Notes for “Un viaje a otras dimensiones: Technology for Sensory Expansion ” Summer 2023

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1 Main Objectives

This course will be split into a pair of minicourses. The first course will be roughly speaking, image processing in julia. We’ll talk about other senses, but it is absolutely easy to gain some incredible insights and advantages in our vision by some relatively simple computing techniques. Afterall, the whole of the course is extending our senses with technology. One particular throughline that we’ll see multiple times is most of our human senses (and many from the animal kingdom) are simply put, “how do we process waves?” Sound, light, heat, and pressure are all waves with varying wavelengths and amplitudes. Thus we can make this course about how do we process different forms of waves with our bodies?

The second mini course is roughly about how to program synthesthesia. That is, how do we combine two senses to tell us the same information. You may have met several people in your life who “hear colors” or “feel colors.” I’ll give two examples of persons I know and have known you describe certain sensations. A neighbor of mine has a different color for every letter. He also assigns colors to words and numbers, and of course, musical notes. It is somewhat advantageous as he’s a profressional pianist, so we he learns a song or a piece on piano, he hears wrong notes by seeing the wrong color. He toldme once that “Clark” appears to him as black and pink, but the letter ‘C’ is blue. Another person who was a classmate of mine many years ago described different sensations as colors. For example, she said pleasureable things (such as eating icecream or a hot shower, not THAT kind of pleasureable) were “brown.” Other feelings, like tiredness were “purple.” It is not the “normal” sensation for humans to cross senses, but in the animal kingdom that is rather more common. We confuse taste and smell, but snakes only have one taste/smell sense. So while some persons already possess this ability, not all of us do, and thus it’s a ripe area for extending our senses with technology.

2 Some Notes on Light and Color

While this section is not strictly necessary, it is absolutely fascinating to hear many of these things about ourselves and animals. Let's begin by talking about humans and our chromatic abilities. As most of you know or have heard, our eyes have two types of light receptors, rods and cones. The rods control the intensity of our vision (we'll see this in RGBA images later as the A channel) and the cones control which wavelengths of light we can perceive. The vast majority of us are trichromats, meaning we have three distinct cones and can perceive three distinct wavelengths of light. These cones generally speaking are Red, Green, and Blue. There is, however, a large fraction of the general population whose cones only pick out two distinct colors. In mammals this is the norm, not the exception and is called dichromacy. In our world we call it colorblindness. There are, however, a few women (only women for reasons we shall soon see) that have four distinct color receptors, and they are called tetrachromats. What the hell must they be seeing all the time? We'll try to get to the heart of it.

Now an important question. Why is it that men cannot be tetrachromats? Before we get too far into gender politics and identity, I'm keeping things simple where woman means two X chromosomes, and man means one X and one Y chromosome. I understand that biology and gender are not that simple, but for the sake of a science club, we'll only think about these classifications. Therefore, it is possible for a transman to be a tetrachromat, but this would be exceedingly rare, and so for the sake of time we shall skip this statistical outliers. Back to our question. Why do women have the ability to have 4 cones, but not men. Well, the answer is actually shockingly simple. The X chromosome carries two color receptors and the Y carries only one. The green receptor is on the X chromosome, so in principle all women have 4 cones, but the two green receptors overlap in the wavelengths that they see so much, that our brains tends to merge them. Dichromacy, happens much more in men, as two of the three receptors have such overlapping wavelengths that the persons bearing these cones have difficulty distinguishing red from green. There are many, many gradiations of colorblindness and we'll explore this in depth. In the same way, there are many gradiations of tetrachromacy, again we'll see what we can pick out. The vision of humans doesn't stop there however. Claude Monet supposedly could see the longer wavelengths of ultraviolet. This supposedly happened after an eye injury damaged his lens on one eye, and so it reflected different wavelengths of light, which moved from blue to violet to ultraviolet. His description was that ultraviolet appeared whitish blue, and we can see this is his painting of water lillies.

Now some interesting quick facts about some animals and they're vision. Bees are particularly fascinating as they see three colors, but not red. They see green, blue, and ultraviolet. Apparently when you look at a flower's ultraviolet wavelengths, the sweet pollen flowers look like a giant bullseye to honey bees. How fascinating! I'll challenge you this week to find an image of a flower that we know bees like, and see if we can find a bullseye. Hummingbirds, also see ultraviolet, but they also see red,what must their world look like? Different animals have every conceivable type and manner of eyes, ability to see colors, polarities of light, motion sensing, etc. There more you look, the more you find. It's an immensely satisfying exploration, and I hightly encourage you to go look and see what you find.

3 Getting Started with Julia

3.1 VSCode

Generally speaking, there are two major platforms by which you can use julialang. My personal preference is VSCode which is free, and supports many, many, many languages Python included. The major advantage with VSCode for julialang is its REPL (Read-Evaluate-Print-Loop) which is supported in VSCode. Once you have VSCode downloaded, you'll want to download the julia extension.

The next step is to download julia from the website

`https://julialang.org/downloads/`

I run a stable 1.8.5 on my personal computer and 1.9.0 at work. Anything more recent than 1.8.0 will be fine. As of July 2023, I believe 1.9.2 is the most recent.

When you have downloaded julia, you will simply need to tell VSCode where the executable file is

`https://code.visualstudio.com/docs/languages/julia`

Open a new text file in VSCode and type println("Hola mis amigos.") Then save as hola.jl and run by hitting the play button on the top bar. This should open julia's REPL and print your statement. If all this happens, then you are ready to go. If this doesn't happen, then we can trouble shoot.

3.2 Anaconda and JuPyteR Notebooks

The second option is to download the entire anaconda suite and open a jupyter notebook. An interesting fact that most of you may not know is that JuPyteR means Julia, Python, and R. So simply choose julia as the kernel in your notebook and run it like normal. For my personal preference I avoid notebooks as much as possible, but you are free to use them for our projects.

4 Getting Started with Julia Images

Once you have julia running in VSCode, the julia REPL does this awesome thing where "]" takes you to the package manager and you can simply type

(@v1.8) pkg > add Random

which will connect to gitHub and download, install, and prepare the package "Random" for you. In anaconda you'll have to use the Pkg command.

julia > using Pkg

julia > Pkg.add("Random")

5 Multiband and Hyperspectral Images

We'll go through these images using a couple of packages. Mostly we'll use Images and MAT. Images is the workhorse here, however MAT allows us to get MatLab files holding only data.

So, what's a multiband image? Generally speaking images in formats like .jpg and .png and .svg etc have three color channels. For the vast majority of us we see Red, Green, and blue and those are the channels that these images show. Some images also have a brightness channel, we'll get to that a little later.

A multiband image, on the other hand, splits images into much smaller slices of light. In particular, let's have a look at the flower image known as scene 4 from the University of Manchester multiband imagery repository

`https://personalpages.manchester.ac.uk/staff/d.h.foster/Hyperspectral_images_of_natural_scenes_04.html`

Let's download this using our MAT package. Check the script in our gitHub repository. A couple things to notice.

1. This is a 33 channel image
2. The bands are split into 10nm wavelengths.

Looking at the following table we can see roughly where the wavelengths fall in terms of our "normal" vision.

Now let's do some fun things! First, let's get an "average" red channel. We do that by

redChannel = mean(mbimg[:,:,27:end])

The symbol ":" in the middle there means "everything" in the first dimension and everything in the second dimension, and we're taking the pointwise average of the pixels in the red channels. Let's do the same for the green and blue channels. Now we can see sort of what the image would look like to us

rgbimg = colorview(RGB,redChannel, greenChannel, blueChannel)

But here's the fun part, I've provided you a bunch of tools for manipulating these channels. You can take negatives with 1 .- redChannel You can switch reds and blue and greens by doing crazy things like

imgLoco = colorview(RGB,blueChannel, redChannel, greenChannel)

You can also see any three channels at a time by

$$\text{rgbimg} = \text{colorview}(\text{RGB},\text{mbimg}[:,:,c_1], \text{mbimg}[:,:,c_2],\text{mbimg}[:,:,c_3])$$

I want you to spend some time exploring this image and what different wavelengths look like and how combining them makes interesting images,and Andy Warhol style art.

One particularly nice thing in julia Images is that we can make a new, larger image by simply concatenating smaller images. Let's say for example, we have img1,img2,im3,img4 all the same size which are just different colorations of the same original image.

we can make a nice larger image by

$$\text{bigIMG} = [\text{img1 img2; img3 img4}]$$

The space is used to say matrices sit next to each other left to right and the semicolon creates a new row. Try it and see what you get!

Let's try something interesting now. We know that some people (women only) are tetrachromats. This happens because the X chromosome carries two color receptors. In most cases the green receptors merge into a single green receptor. It is estimated that nearly 12% of women actually have 4 distinct cones, the vast majority of those still have the green color receptors merge to respond to the same wavelengths. True tetrachromacy is something entirely different. A true tetrachromat will be able to see and detect and distinguish between far more colors than we do. So let's see if we can use the technology at our fingertips to see if we can replicate a little bit of that. There are two ways I'm thinking of attempting this. First, let's start with our multiband image. Choose any image that you like. Let's make red anc blue average channels as before

5.1 Altering Brightness

In the same way we can manipulate a three color image, we can have a four dimensional image where the fourth dimension is acuity or brightness. Generally referred to as A in the RGBA scheme. Normal images which do not take brightness into account have brightness set to 1. In julia that would be ones(size(img)). Let's make our images twinkle a little. Let's go back to our averaged red,green,and blue channels.

Now try looking at images like

$$\text{colorview}(\text{RGBA},\text{red},\text{green},\text{blue}, \text{rand}(\text{Float64},\text{size}(\text{red})))$$

A quick note. size(red) will be a double something like (1024, 1920) meaning 1024 rows and 1920 columns. If we say rand((1024,1920)) julia will spit out an integer either 1024 or 1920, but what we want is an array of intensities. So we add the Float64 in front to indicate that we want rand numbers of type Float64, and we will tell the size of the array second. Similarly in julia rand(1:5) gives and integer, but rand(1:5,(2,3)) gives a 2×3 matrix of integers between 1 and 5 (not 1 and 4 which python does for some strange reason.)

If you come across an image you want to save, that's also easy.

save(filepath, img)

In the next major section we'll loop through to create lots of images and piece them together as a video. (I'll let you add the music.)

6 Colorblindness

Just to have this right up top let's have a list of colorblindness transformations. `https://www.inf.ufrgs.br/%7Eoliveira/pubs_files/CVD_Simulation/CVD_Simulation.html`

Colorblindness in humans takes many, many different forms. In principle it's a very simple physical effect. One or more of the cones in a "colorblind" person's eyes doesn't pick up reflectances of certain wavelengths of light. That's kind of it. The consequences are incredible because we, as a species are so incredibly sight driven. Sight is, by far, our most dominant sense (as a species) and so it is as hard for us to imagine what a tetrachromat sees as it is for a colorblind person to imagine what we see. It turns out that so many animals in the animal kingdom only have two color receptors, and thus we would consider them color blind. Additionally, other animals pick up three different channels than we pick up. For example, hummingbirds can see the standard RGB plus ultraviolet. Being that purple is the English language word for the combination of red and blue, writer Ed Yong has deemed these colors formed with ultraviolet as Rurple (red + UV), grurple (green + UV) and Yurple (yellow + UV). In essense humans are colorblind to these colors.

Again, in the animal kingdom, many, many, many animals only have two color receptors. Despite our trichromacy, this turns out to not be a disadvantage to all animals. For example, animals which don't see green very well are able to see "leaf bugs" and stick bugs and katydids etc where humans have a difficult time seeing them. This means we see green and are unable to distinguish outlines and edges where as animals that eat such insects see outlines and are easily able to pick out their food.

Let's go through some examples. I want you to open the script on colorblindness and download some very colorful pictures. In the script I show how to transform the RGB color channels into color blind channels using the matrices provided in the link above. Perhaps you want to solve some equations and make a short movie interpolating between different levels and types of colorblindness. Maybe you'd like to try all three simulataneously and give an Andy Warhol type video.

7 Convolutions and Edge Detection

In modern image processing with artificial intelligence, we use the idea of convolutions. You may remember from math class that these things look like

$$f * g(t) = \int_{-\infty}^{\infty} f(t-\tau)g(\tau)d\tau$$

If you haven't seen these things yet don't worry the intuition is simple. We have some filter which in the above equation is called g. We pass our filter over some function f and the result is the convolution of the two. In the case of images we do almost the same thing. If we think of every pixel as having an image intensity (some number between zero and 1) then we pass a filter over the close by pixels and take a dot product. This is not the standard dot product but the pointwise dot product. Here's an example

$$\begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \circledcirc \begin{bmatrix} 0.1 & 0.2 & 0.3 \\ 0.4 & 0.5 & 0.6 \\ 0.7 & 0.8 & 0.9 \end{bmatrix} = 0(0.1)+(-1)(0.2)+0(0.3)+\cdots+(-1)(0.8)+0(0.9) = 0.$$

This tells us that the pixel in the mew img would have intensity 0. We have an easy julia package for this called DSP (Digital Signal Processing)

] add DSP

And in DSP we have the function `conv`. When you play around with conv, you'll notice that it gives you a slightly larger matrix than the one you started with. Why is that?

When performing a convolution (in DSP package) the image which is larger is padded with extra zeros. So the final size of an $n \times k$ convolved with $m \times \ell$ is $n + m - 1 \times k + \ell - 1$

I've provided you several examples of common convolutions used in neural networks and some other goodies. See if you can figure out which convolutions do which things.

Now let's play with this a little more. Let's see what kind of details we can pick up in some images using any combination of techniques you can. We have at our disposal now:

1. Averaging
2. Channel switching
3. Negatives
4. color blindness filters
5. convolutions

6. fourth channel intensity

We should be able to manipulate several extremely interesting images and in the next section we'll learn how to make a short movie from our individual frames. This will bring into effect the final piece of our vision, motion!

8 A Simple movie by FFMPEG

I highly recommend to you some additional reading. While Frank Wilczek's book is amazing and definitely worth your while to read. I really want to point to another recent book "An Immense World" by Ed Yong. We writes at length about the many senses that animals have and how different animals take advantage of different senses. One through line that we see in many of the senses is that we have different methods of perceiving waves. Waves, as you're likely well-aware, can be standing waves or moving waves. And thus it stands to reason that motion is another dimension of how we perceive the world around us. Let's take this to the logical next step. We want to have many still images and piece them together

Here's how we do it...
you'll need to download ffmpeg via command line. Now naviagate to the folder where you've stored all the images and type

ffmpeg -r 20 -i %3d.png -pix_fmt yuv420p myScene.mp4

There are some weird notations here. -r 20 means frame rate of 20 per second. -i means iterate through The command %3d.png means find all the frames which are label with 3 digits and .png extension. So you should name your images 000.png, 001.png, etc. -pix_fmt yuv420p says to format the pixels at the density of 420p (HD video is 1080p for example) Then finally, the output name. I want to name this myScene.mp4. You can use .avi, .gif or whatever format you need.

9 Some Useful Websites

Spectral reflectance database from hyperspectral images
`https://ridiqulous.com/spectral-reflectance-database/`

MultispectralImage DataBase from Columbia University.
This site has images of real and fake objects. See if you can find a multiband channel that exhibits this clearly!
`https://www.cs.columbia.edu/CAVE/databases/multispectral/`

Working with the MAT package in julia.
`https://github.com/JuliaIO/MAT.jl`

A list of colorblindness transformations.
https://www.inf.ufrgs.br/%7Eoliveira/pubs_files/CVD_Simulation/CVD_Simulation.html

Another Hyperspectral Imaging Library in julia
https://github.com/usnistgov/HyperspectraWithNeXL.jl/blob/main/notebooks/quant.ipynb