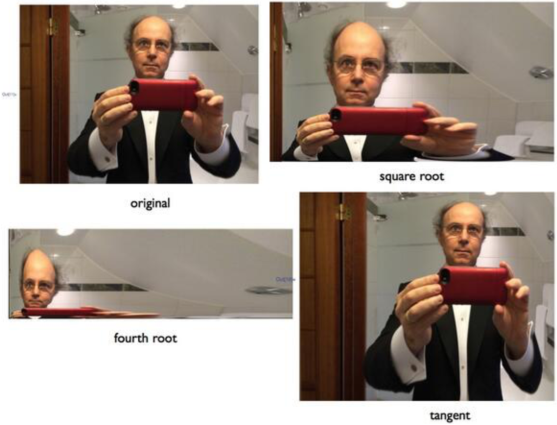
15x15 pixels

Each pixel contains 3 numbers, so the 15x15 picture has 15x15x3=675 numbers.

Manipulating Images

Manipulating Images

- Since the information about an image is stored digitally, as numbers, it is easy to manipulate.
- To do image processing, one does mathematical operations on the numbers, thus generating a new processed image data file, and then translates that file back into a processed image.



original

square root

fourth root

tangent

Manipulating Images

- Python supports a rich toolkit for image manipulation, as does (for example) Mathematica.
- You have been working in the Python ecosystem. You might also enjoy playing with Mathematica and browsing in its excellent documentation.
- Highly recommended for background and context:
  - http://reference.wolfram.com/language/guide/ImageProcessing.html
  - This goes into many important topics we will not cover, notably feature detection.

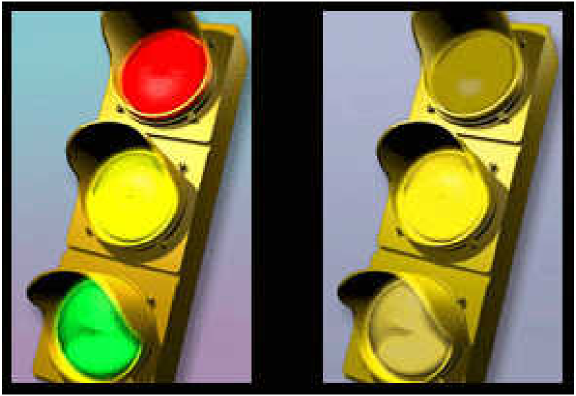
The Challenge of Hyperspectral Information

Hyperspectral Information

- As we've seen in our color-tone work, it can be fun to bring out more than three information channels in images (while retaining the spatial structure).
- The tone strategy is effective locally, but it is ill- suited to giving a global picture.
- It would be powerful to do something similar to all the pixels at once, in a visual display but our visual color system projects to only three dimensions, however many we try to force-feed it.
- Problem: How can we get past that limitation?

Curing Red-Green color blindness

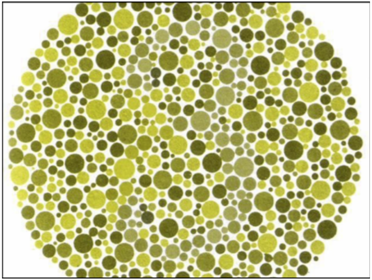
- Before discussing TIP in a general way, it will be good to look at an instructive example: We will use it to “cure” color blindness.
- Let’s look at Red-Green color blindness for example.



Curing Red-Green color blindness

- A crude but roughly correct way to simulate the most common form of color blindness - red-green color blindness - is to replace the R, G, B content of each pixel in an image by (R+G)/2, (R+G)/2, B. LetâĂŹs call this operation RGA (for red green averaging).
- Images that appear the same to a trichromat after RGA will appear the same to a dichromat even before RGA.
- Images that appear different to a trichromat after RGA will also appear different to a dichromat after RGA.
- The RGA projection allows trichromats to visualize the difficulty dichromats encounter in the standard Nishihara test for color blindness:

What number do you see?

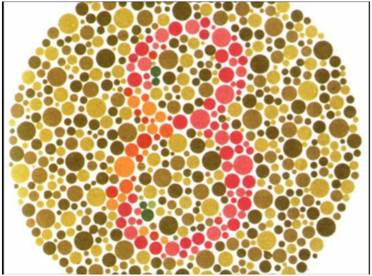


Before RGA

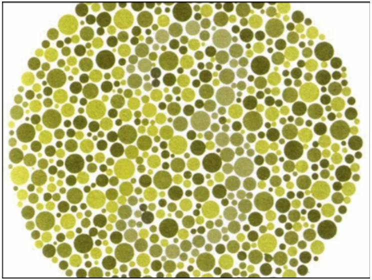
After RGA

Curing Red-Green color blindness

What number do you see?



Before RGA



After RGA

The RGA projection allows trichromats to visualize the difficulty dichromats encounter in the standard Nishihara test for color blindness.

Exploiting the Time Dimension(s)

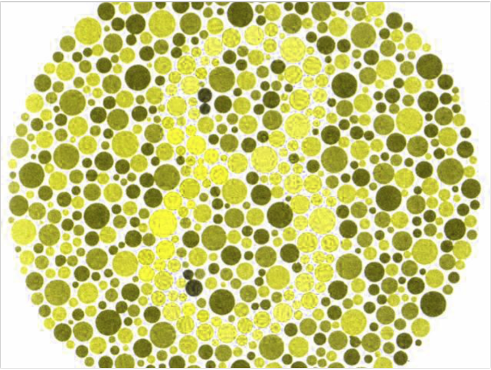
- By encoding the missing information as a time- dependent modulation of the signal which is unaffected by RGA, we can make it available to dichromats.
- This can be done in many ways. Some simple, reasonably effective ones involve formulas like this:

$$R, G, B \to Rf(t) + Gg(t), Rf(t) + Gg(t), B$$

- where f and g are two different functions of time. (Note that R = G as displayed.)

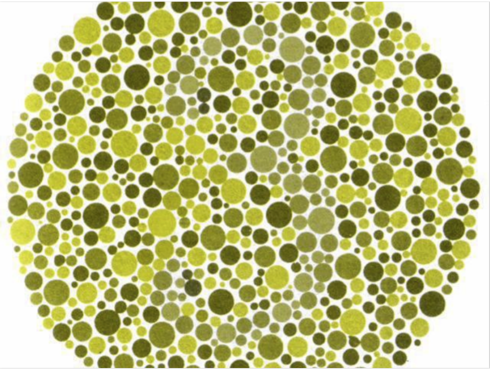
Exploiting the Time Dimension(s)

Here is what you get with $f(t) = \cos^2 kt$, $g(t) = \sin^2 kt$:



Exploiting the Time Dimension(s)

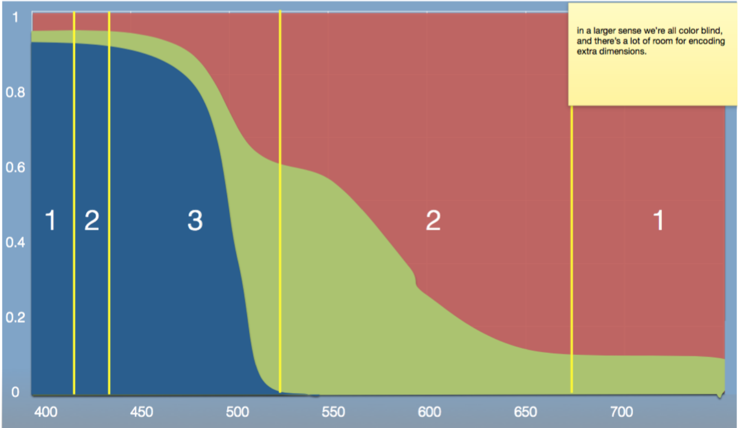
And here is what you get with an encoding where f and g have slightly probabilistic features:



In a larger sense, we are all nearly color-blind.

Exploiting the Time Dimension(s)

This becomes strikingly evident if you plot differential sensitivities of the opsins as a function of spectral wavelength:



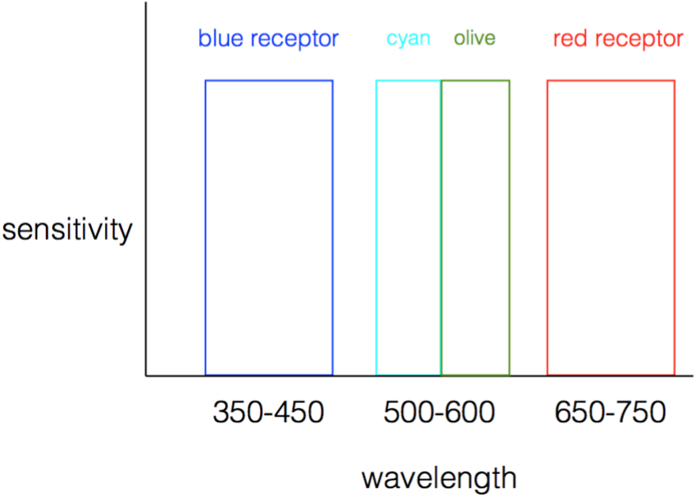
The white numbers indicated the effective dimensionality of human color vision in different wavelength ranges

Exploiting the Time Dimension(s)

- But we can use TIP to open up extra channels.
- Previously, we used TIP to go from a 2-dimensional color space (after RGA) to a 3-dimensional color space. But essentially the same trick will allow us to go from 3 to 4, or more.
- To be concrete, let's imagine we want to resolve Green into Olive and Cyan:

Exploiting the Time Dimension(s)

(toy model)



Exploiting the Time Dimension(s)

- Again, there are many ways to do this. In our toy model, perhaps the most natural is to put all the action in the G channel:

$$R, G, B \to R, Of(t) + Cg(t), B \tag{1}$$

- It is an open question, what are the most effective and attractive TIP methods to transmit hyperspectral, and more generally extra-dimensional, information.
- You'll get to explore this issue.

Varieties of Color Vision in the Animal World

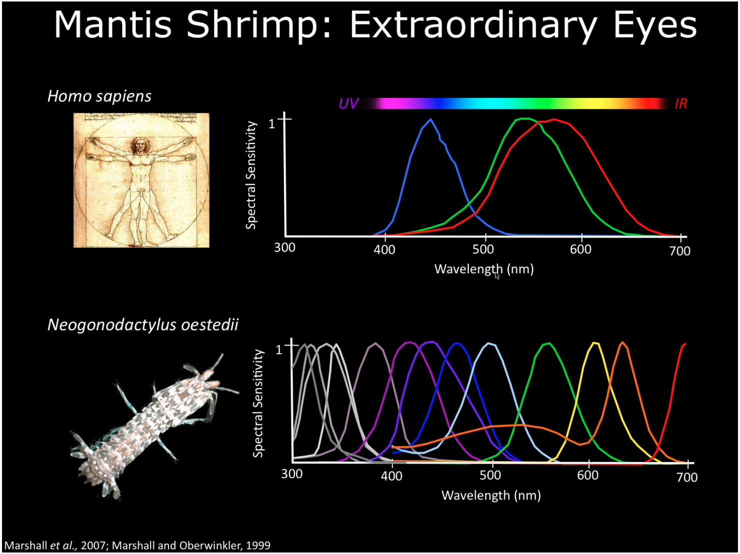
Varieties of Color Vision

Color Dimension	Color Discrimination*	Examples
1	100	marine mammals, owl monkey, some (nocturnal) primates
2	10,000	most mammals, some primates (New World monkeys)
3	10,000,000 (10^7)	most primates, including great apes, some insects**
4	10^8	most reptiles, amphibians, birds and insects. Humans?***
5	10^{10}	some insects, some birds, e.g. pigeons

*These numbers are rough estimates, and not to be trusted.

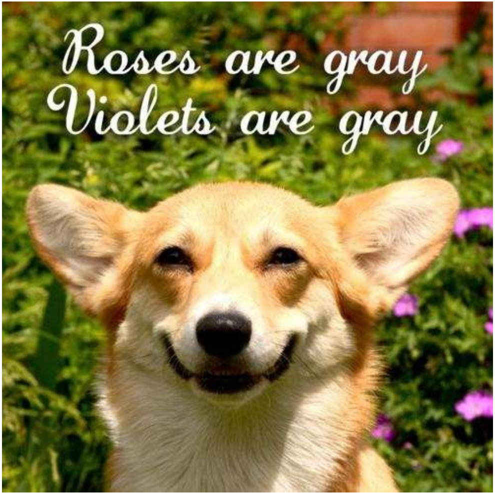
Varieties of Color Vision

Mantis Shrimp seems to be the champ:



Varieties of Color Vision

- Most non-primate mammals are less capable (in different ways):

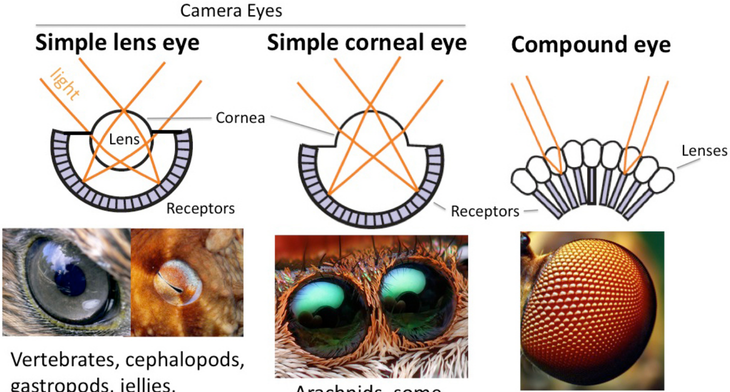


Varieties of Color Vision

We can mimic these variations in software or hardware.

Varieties of Color Vision

It's interesting and relevant to note that insect and crustacean eyes are based on radically different principles from our "imaging" eyes.



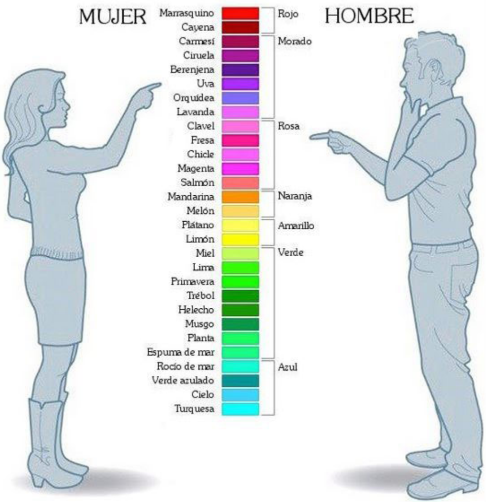
Vertebrates, cephalopods, gastropods, jellies, annelids, at least one copepod crustacean

Arachnids, some vertebrates, some larval insects

Insects, crustaceans, some mollusks and annelids

Varieties of Color Vision

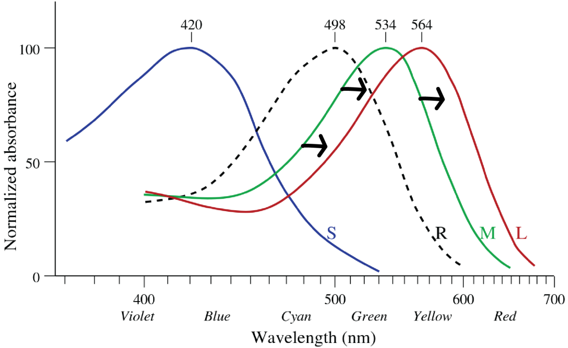
- There's some evidence that a small percentage of women exhibit tetrachromacy. Thus they can discriminate colors that elude most humans.



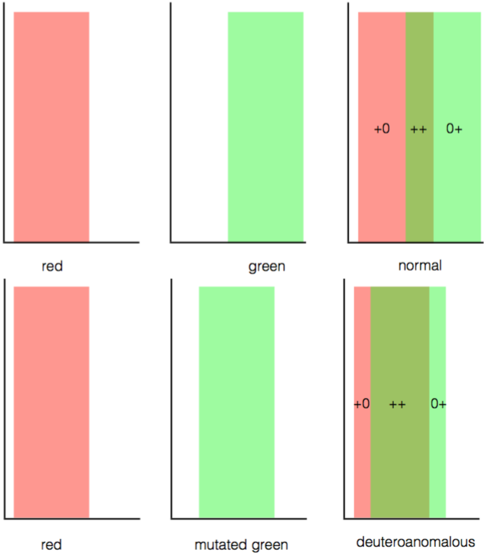
More About Dichromats and Tetrachromats

Dichromats and Tetrachromats

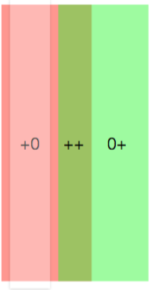
- The most common type of color blindness is "deuteroanomaly", which affects about 6% of males.
- Deuteroanomalous individuals still have three kinds of opsins and cone cells, but their "green" opsin contains a mutation, which shifts its sensitivity curve toward red.
- Thus they have two closely similar receptors, which gives less resolving power.

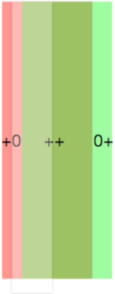


A simple example



Dichromats and Tetrachromats





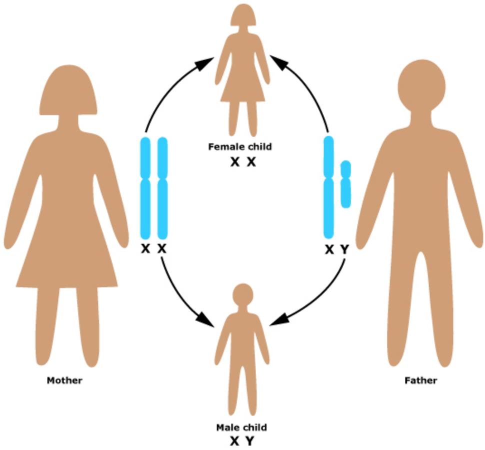
- On comparing these diagrams, several disadvantages of our model "deuteroanomalous" opsins are evident. There is a larger $++$ zone, wherein frequencies are not discriminated, narrower opposition zones, and a significant new blind region.
- On the other hand, if the illumination is heavily weighted toward red, the deuteroanomalous opsins are *advantaged*.

Dichromats and Tetrachromats

- One simple yet striking conclusion is clear and robust: Deuteroanomalous "color blind" individuals actually can resolve some (red-heavy) color combinations that look the same to normal trichromats.
- It would be a nice project to demonstrate this directly.
- You'll be making tools which are adequate to that task.

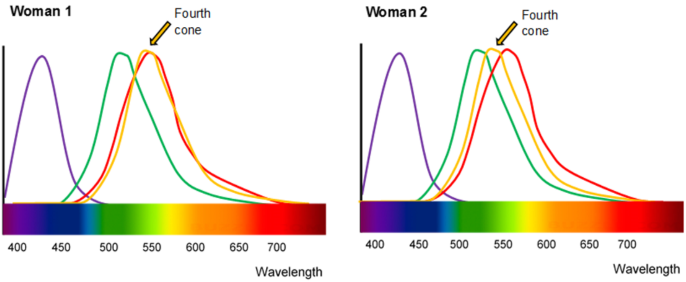
Dichromats and Tetrachromats

- The mutated green opsin gene is carried on the X chromosome.
- Thus males, (one X chromosome), are susceptible to red-green deuteroanomalous (RGD) color blindness.



Dichromats and Tetrachromats

- On the other hand, females may carry both the normal and the mutated green opsins, one on each of their two X chromosomes.
- If both are expressed, in different cone cells, the individual will have four different opsins altogether, and she will be a tetrachromat.
- We should expect this for sisters and daughters of RGD males, and in about 9% of females altogether.



Dichromats and Tetrachromats

- The manifestations of this sort of tetrachromacy might be rather subtle, since two of the opsins - red and mutated green - have very similar receptive characteristics.
- But the same tests that bring out extra resolving power in RGD males should also bring out this sort of tetrachromacy.

Picture Citations

CdeC logo (accessed 13 July 2017): https://www.clubesdeciencia.mx
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Star Trek (accessed 17 July 2017):
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