
The Ancient
Secrets
Computer Vision

Logistics:

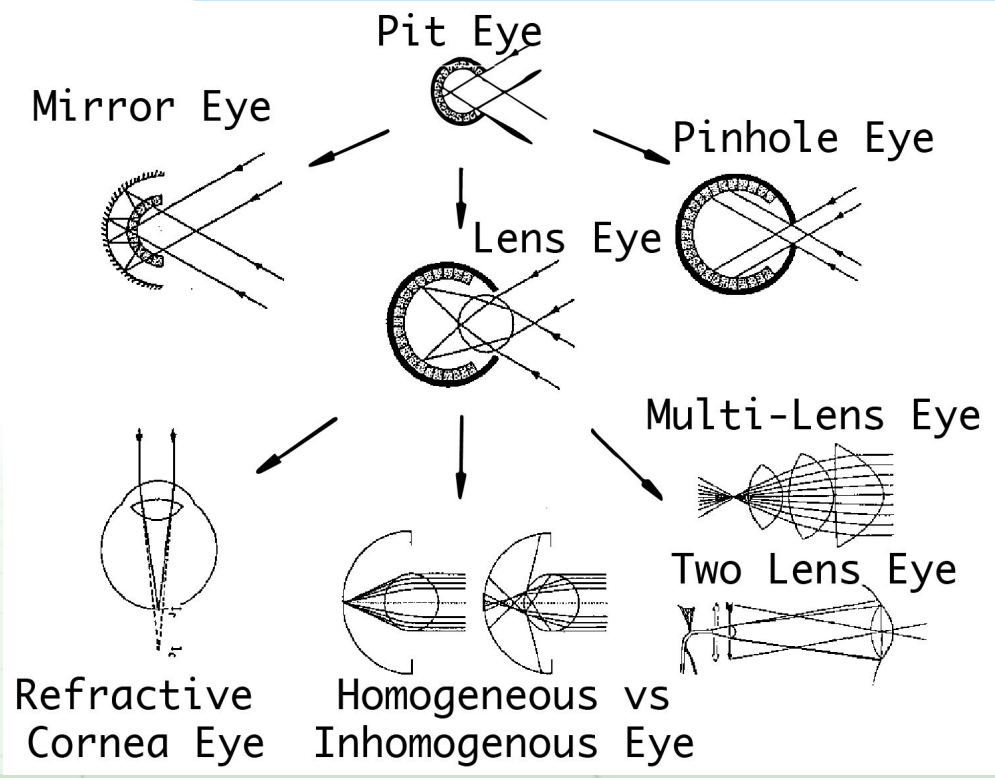
- Homework 1 is out!
  - Due on Thursday
  - Should be pretty straightforward, get you used to the image framework you'll be building
  - Start now so you can let us know if you have trouble
- Wednesday office hours with Nancy changed
  - 4-5pm, CSE 007
  - Just this week


Previously
On
the
Ancient Secrets
of Computer Vision

Vision is good!

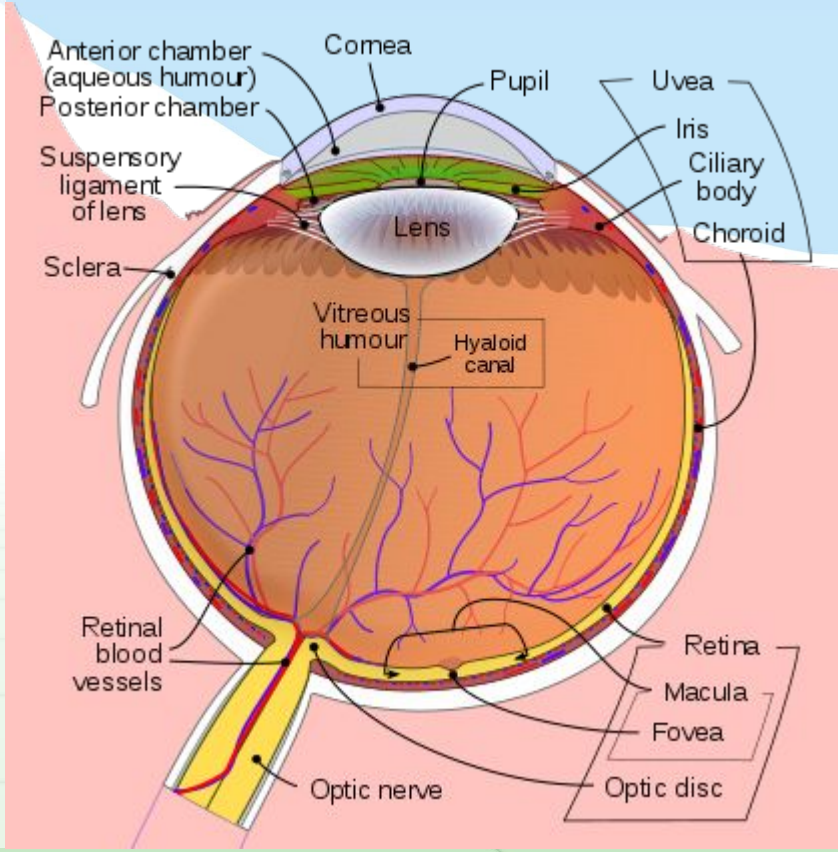
Simple eyes:28 of 33 animal phyla

Complex eyes: 6 of 33 phyla, 96% of species!



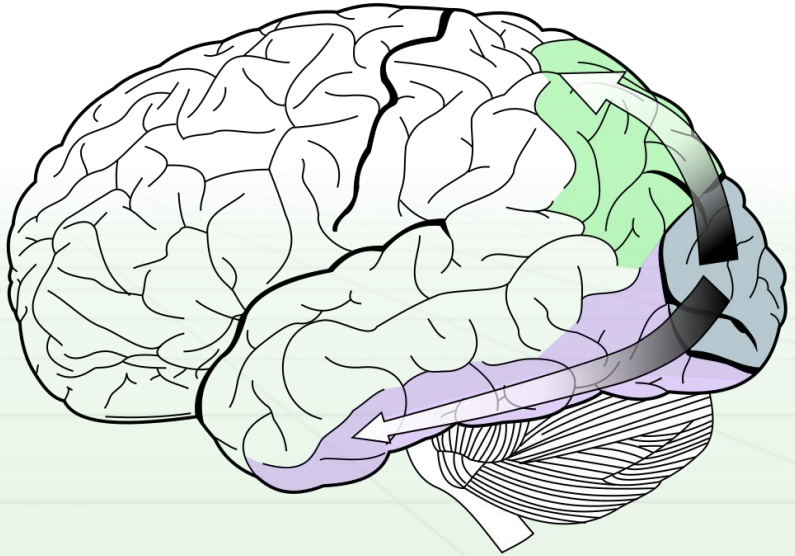
Human eyes

- Light passes through
  - Cornea, humours, lens refract light to focus
- Hit the retina
- Absorbed by rods, cones
- Info transmitted through optic nerve, processed by visual cortex

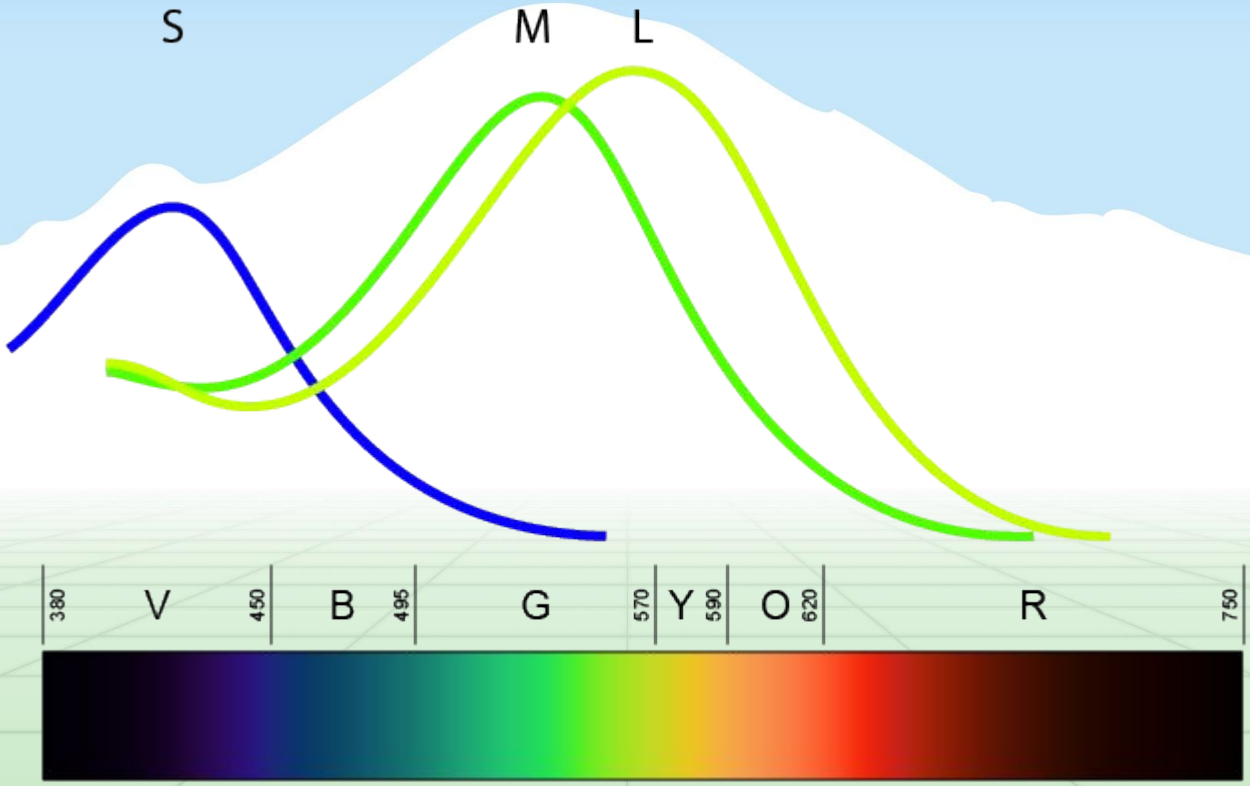


Ventral/dorsal split

- Ventral: fine grained visual recognition
- Dorsal: vision related to motion and planning
- The brain is integral to human vision, even when we are conscious of it!

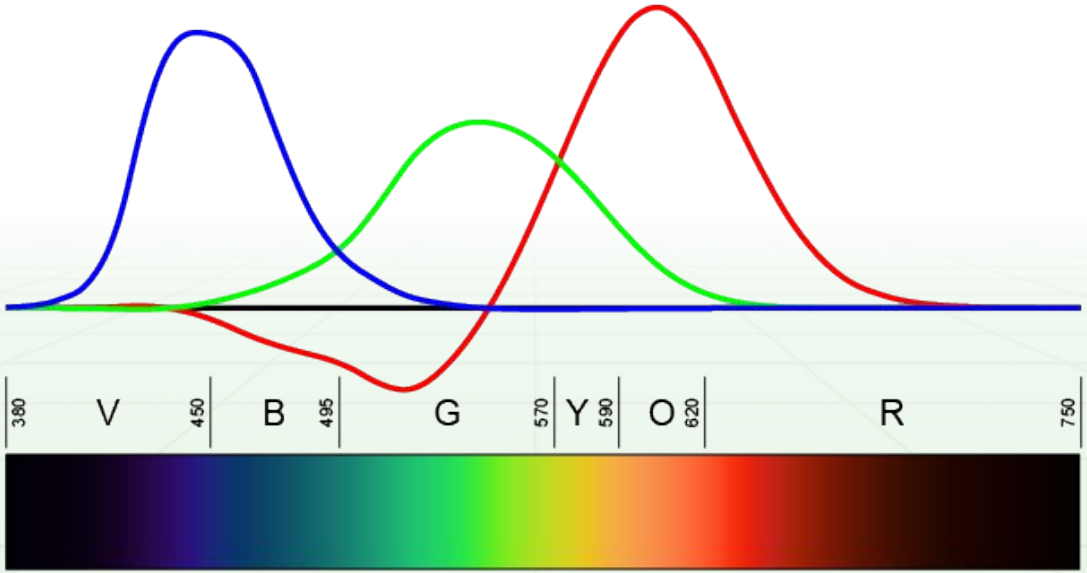


Rods and Cones: Color!



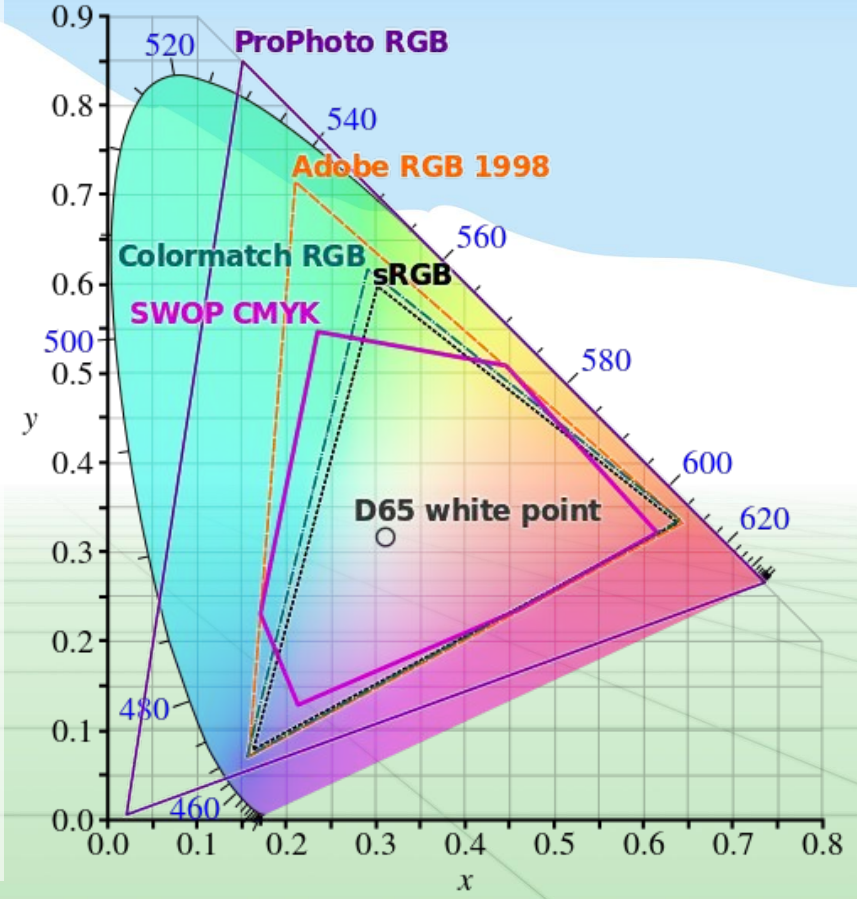
CIE 1931 color matching

- Match single wavelength with mix of primaries
- Most participants had similar mixes

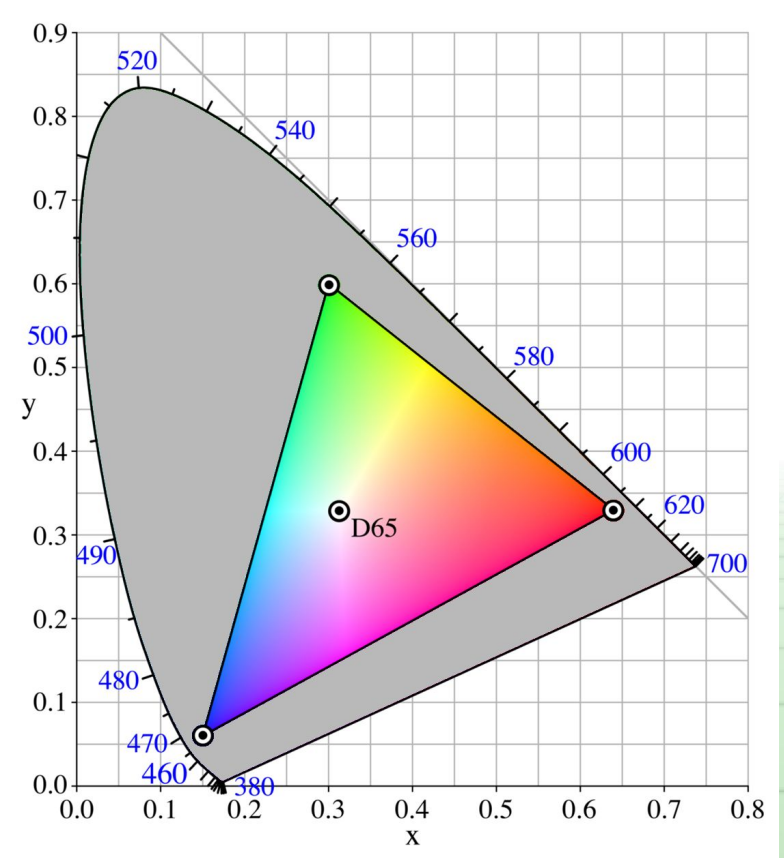


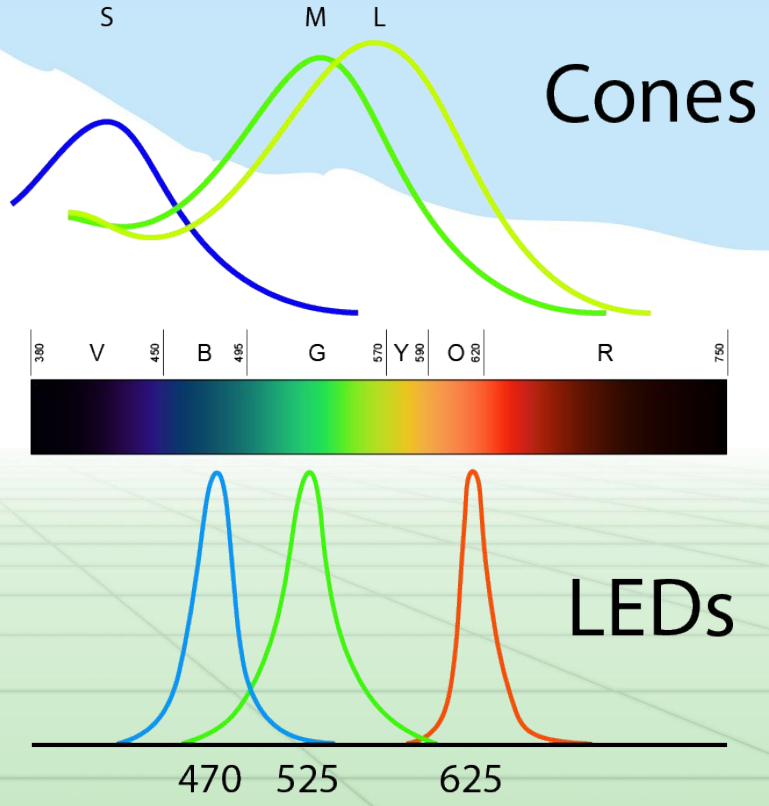
Can make a “map” of color

- Can make new colorspace by choosing primaries
- Range of representable colors: gamut
- Not all colors are representable! Have to go outside sometimes…



sRGB: most widely used colorspace

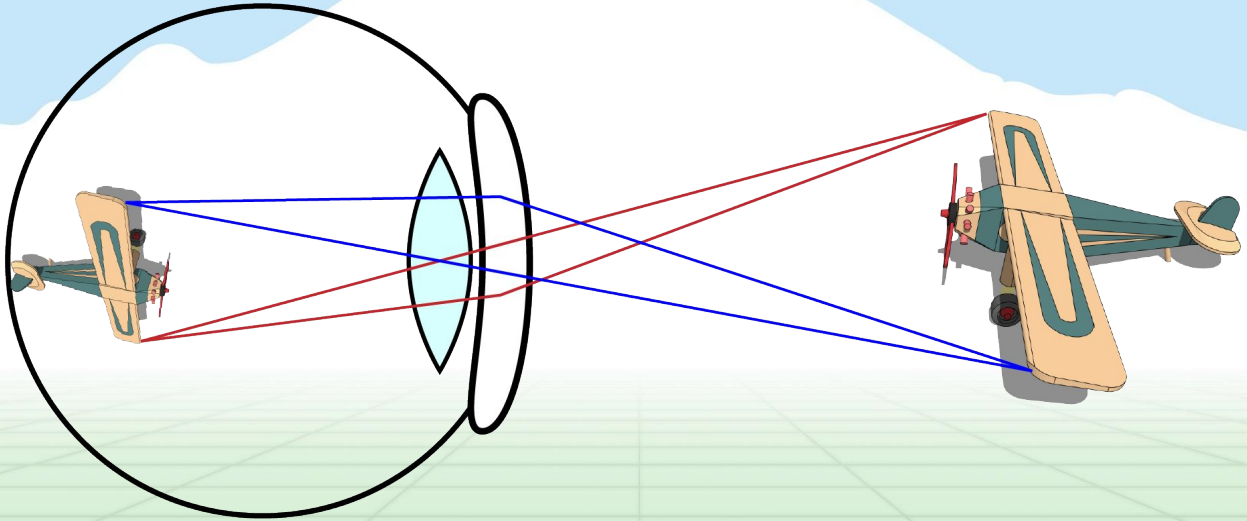




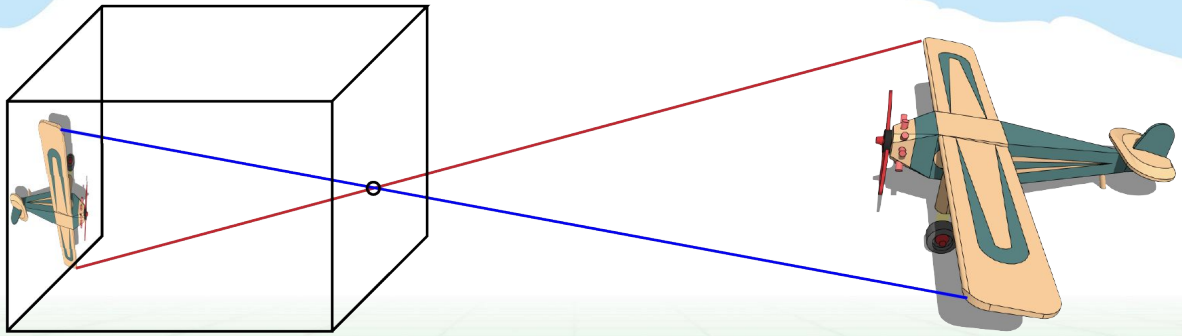

Chapter Three
Image Basics

So what is an image?

Eyes: projection onto retina



Model: pinhole camera



Model: pinhole camera

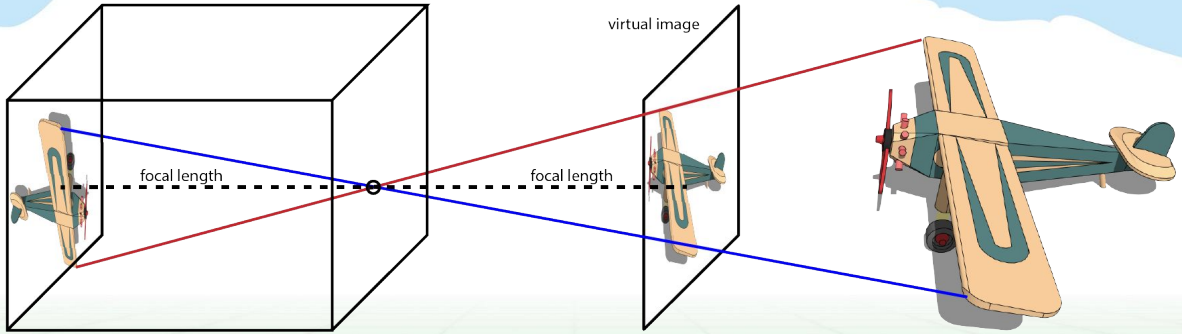


Image: 3d -> 2d projection of the world

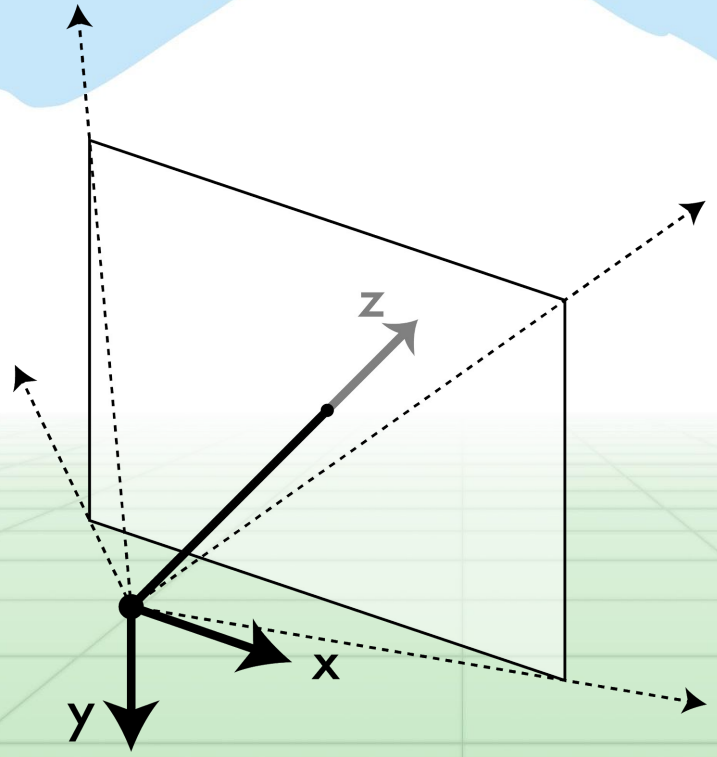


Image: 3d -> 2d projection of the world

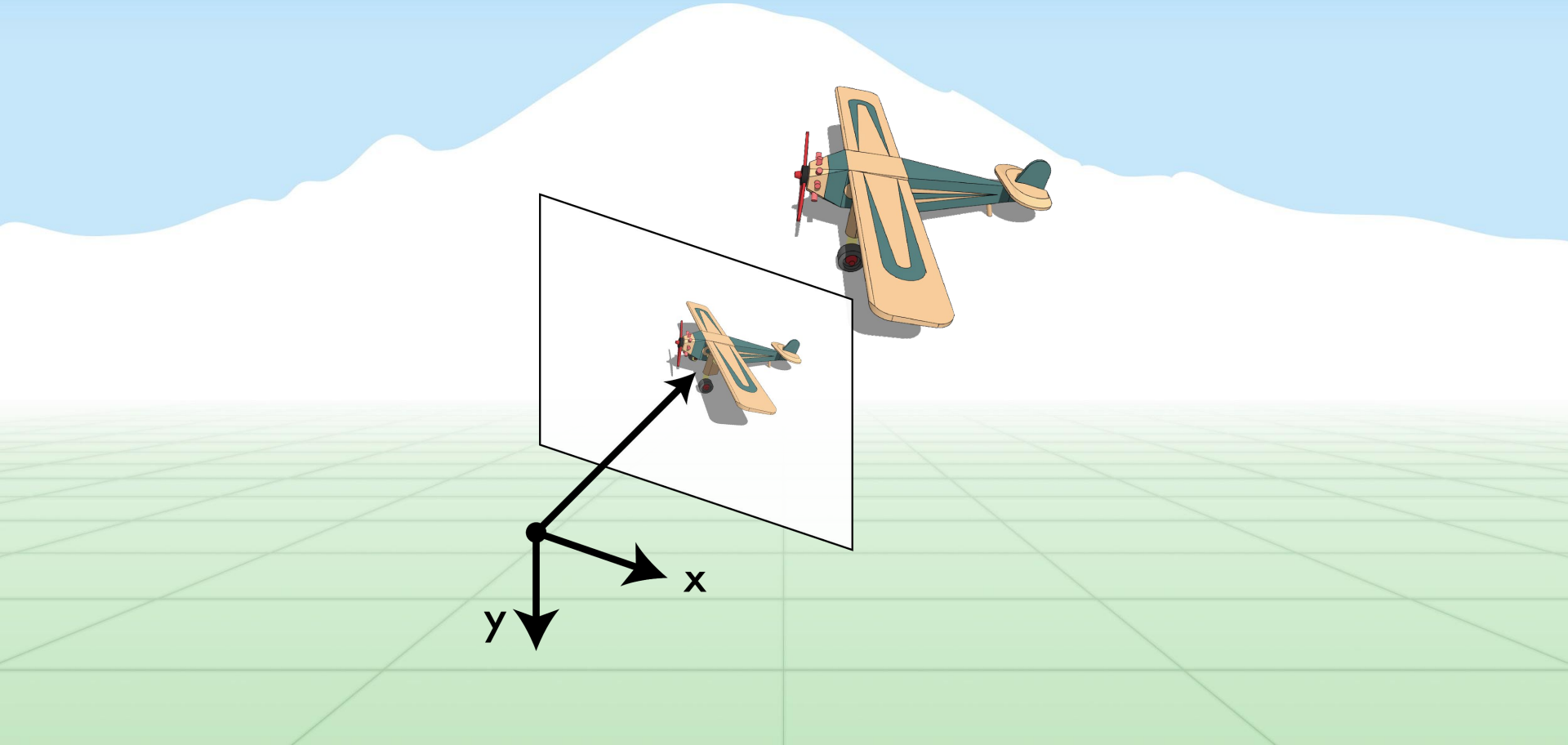


Image: 3d -> 2d projection of the world

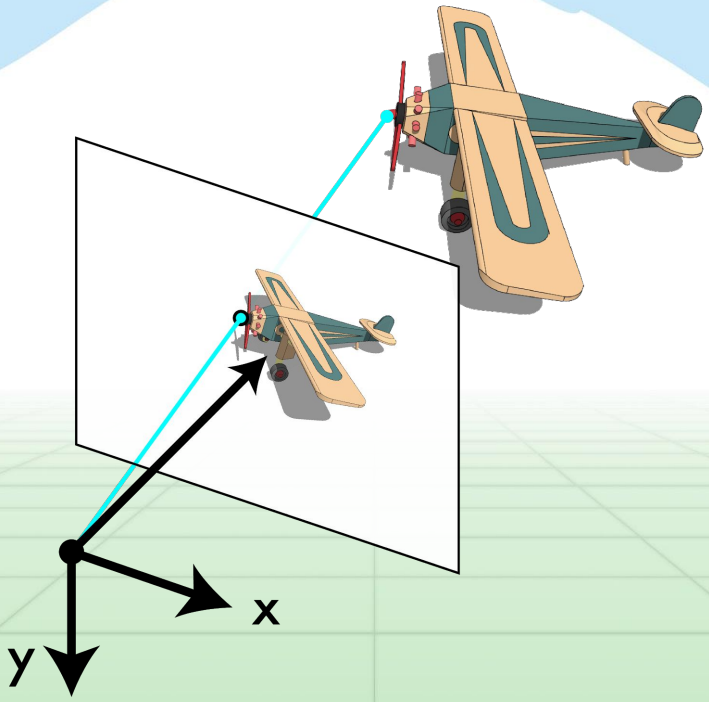


Image: 3d -> 2d projection of the world

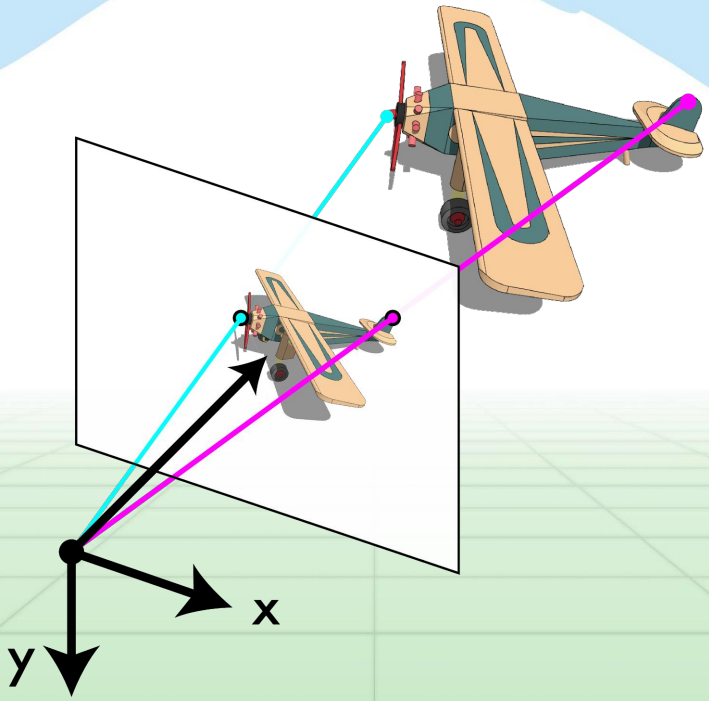


Image: 3d -> 2d projection of the world

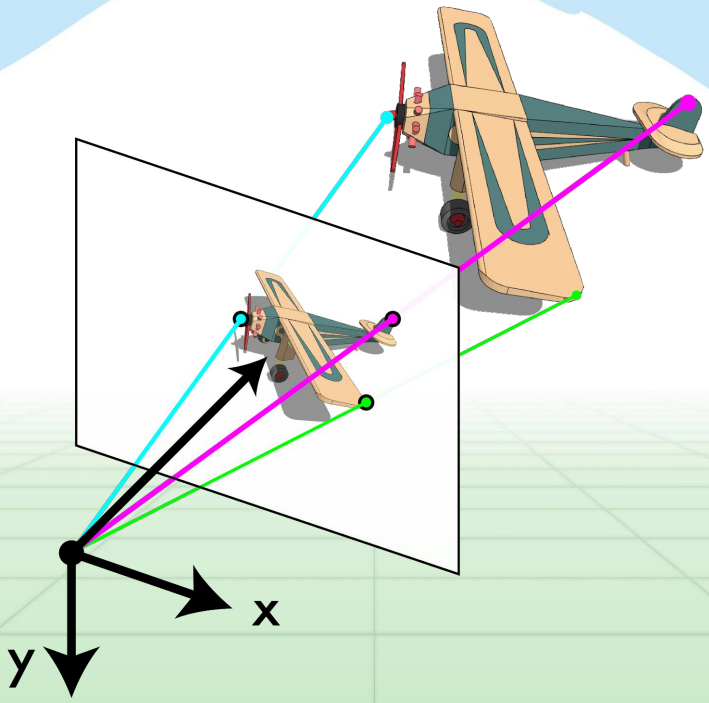
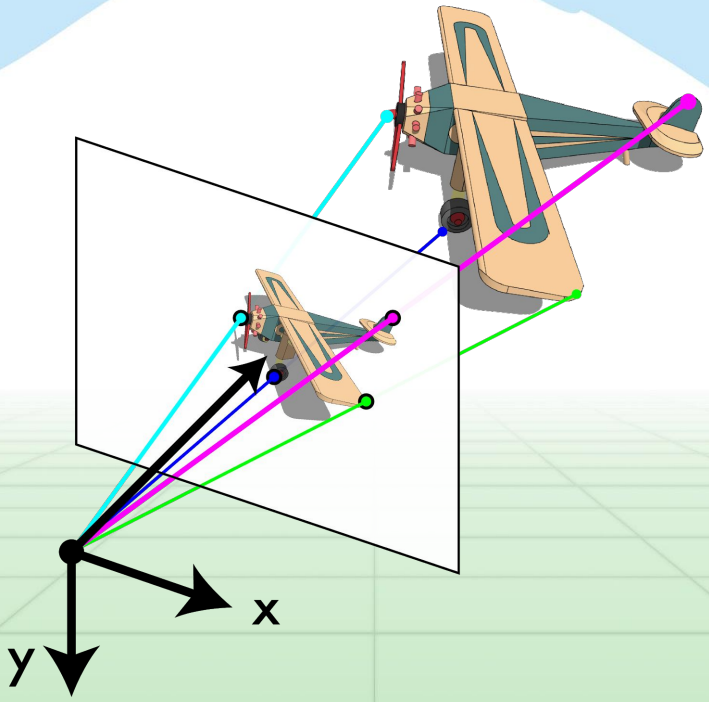
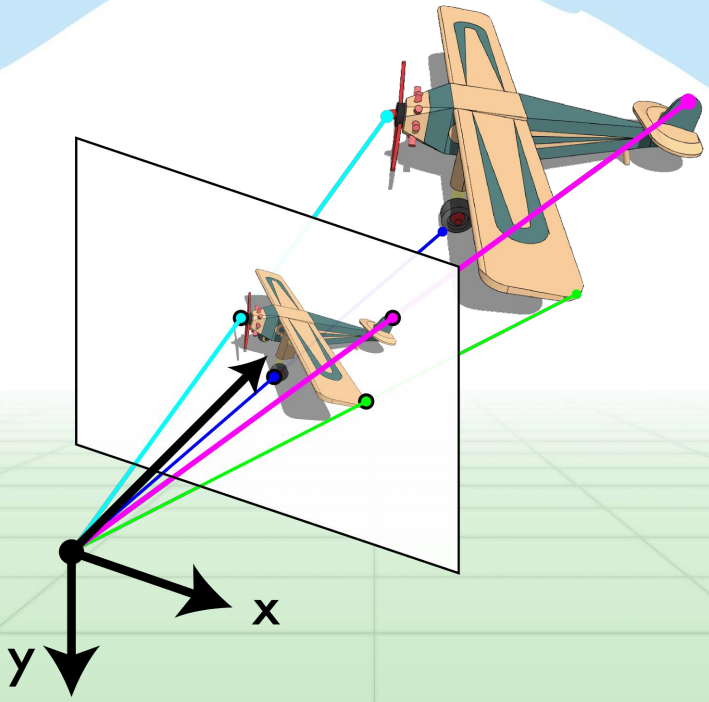


Image: 3d -> 2d projection of the world



At each point we record incident light



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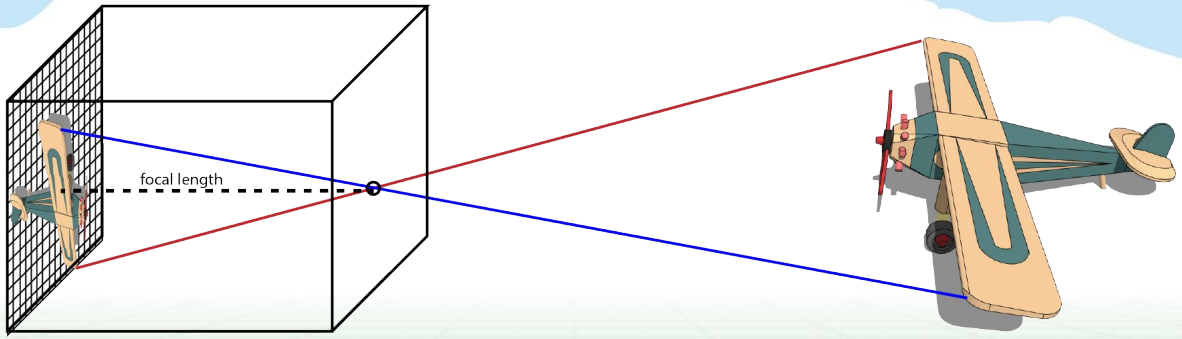
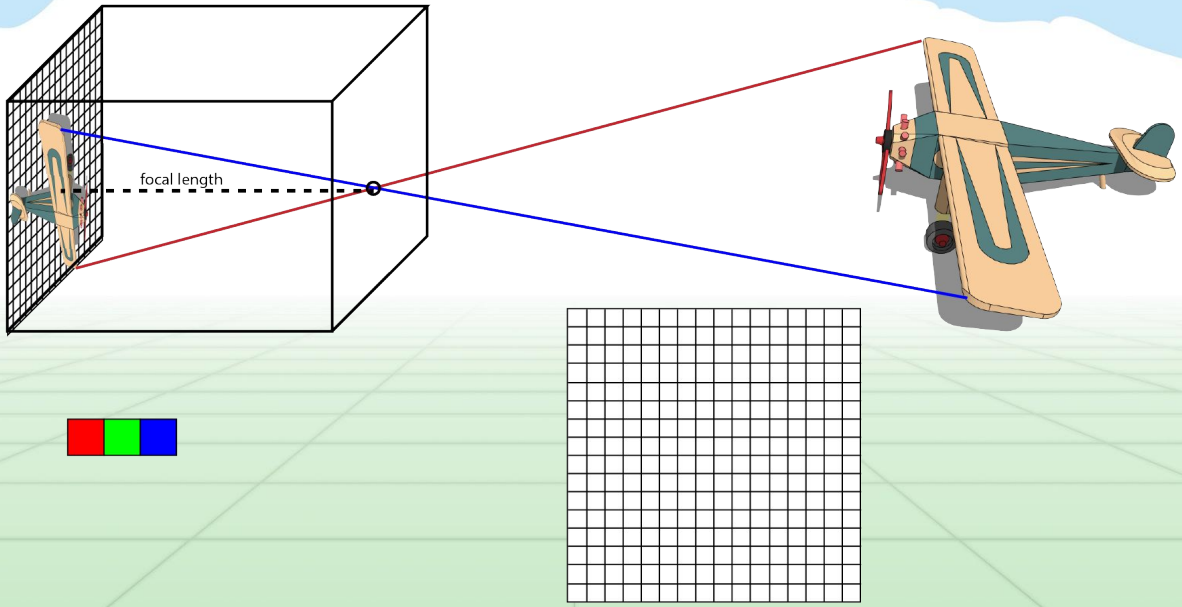
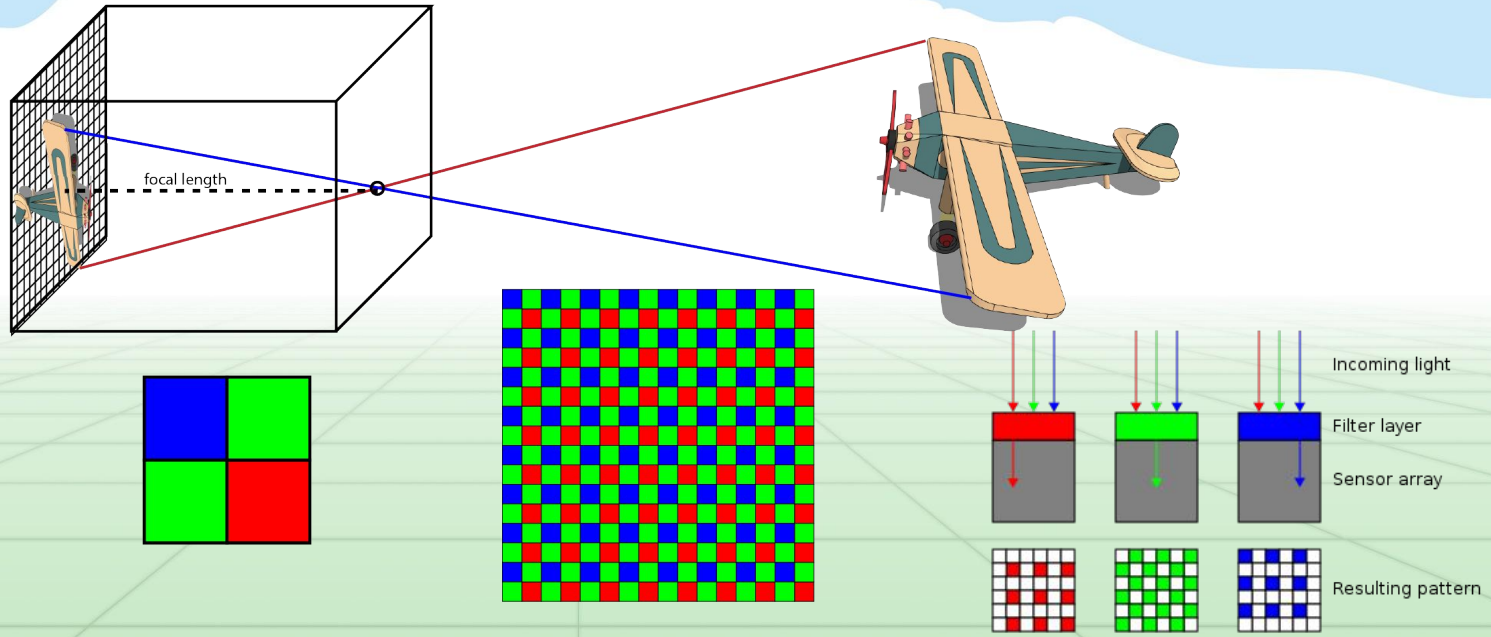


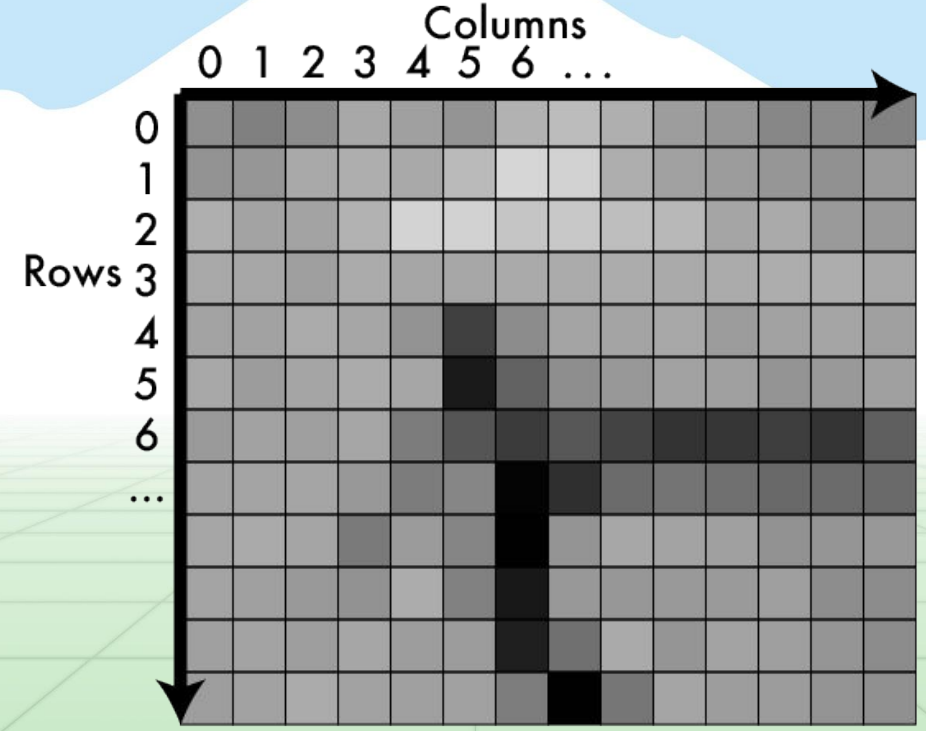
How do we record color?



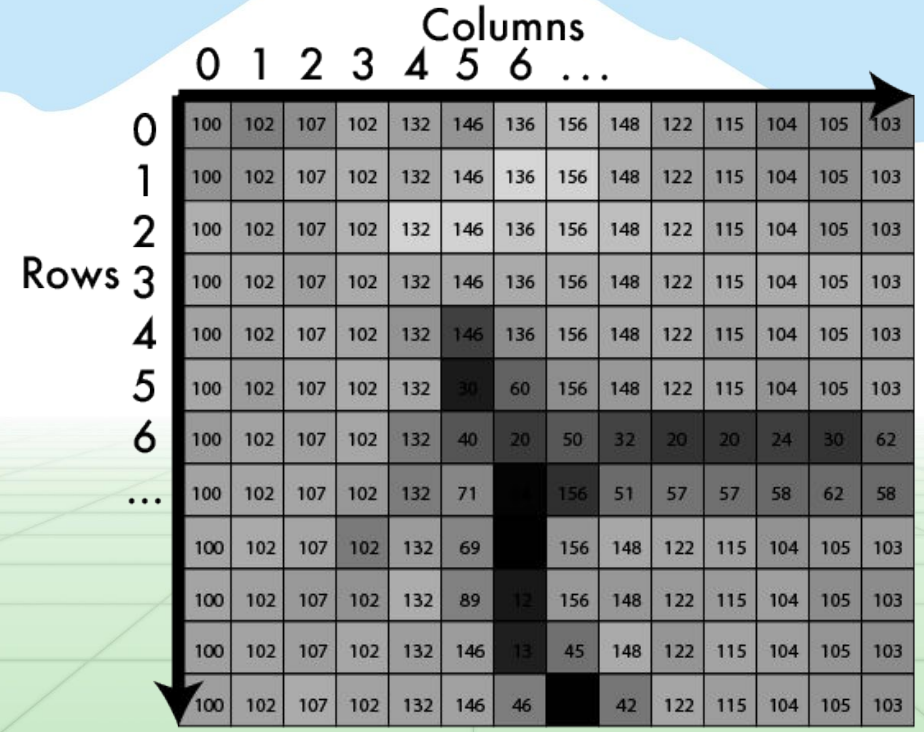
Bayer pattern for CMOS sensors



An image is a matrix of light

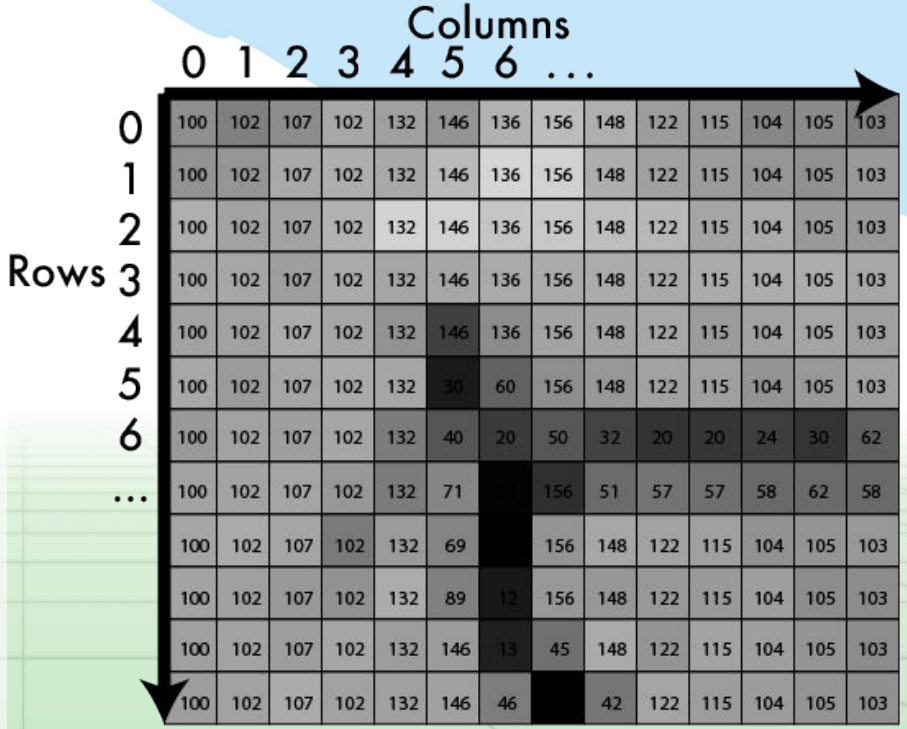


Values in matrix = how much light



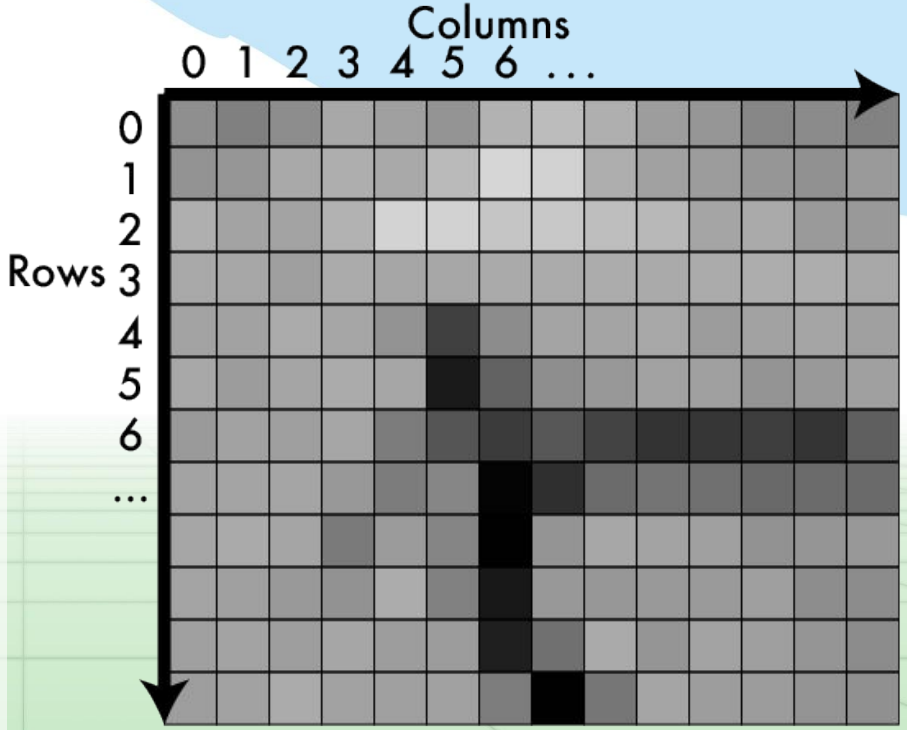
Values in matrix = how much light

- Higher = more light
- Lower = less light
- Bounded
  - No light = 0
  - Sensor/device limit = max
  - Typical ranges:
    - [0-255], fit into byte
    - [0-1], floating point
- Called pixels

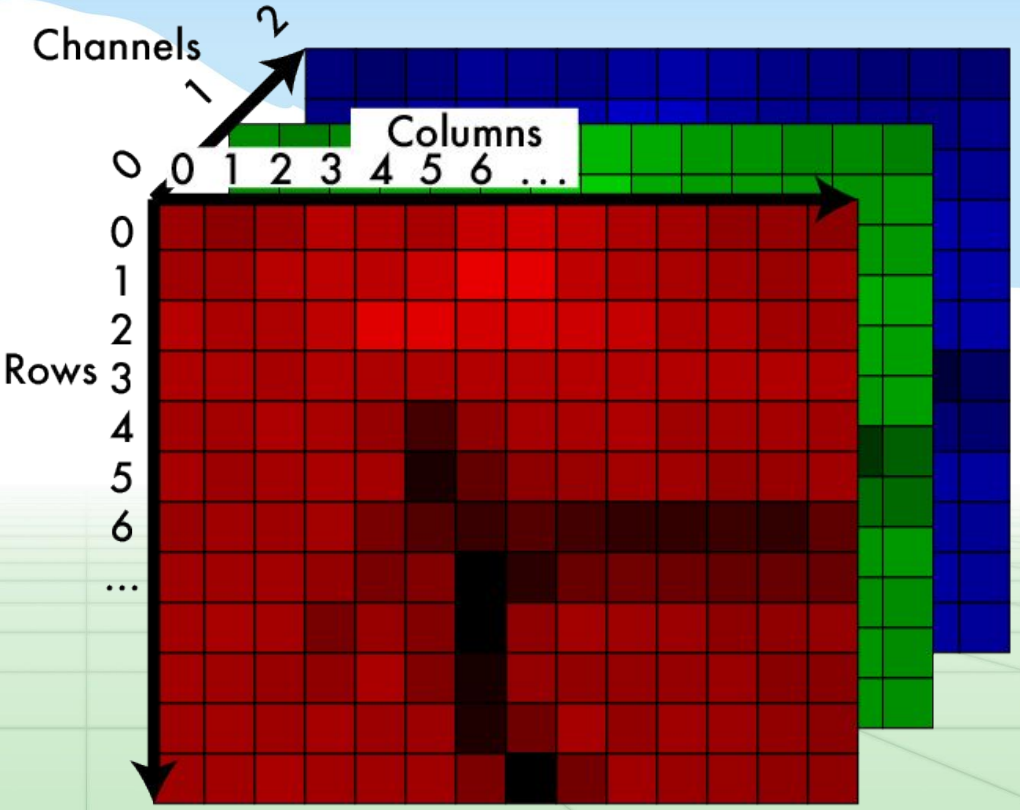


Addressing pixels

- Ways to index:
  - (x,y)
    - Like cartesian coordinates
    - (3,6) is column 3 row 6
  - (r,c)
    - Like matrix notation
    - (3,6) is row 3 column 6
- I use (x,y)
  - So does your homework!
  - Arbitrary
  - Only thing that matters is consistency



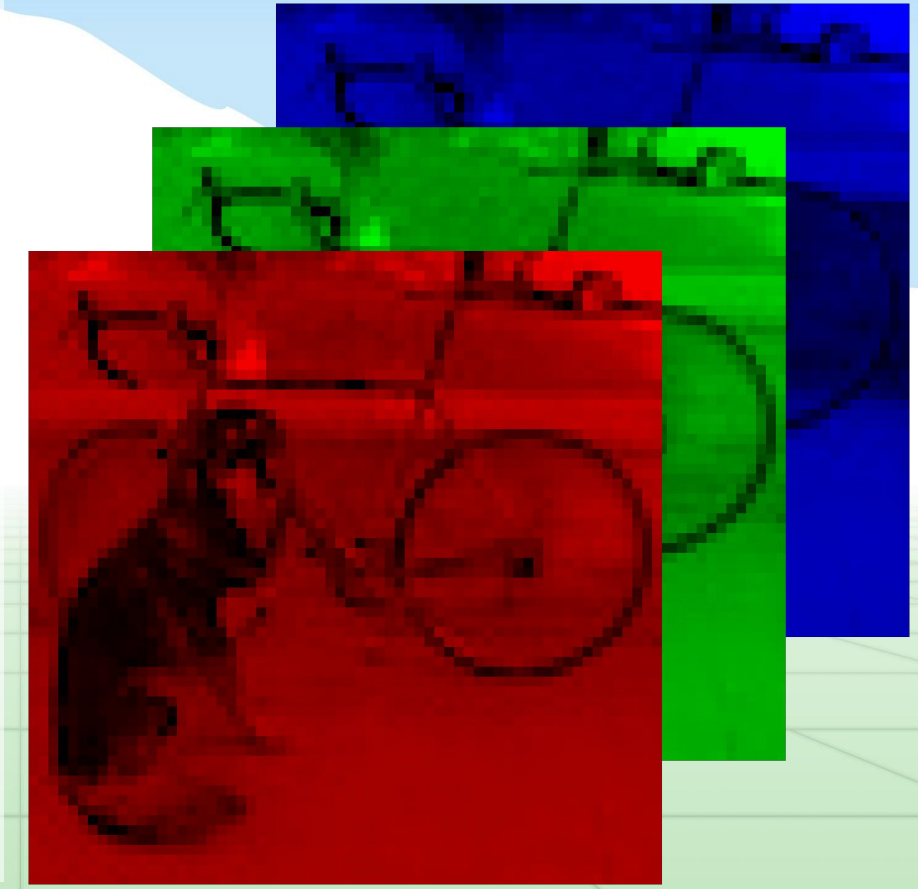
Color image: 3d tensor in colorspace



RGB information in separate “channels”

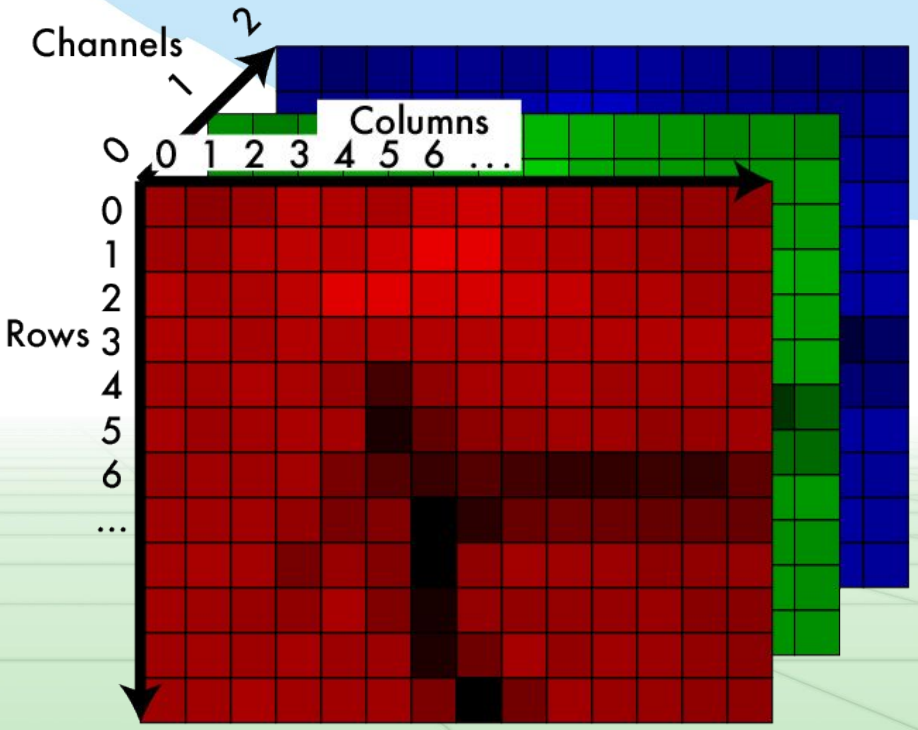
Remember: we can match “real” colors using a mix of primaries.

Each channel encodes one primary. Adding the light produced from each primary mimics the original color.

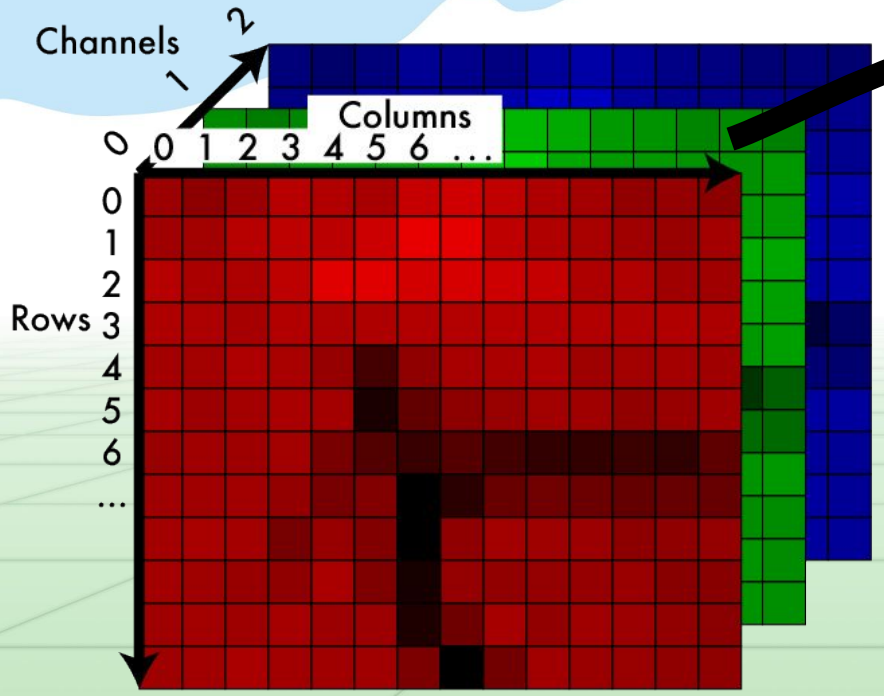


Addressing pixels

- I use (x,y,c)
  - (1,2,0):
    - column 1, row 2, channel 0
- Still doesn’t matter, just be consistent
- But do what I do for homeworks :-)
- Also for size:
  - 1920 x 1080 x 3 image:
    - 1920 px wide
    - 1080 px tall
    - 3 channels

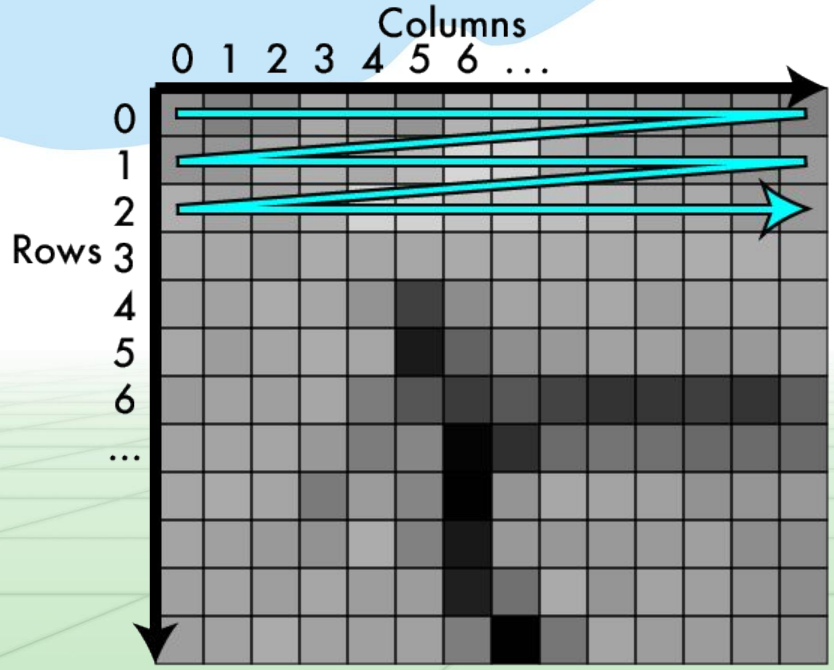


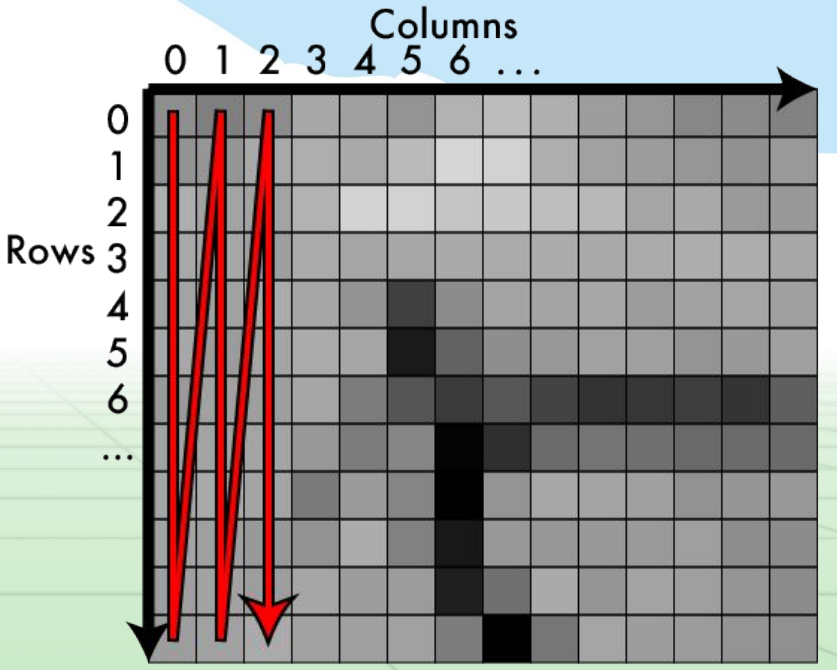
How do we store them?



129	131	152	159	135	163	142	82	182	...

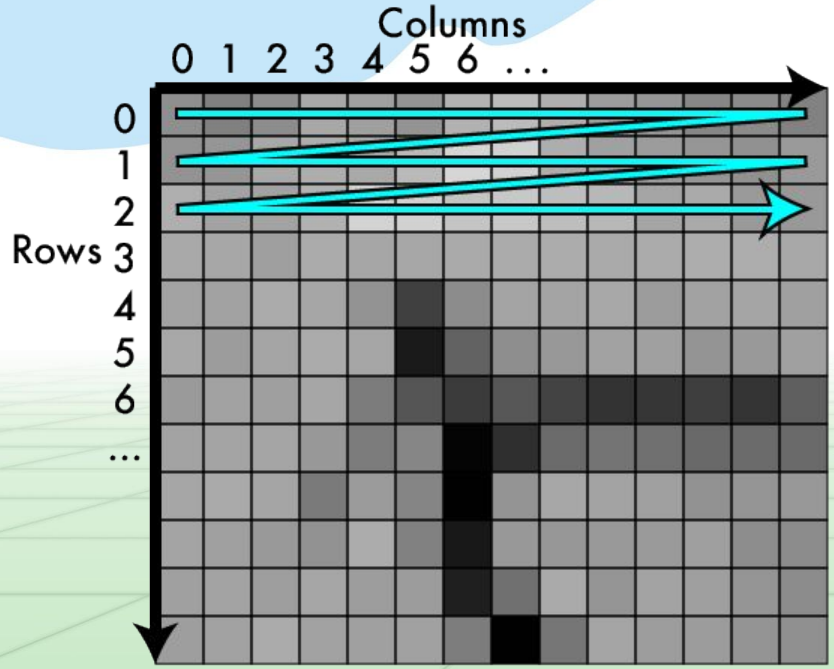
Storage: row major vs column major



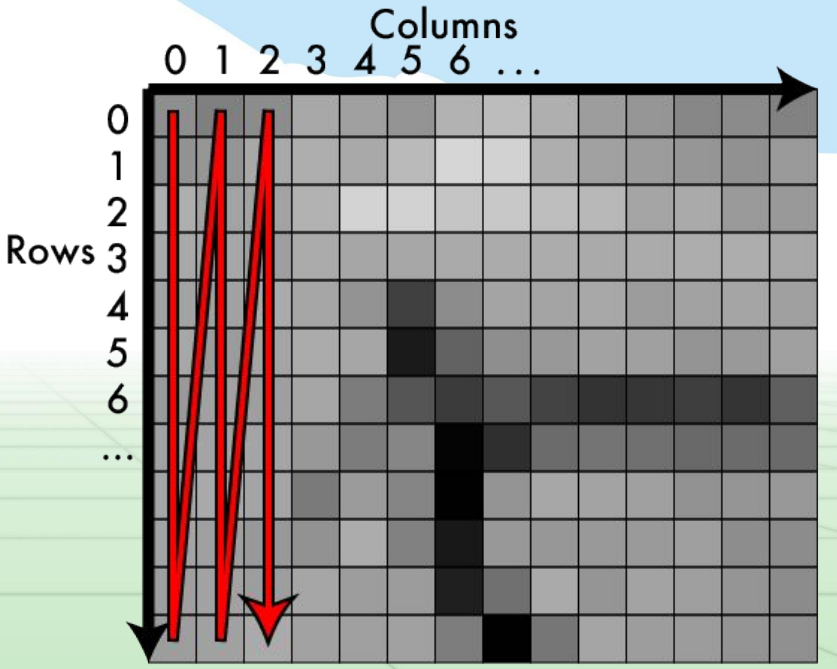


Storage: row major vs column major

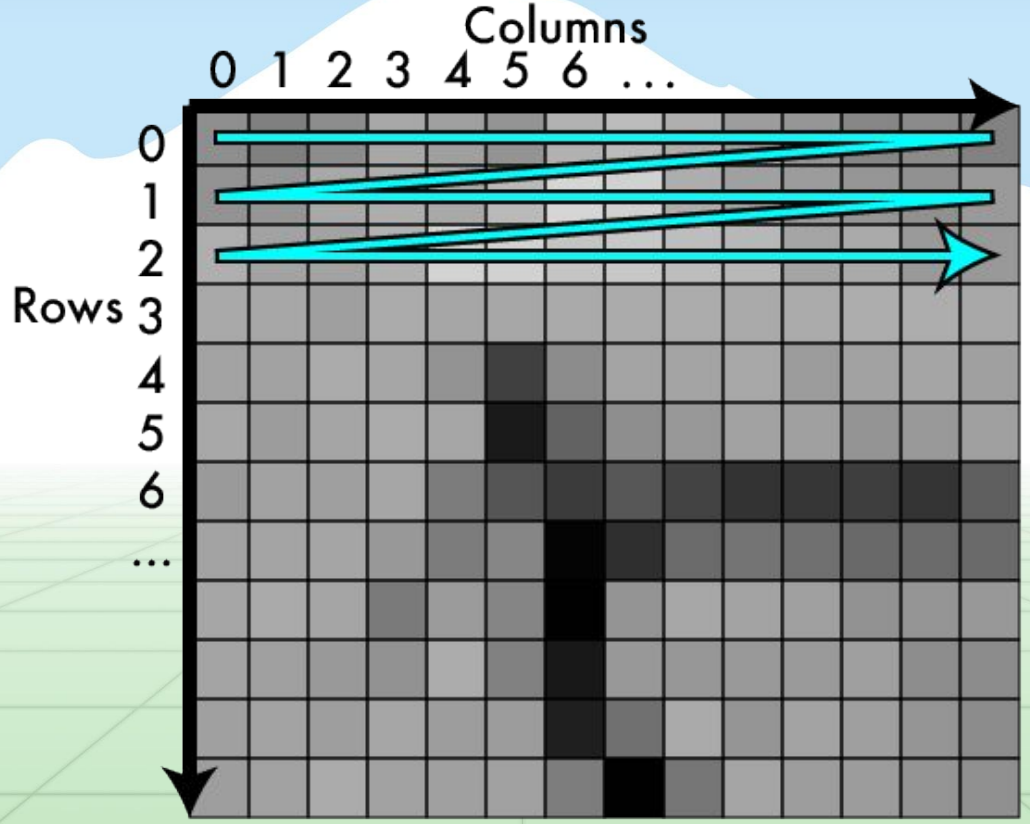
HW



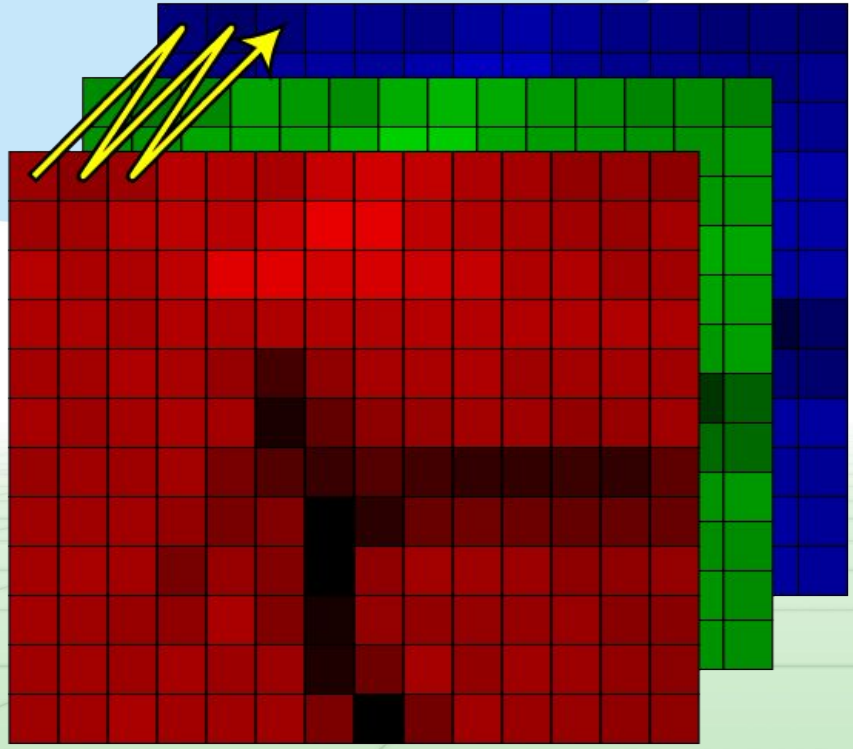
WH

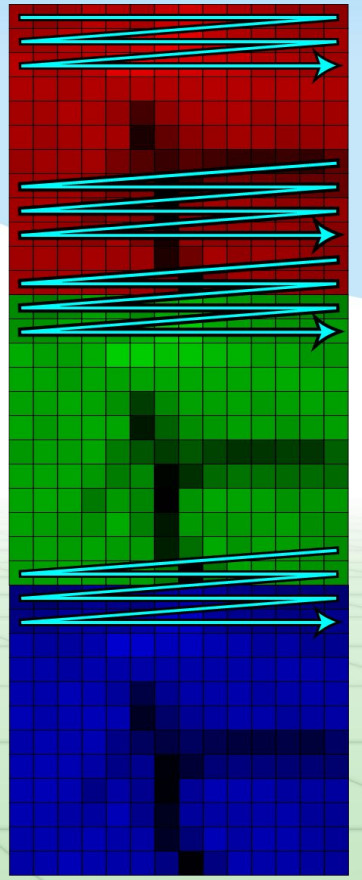


Typically use row-major or HW

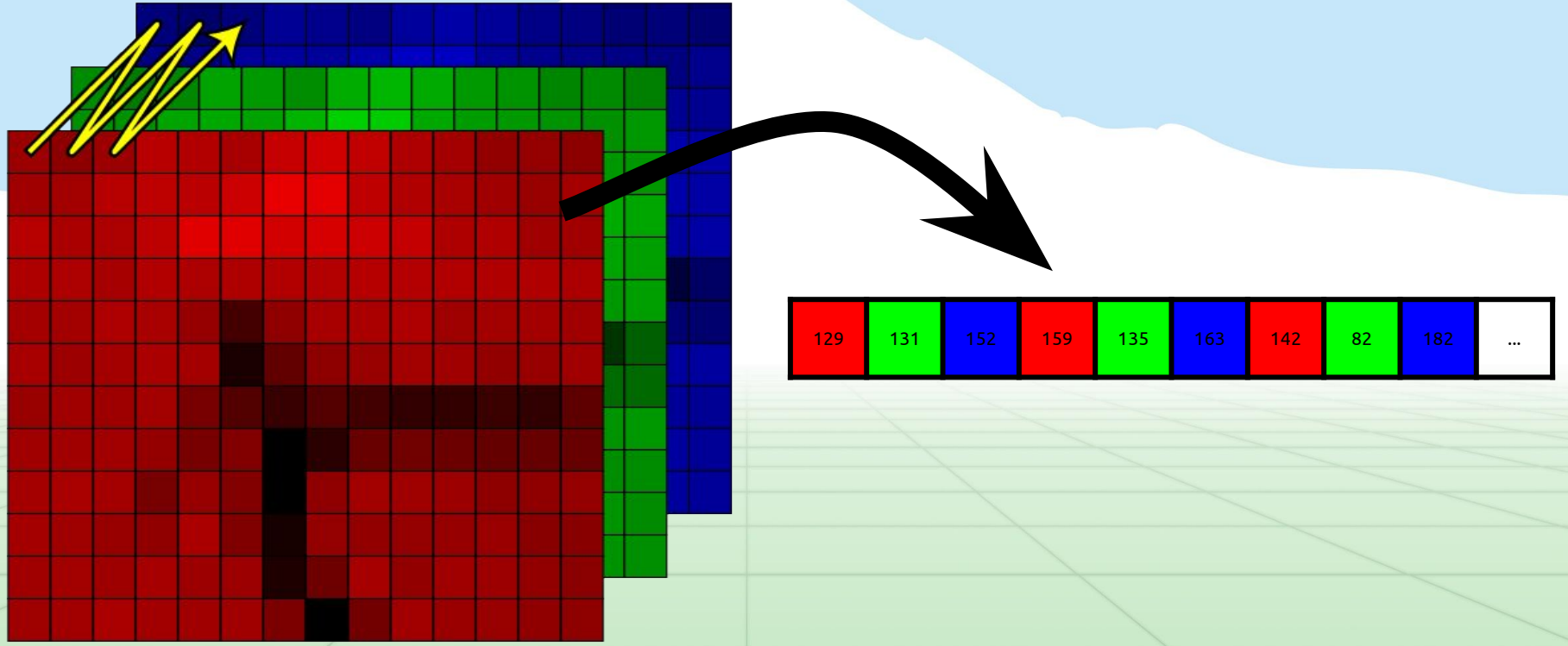


In 3d we have more choices!

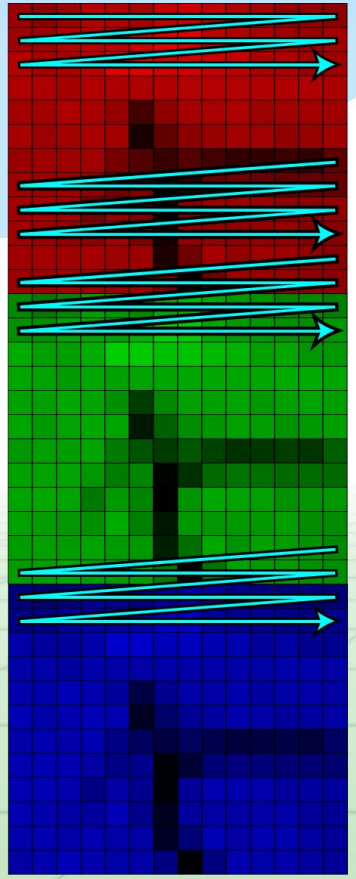


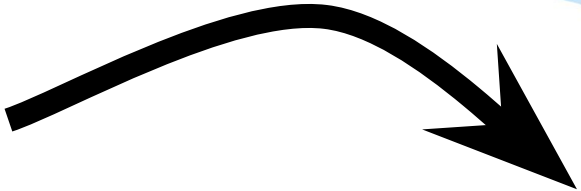


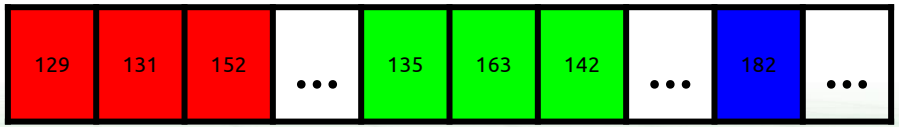
HWC: channels interleaved



CHW: channels separated





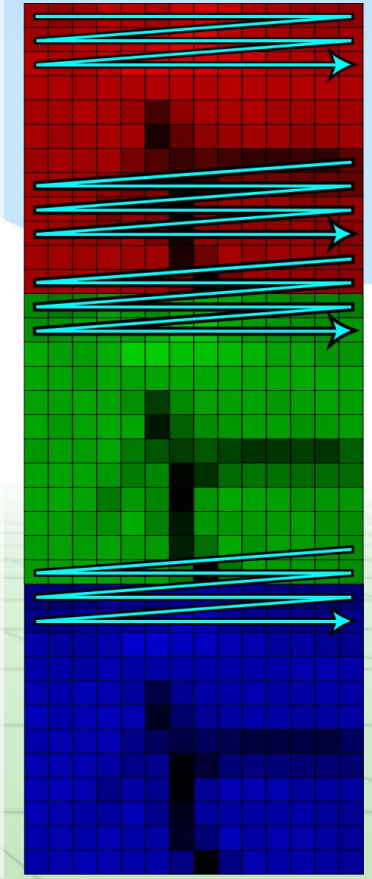


CHW Pop quiz

We'll use CHW, it's what a lot of other libraries use.

In an array for a 1920 x 1080 x 3 image what entry would contain the pixel (15,192,2)?

In groups, discuss for 2 minutes.



CHW Pop quiz

In an array for a 1920 x 1080 x 3 image what entry would contain the pixel (15,192,2)?

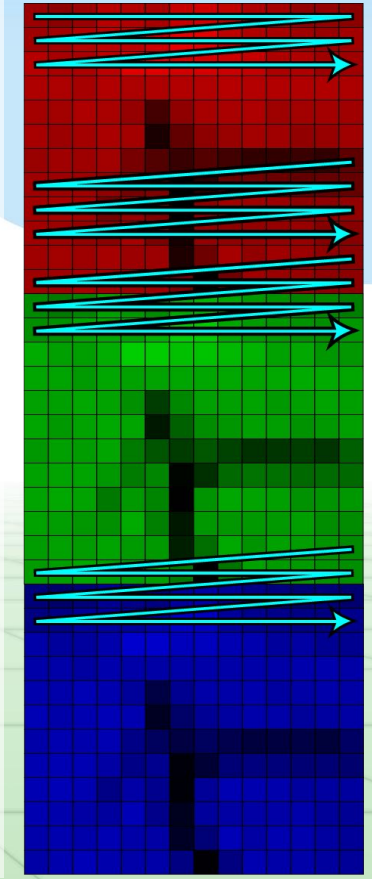
In general for (x,y,z) of image (W,H,C)

x + y*W + z*W*H

15 + 192*1920 + 2*1920*1080 = 4,515,855

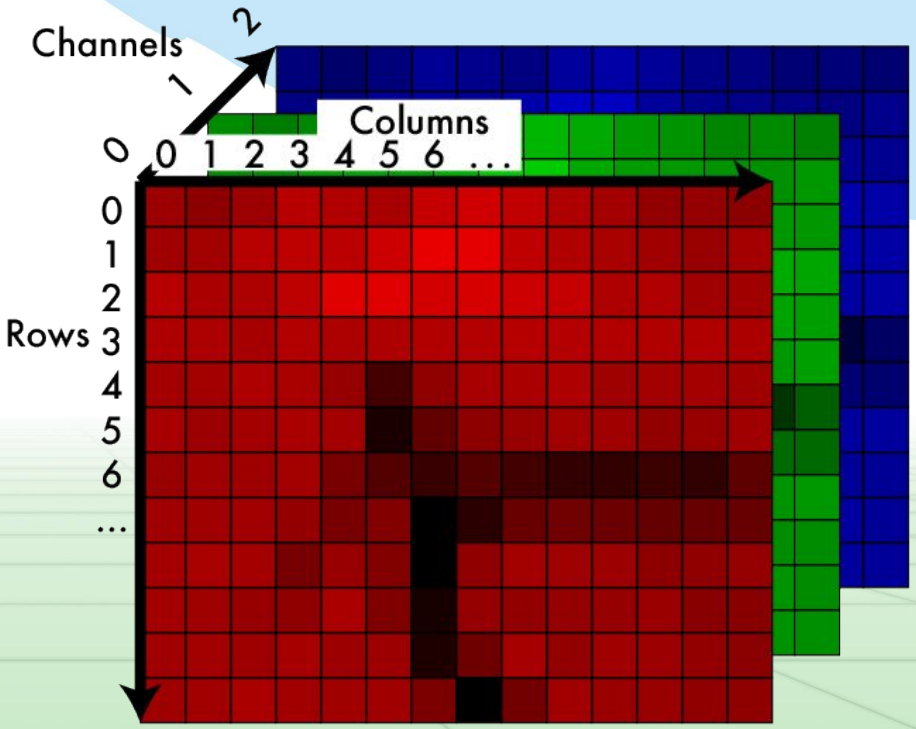
Remember, everything is 0 indexed

This isn’t MATLAB 🙃



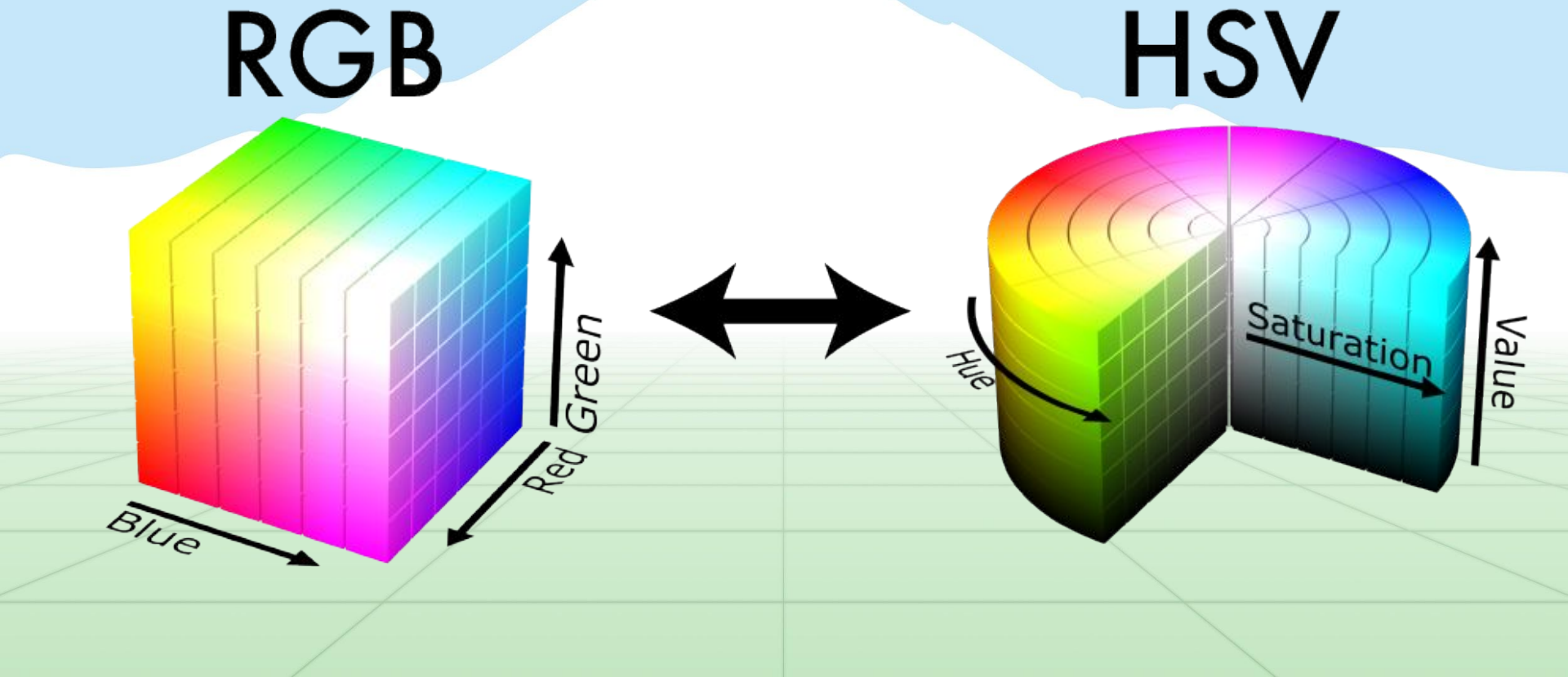
In your homework

```
typedef struct {
    int w,h,c;
    float *data;
} image;
```

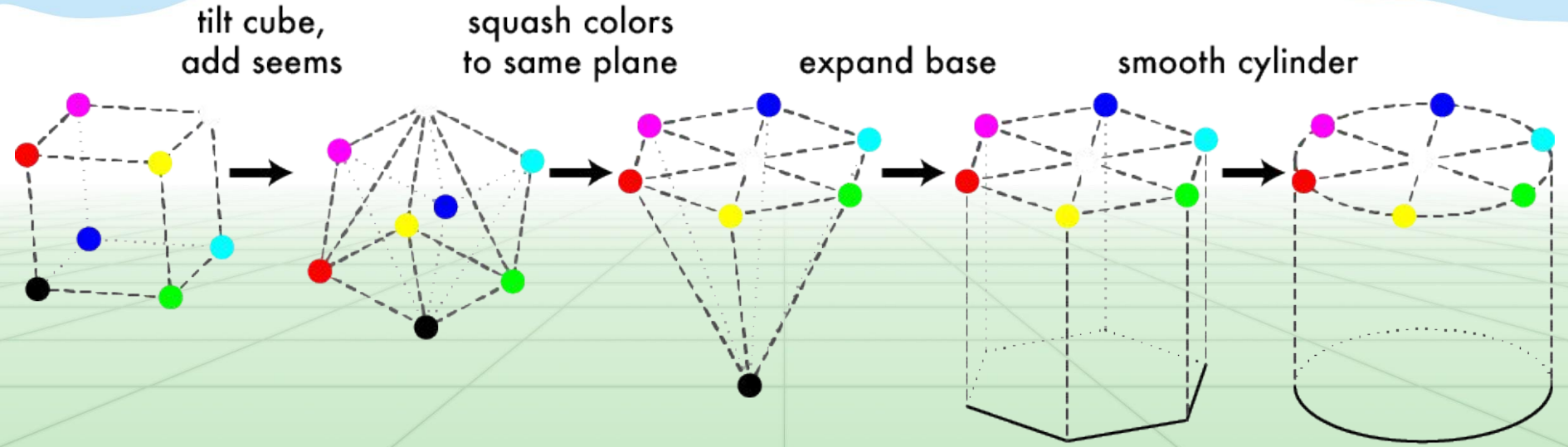


Fun with other colorspaces!

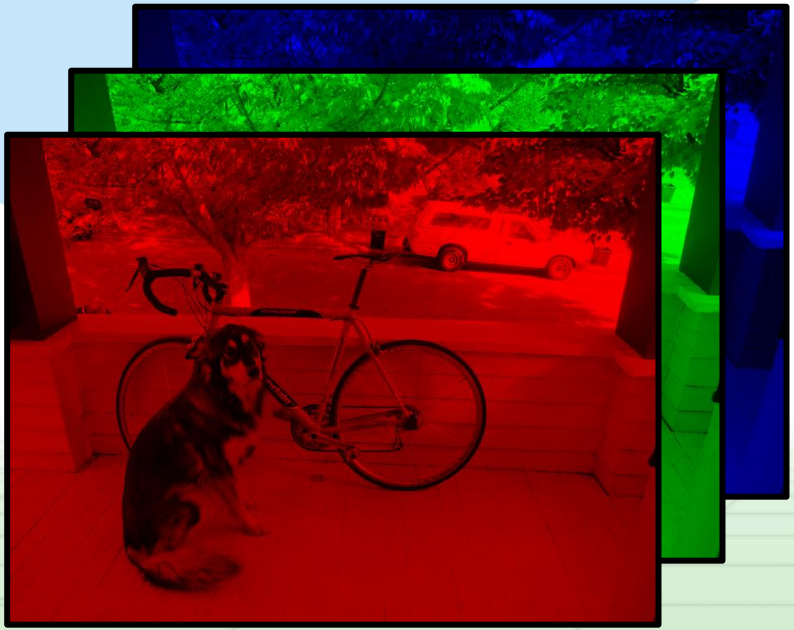
Other colorspaces are fun!

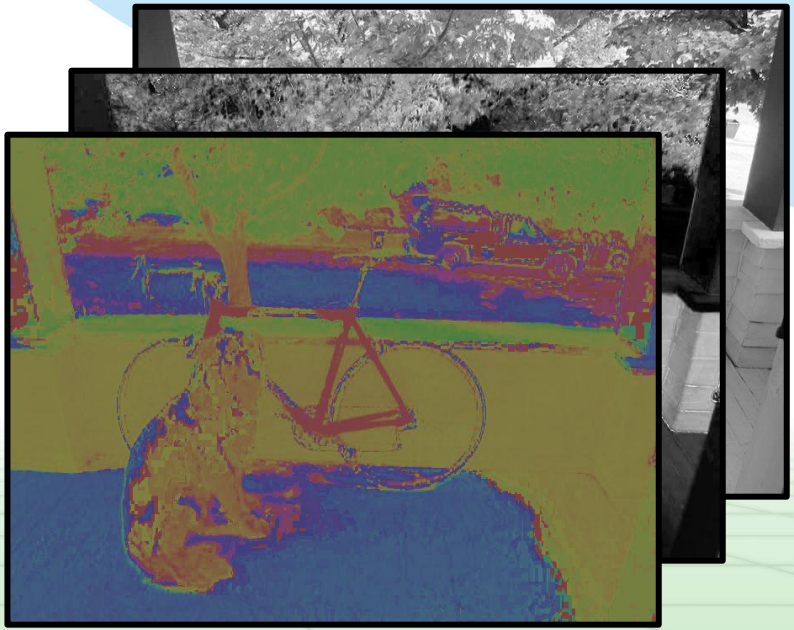


Geometric HSV to RGB:

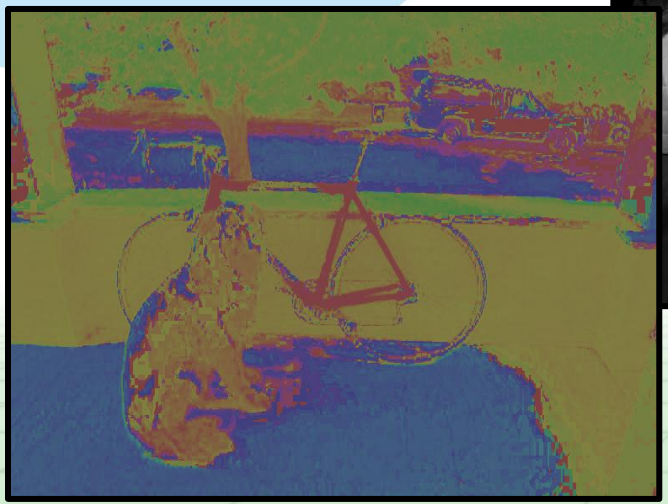


Still 3d tensor, different info

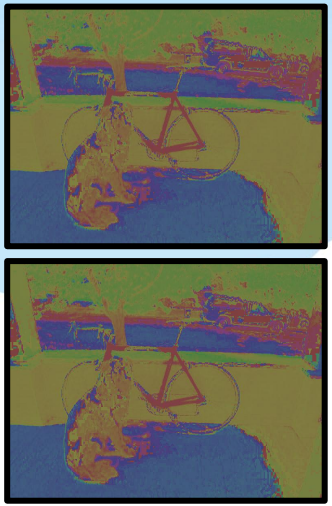




Hue Saturation Value

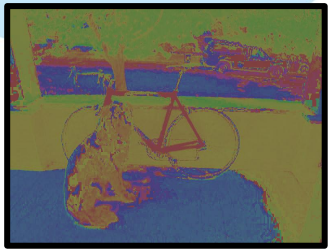


More saturation = intense colors



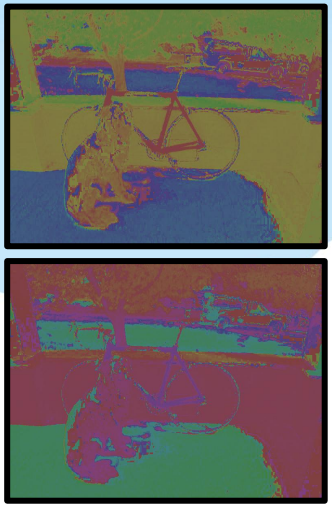
2x

More value = lighter image

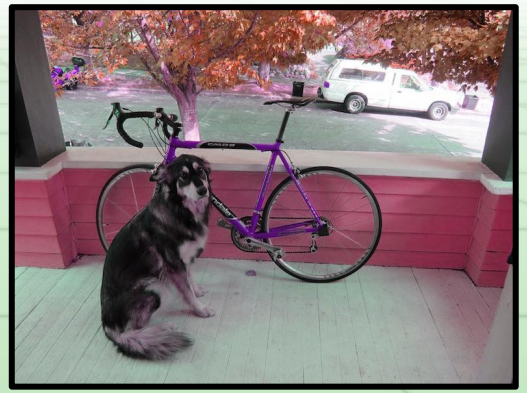


2x

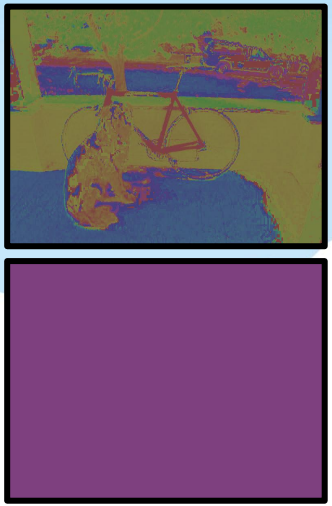
Shift hue = shift colors



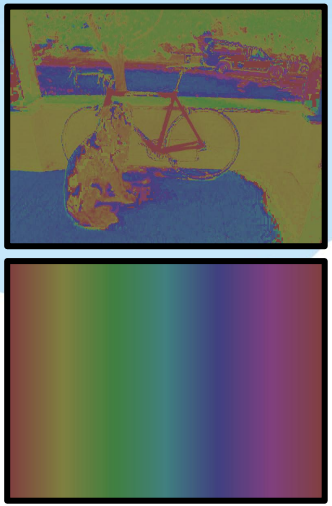
-.2



Set hue to your favorite color!



Or pattern...



Increase and threshold saturation

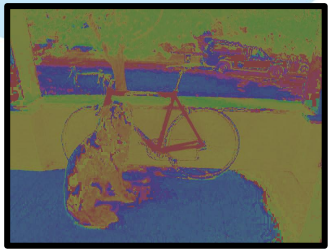


Image interpolation and resizing

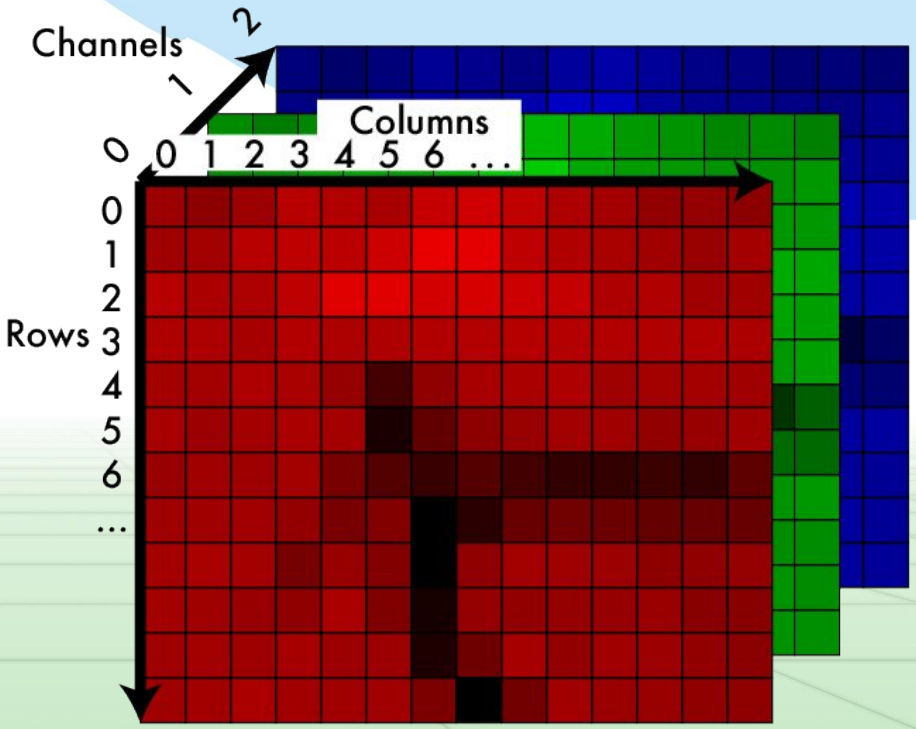
An image is kinda like a function

An image is a mapping from indices to pixel value:

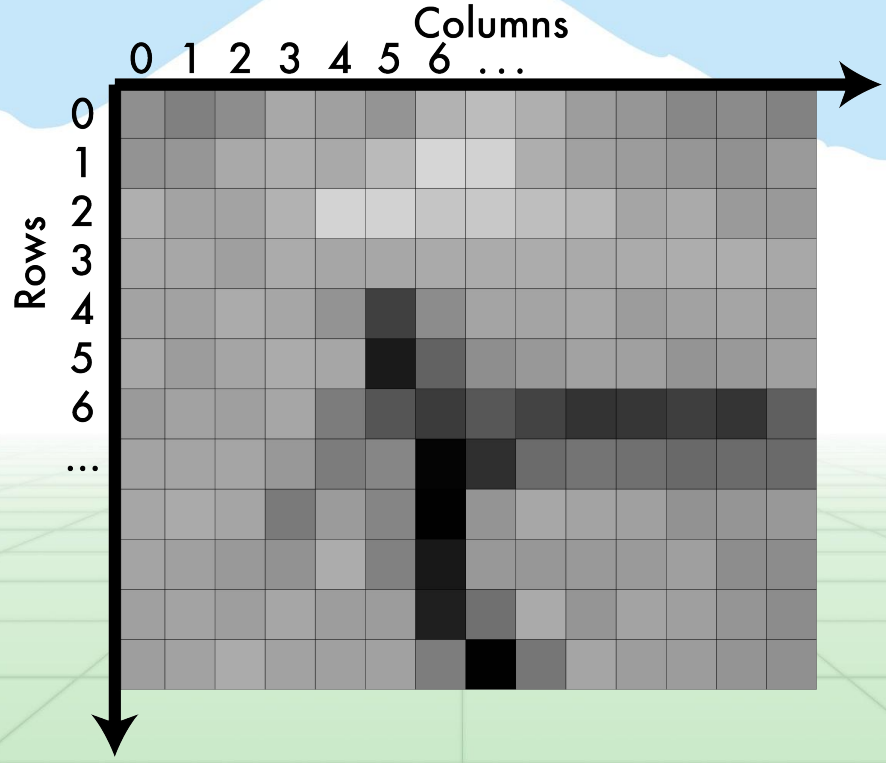
- Im: I x I x I -> R

We may want to pass in non-integers:

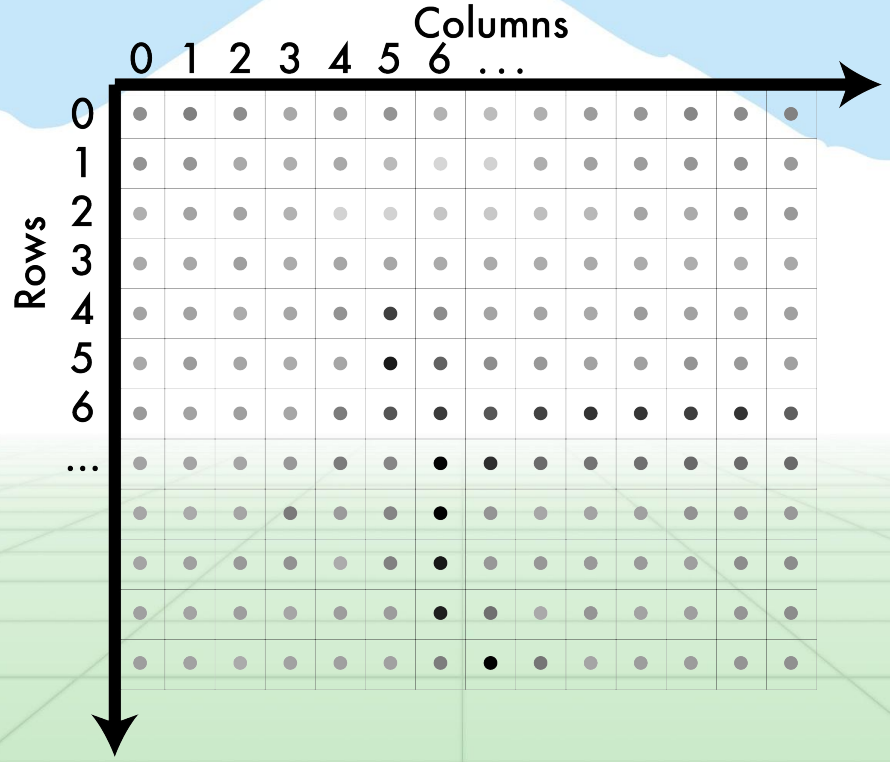
- Im’: R x R x I -> R



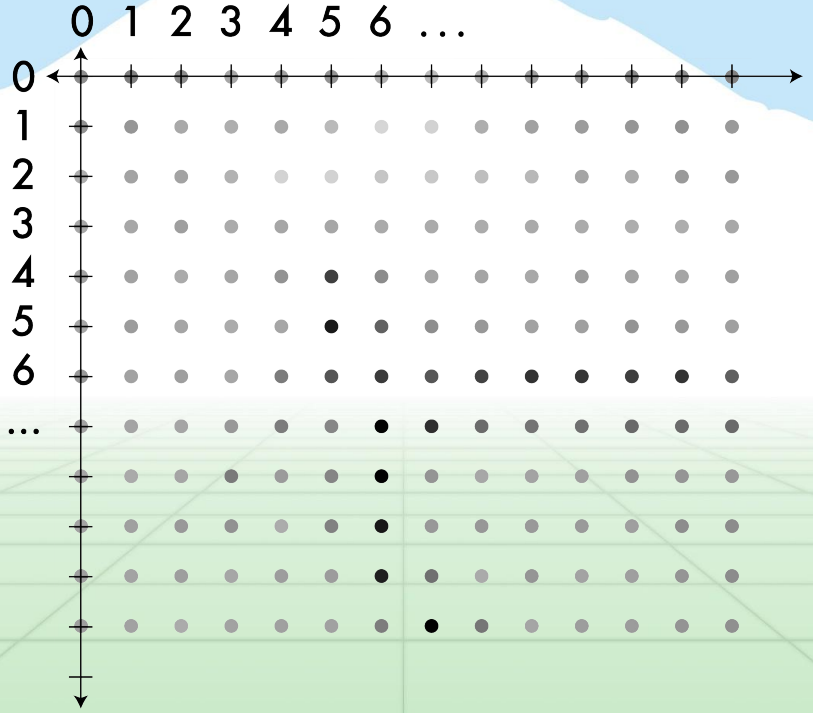
A note on coordinates in images



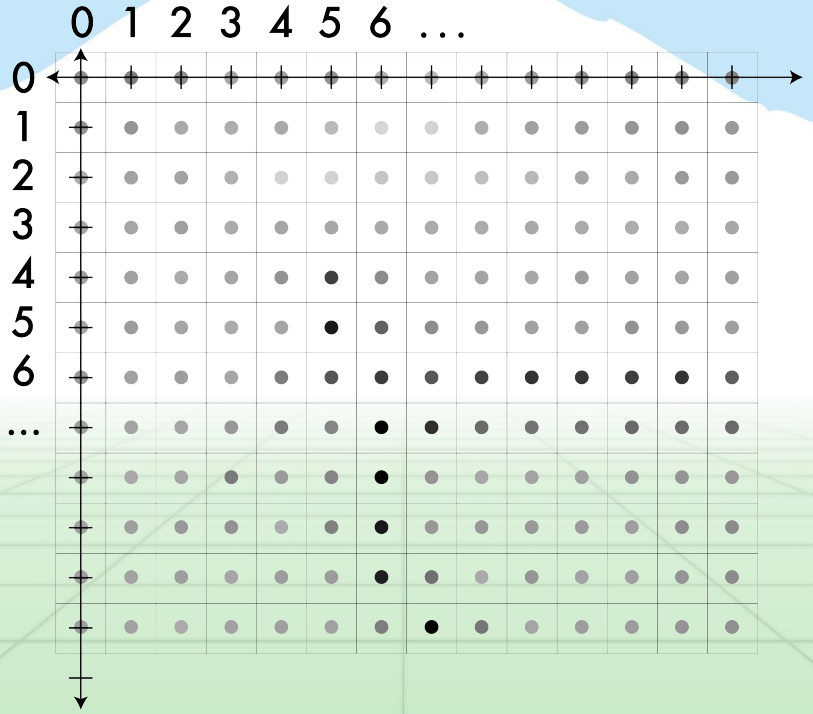
A note on coordinates in images



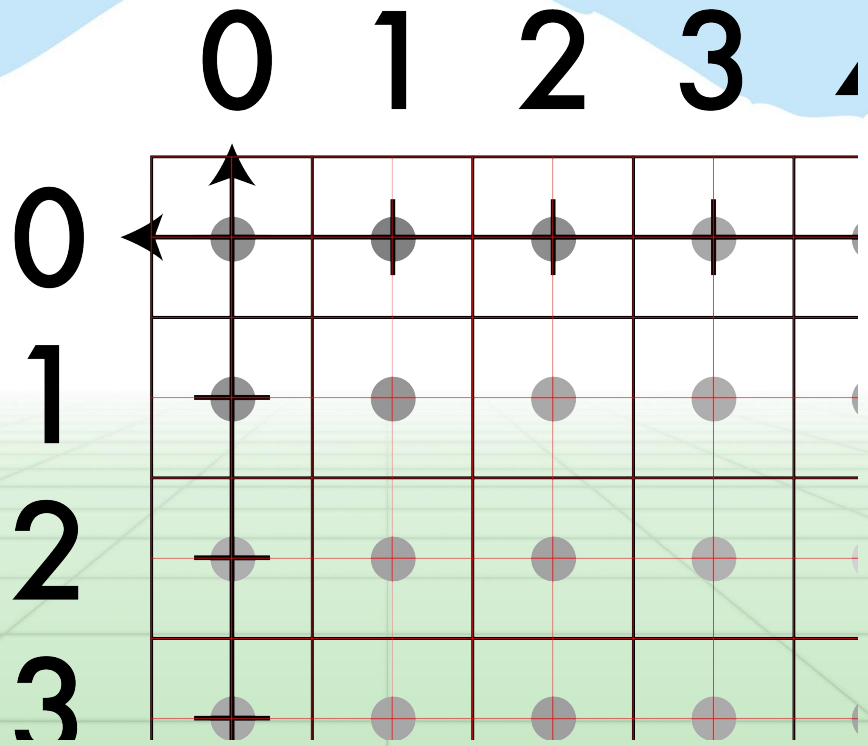
A note on coordinates in images



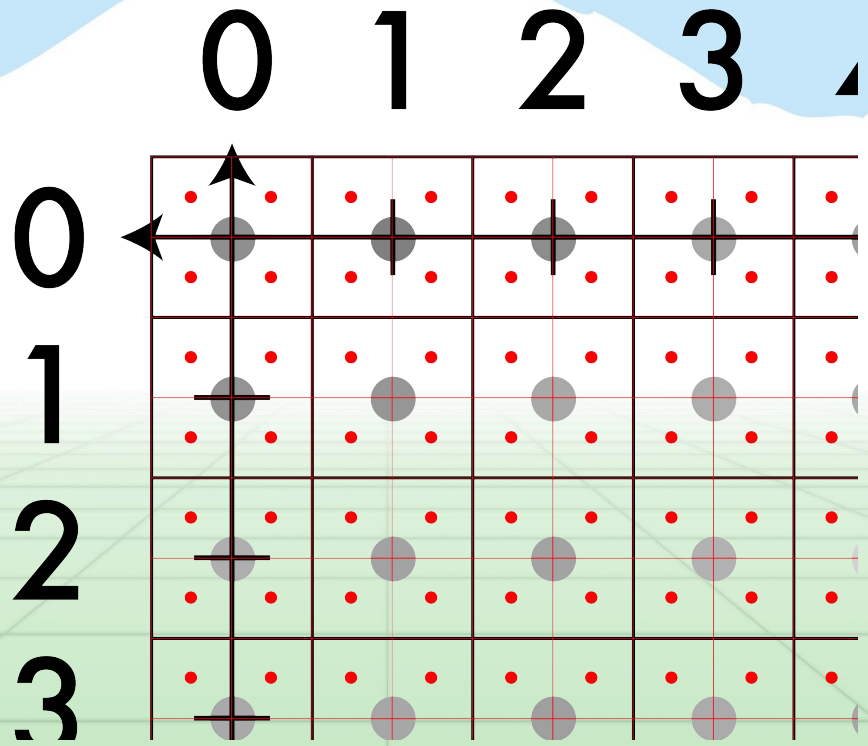
A note on coordinates in images



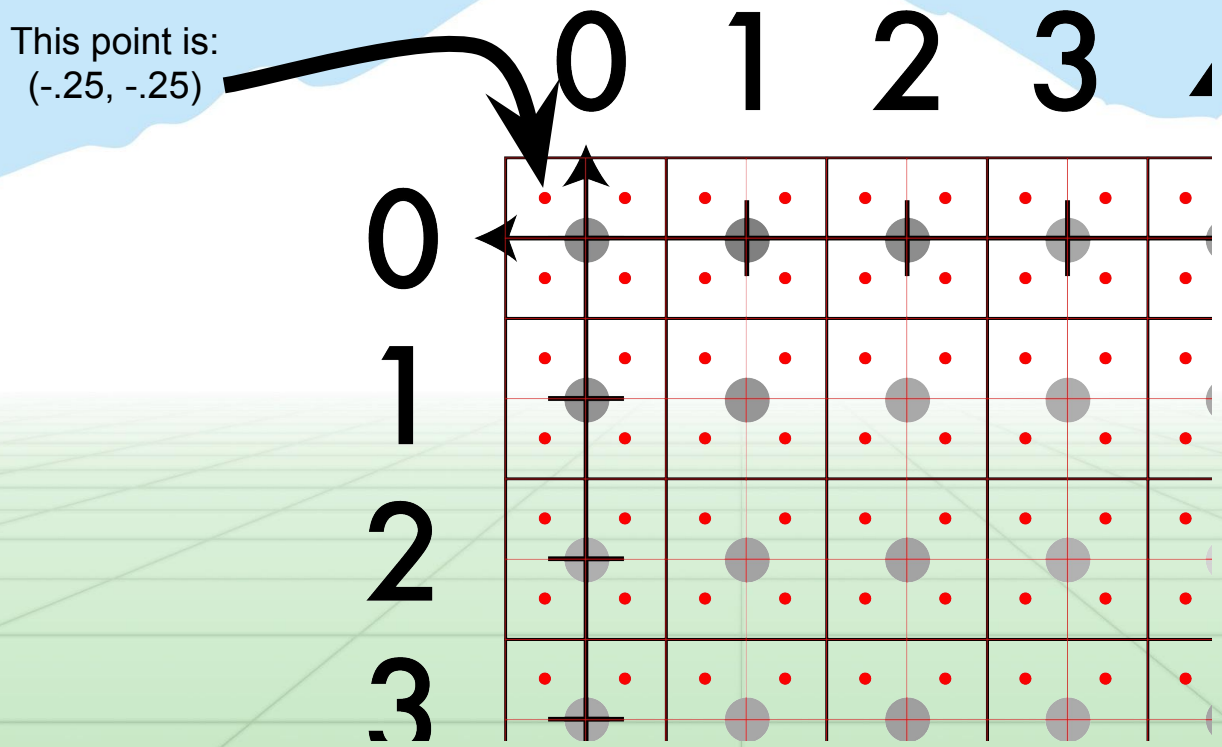
A note on coordinates in images



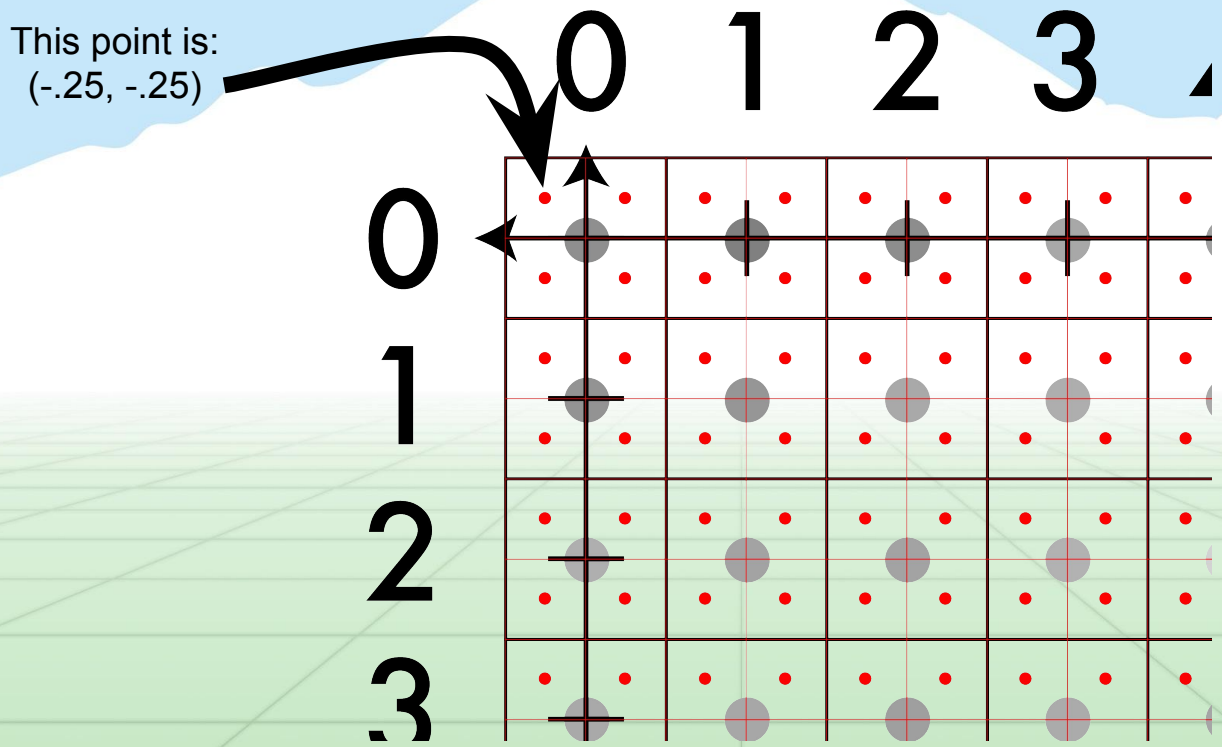
A note on coordinates in images



A note on coordinates in images



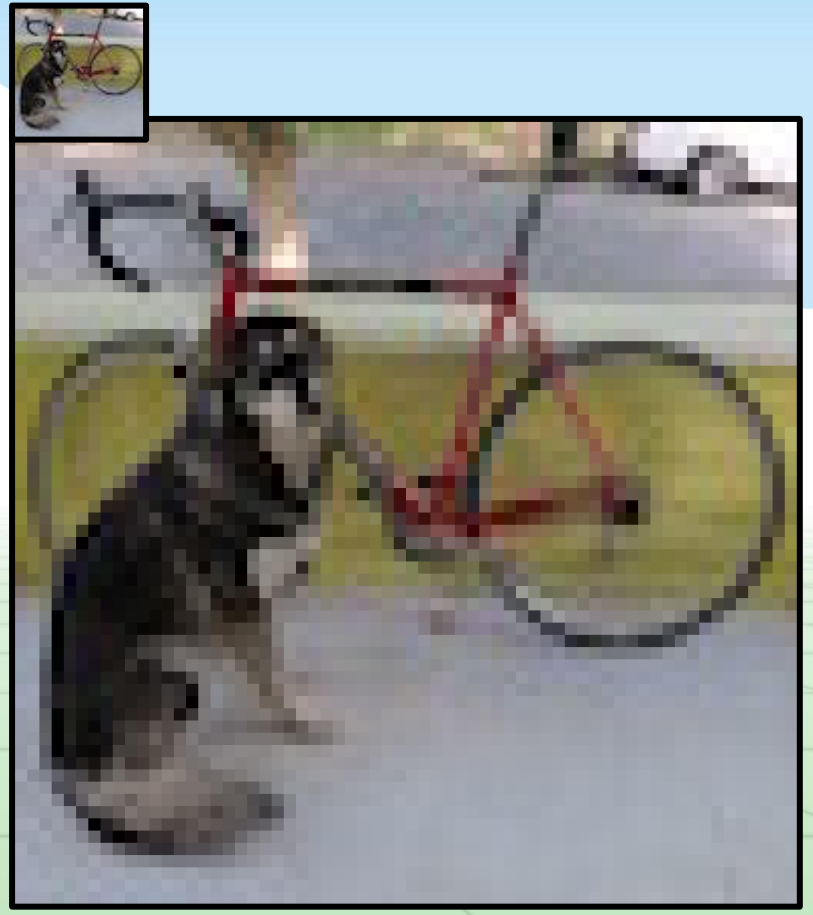
Just be careful, lots of pitfalls



Nearest neighbor: what it sounds like

```
f(x,y,z) = Im(round(x), round(y), z)
```

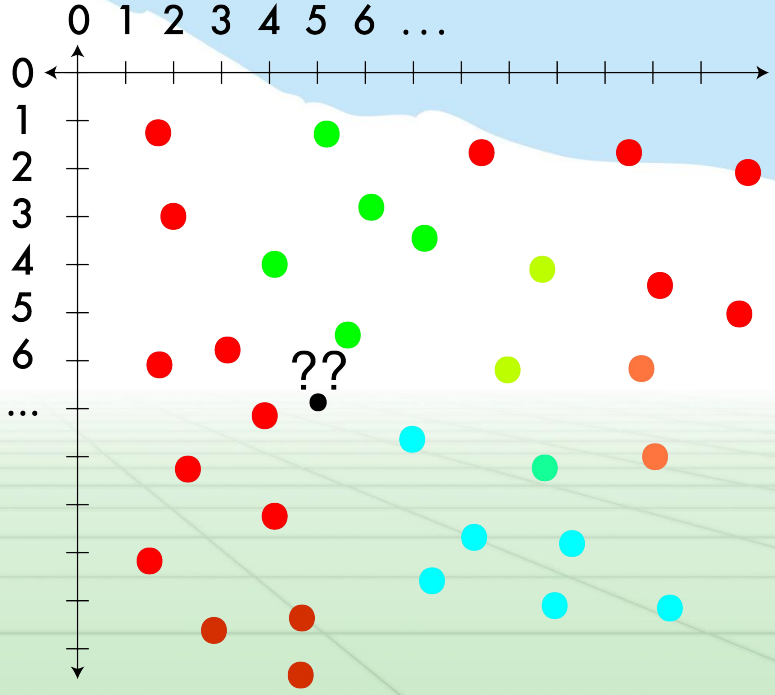
- Looks blocky
- Common pitfall:
  Integer division
  rounds down in C
- Note: z is still int



Triangle interpolation: for less structured image

Sometimes you have a regular grid, sometimes you don’t.

When you don’t look for triangles!



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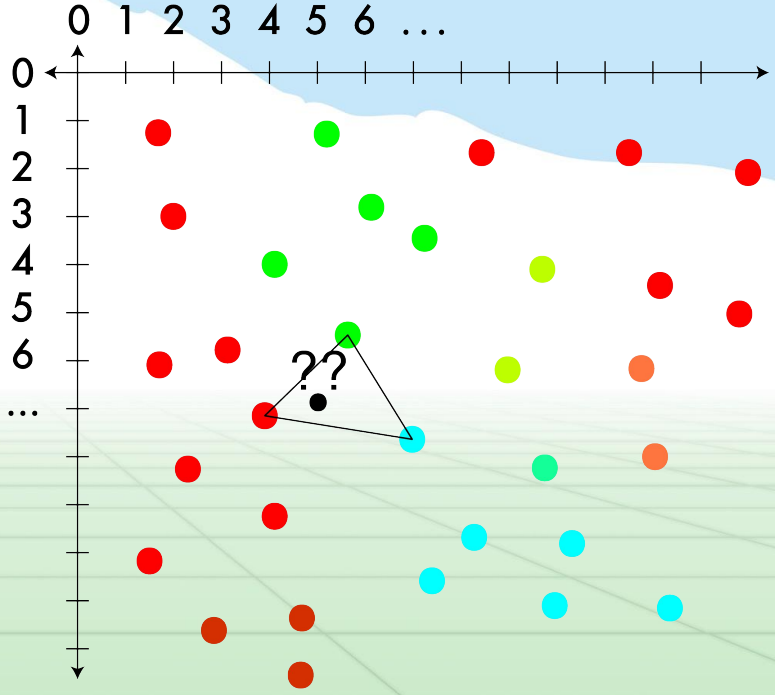

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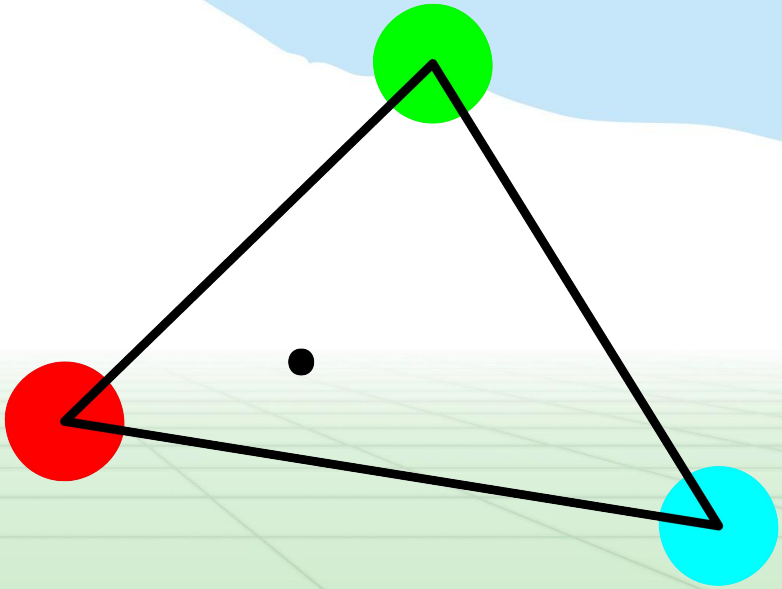
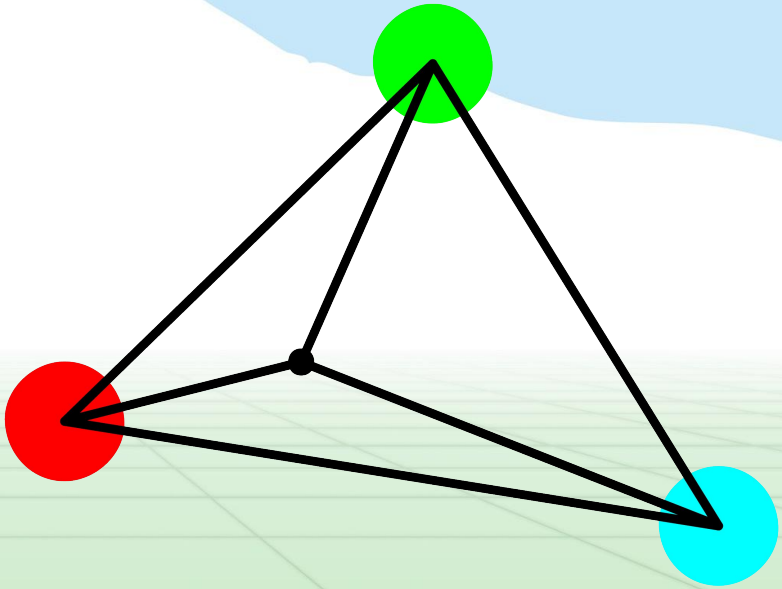


Triangle interpolation: for less structured image

Sometimes you have a regular grid, sometimes you don’t.

When you don’t look for triangles!

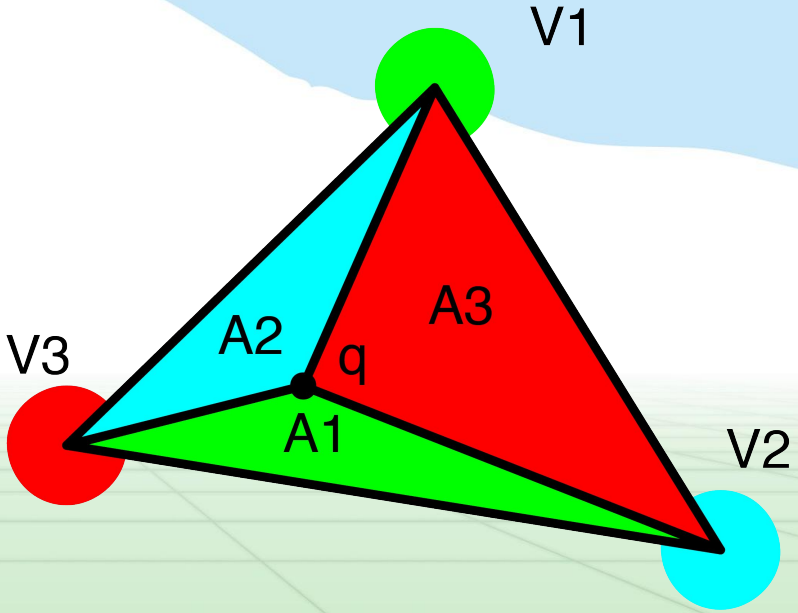


Triangle interpolation: for less structured image

Weighted sum using of triangles:

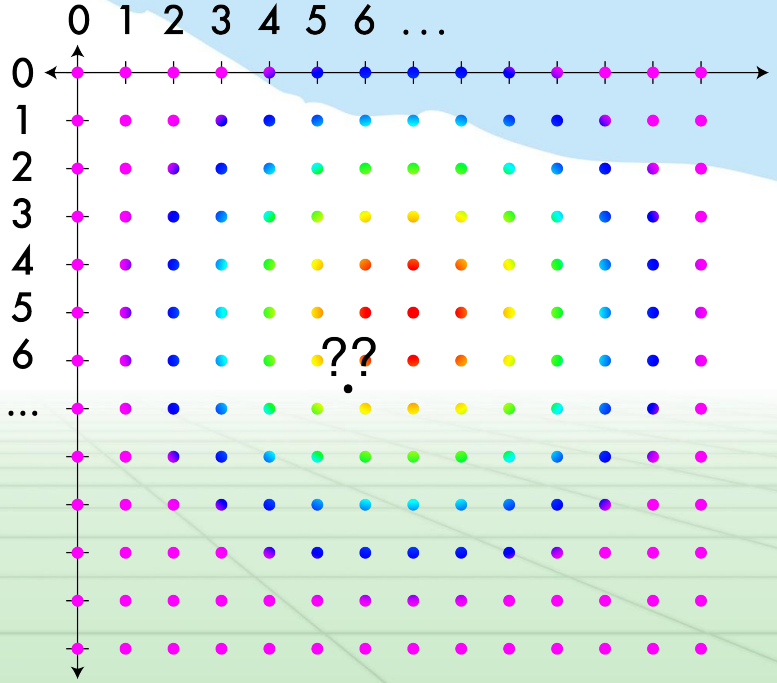
Q = V1*A1 + V2*A2 + V3*A3

Should normalize this based on total area



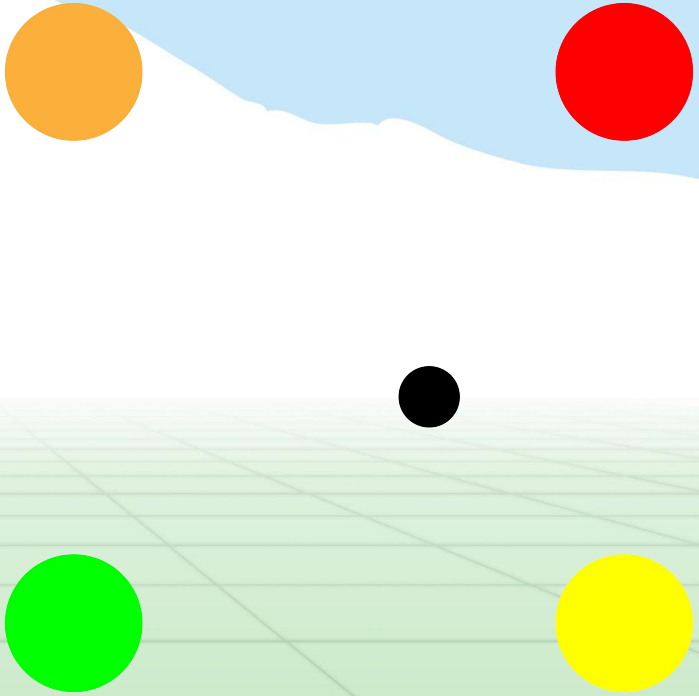
Bilinear interpolation: for grids, pretty good

This time find the closest pixels in a box



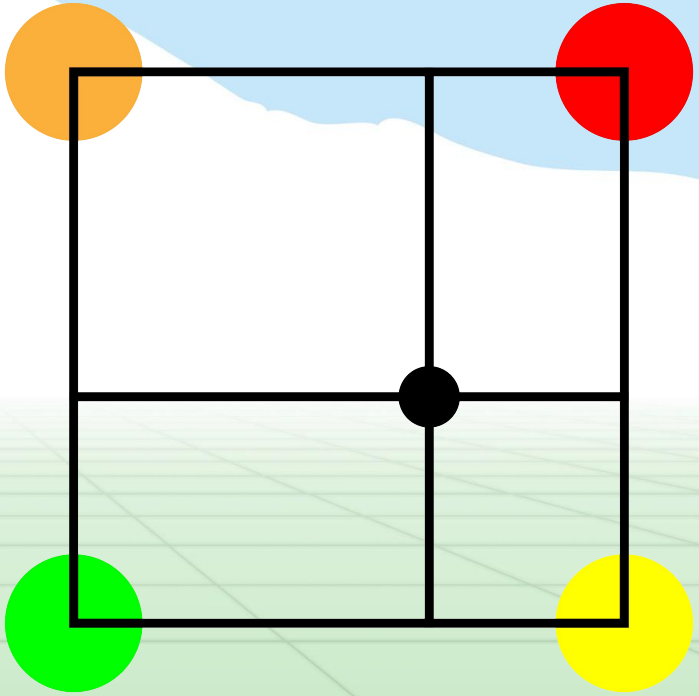
Bilinear interpolation: for grids, pretty good

This time find the
closest pixels in a box



Bilinear interpolation: for grids, pretty good

This time find the closest pixels in a box



Bilinear interpolation: for grids, pretty good

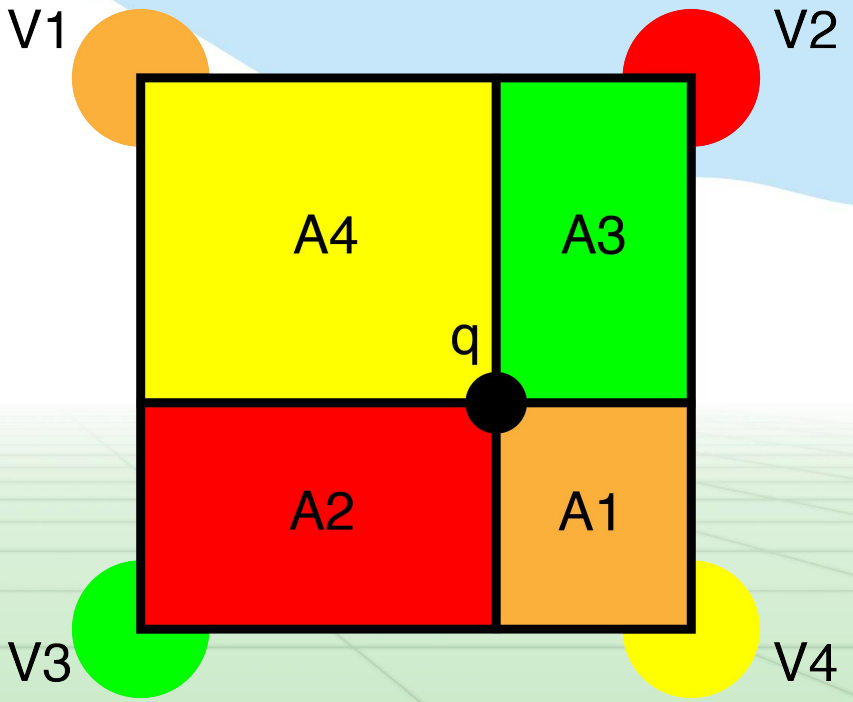
This time find the closest pixels in a box

Same plan, weighted sum based on area of opposite rectangle

$$Q = V1*A1 + V2*A2 + V3*A3 + V4*A4$$

Still need to normalize!

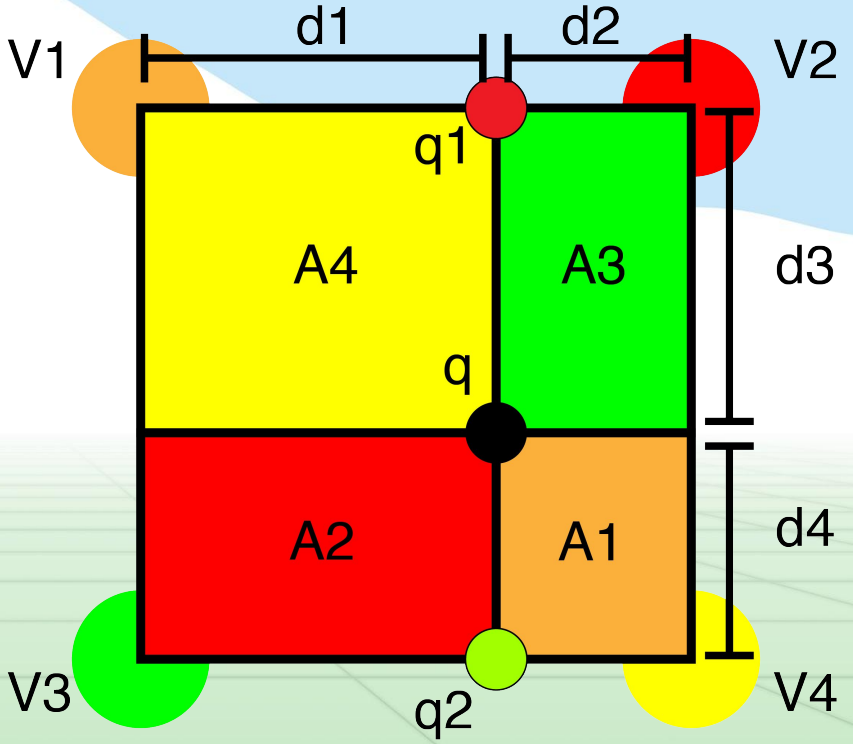
Or do we?



Bilinear interpolation: for grids, pretty good

Alternatively, linear interpolation of linear interpolates

```
q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3
```

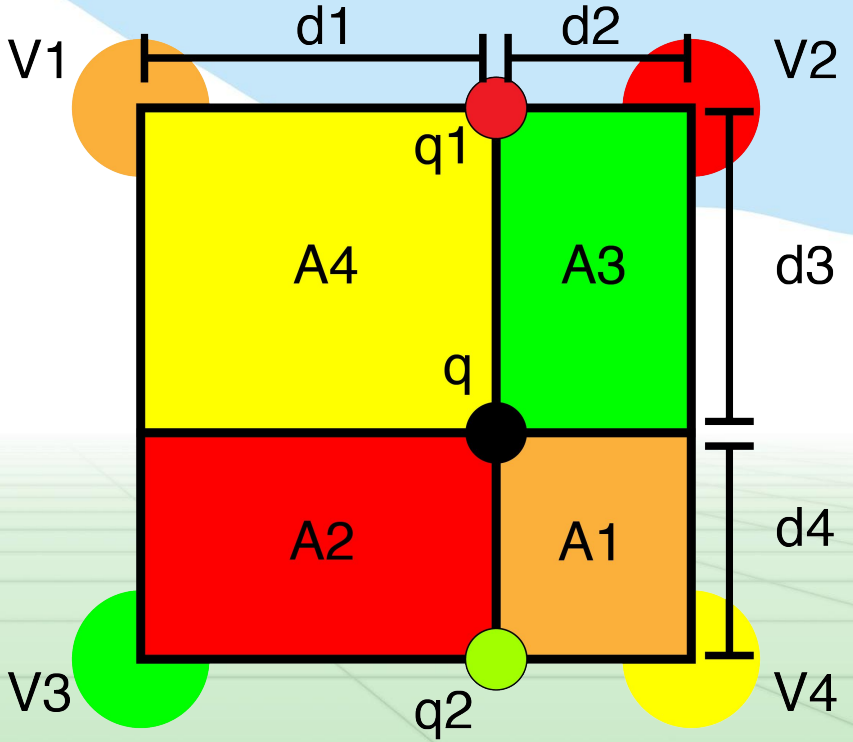


Bilinear interpolation: for grids, pretty good

```
q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3
```

Equivalent:

```
q = q1*d4 + q2*d3
```

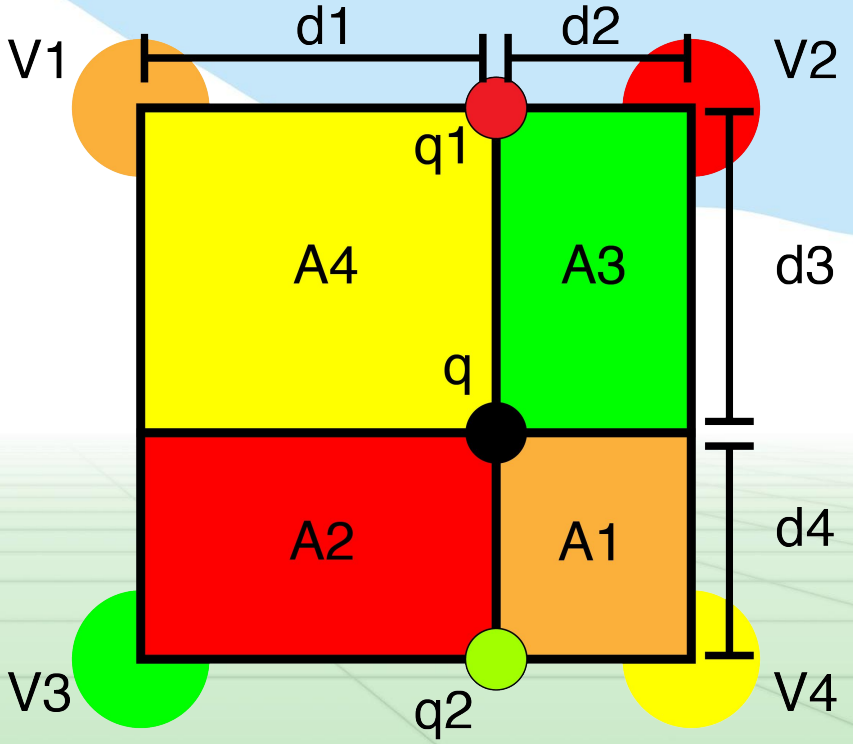


Bilinear interpolation: for grids, pretty good

```
q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3
```

Equivalent:

```
q = q1*d4 + q2*d3
q = (V1*d2 + V2*d1)*d4 + (V3*d2 + V4*d1)*d3 (subst)
```

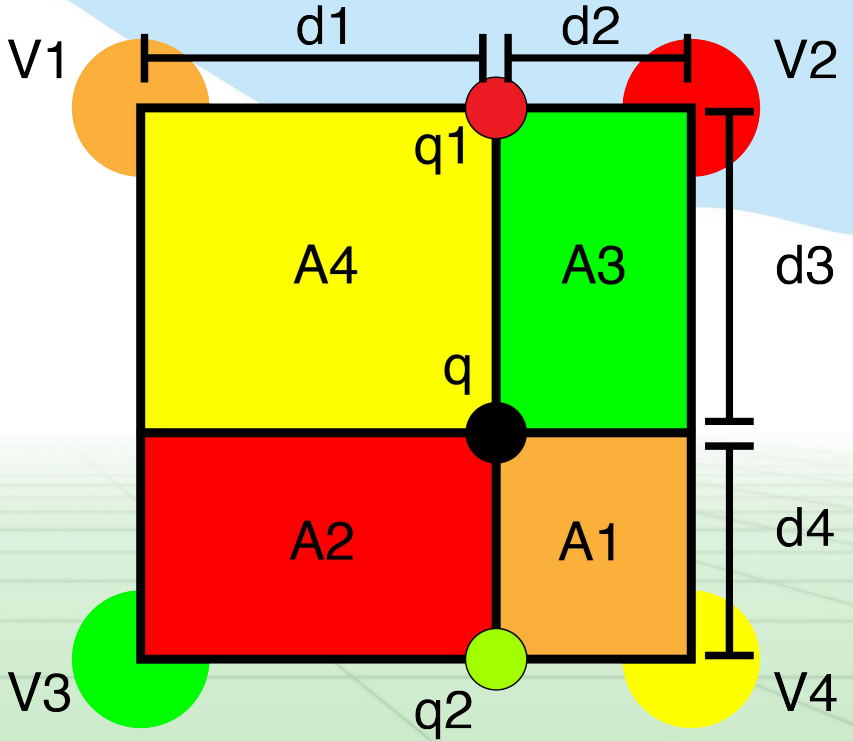


Bilinear interpolation: for grids, pretty good

```
q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3
```

Equivalent:

```
q = q1*d4 + q2*d3
q = (V1*d2 + V2*d1)*d4 + (V3*d2 + V4*d1)*d3 (subst)
q = V1*d2*d4 + V2*d1*d4 + V3*d2*d3 + V4*d1*d3 (distribution)
```



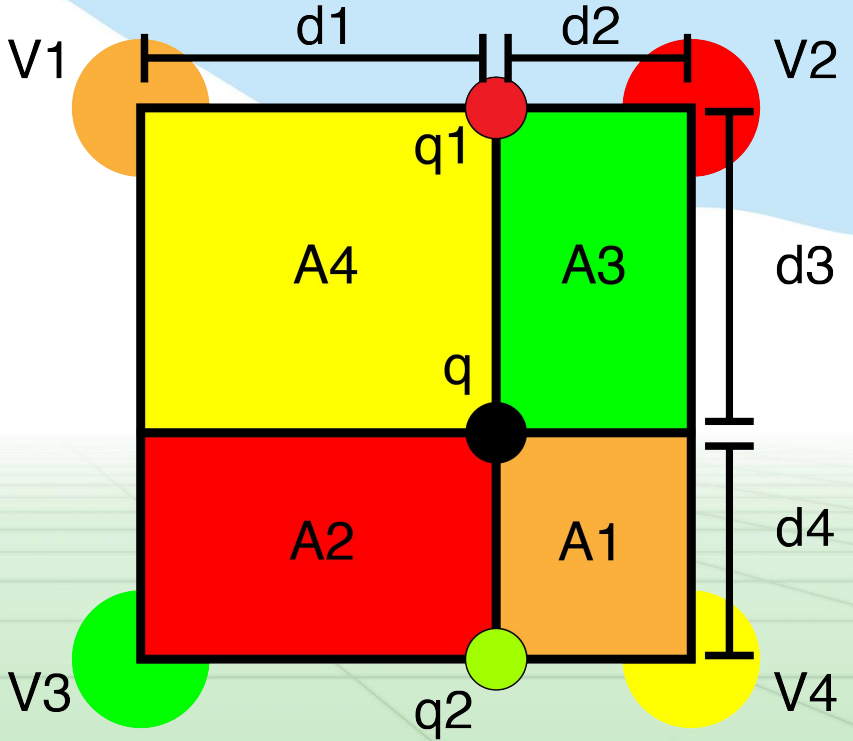
Bilinear interpolation: for grids, pretty good

```
q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3
```

Equivalent:

```
q = q1*d4 + q2*d3
q = (V1*d2 + V2*d1)*d4 + (V3*d2 + V4*d1)*d3 (subst)
q = V1*d2*d4 + V2*d1*d4 + V3*d2*d3 + V4*d1*d3 (distribution)

Recall:
A1 = d2*d4
A2 = d1*d4
A3 = d2*d3
A4 = d1*d3
```



Bilinear interpolation: for grids, pretty good

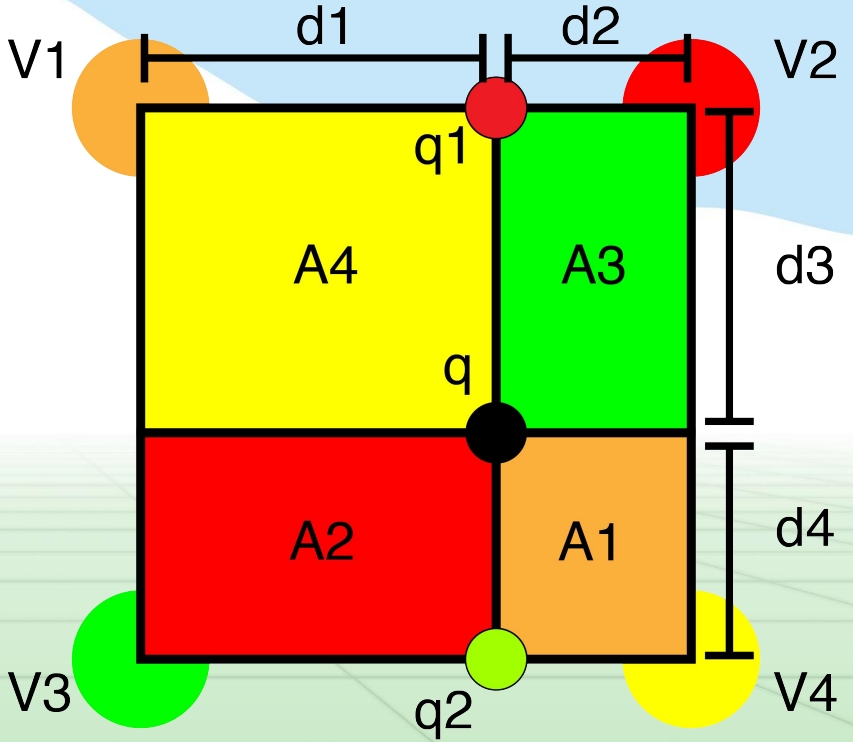
```
q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3
```

Equivalent:

```
q = q1*d4 + q2*d3
q = (V1*d2 + V2*d1)*d4 + (V3*d2 + V4*d1)*d3 (subst)
q = V1*d2*d4 + V2*d1*d4 + V3*d2*d3 + V4*d1*d3 (distribution)

Recall:
A1 = d2*d4
A2 = d1*d4
A3 = d2*d3
A4 = d1*d3
```

```
q = V1*A1 + V2*A2 + V3*A3 + V4*A4
```



Bilinear interpolation: for grids, pretty good

```
q1 = V1*d2 + V2*d1
q2 = V3*d2 + V4*d1
q = q1*d4 + q2*d3
```

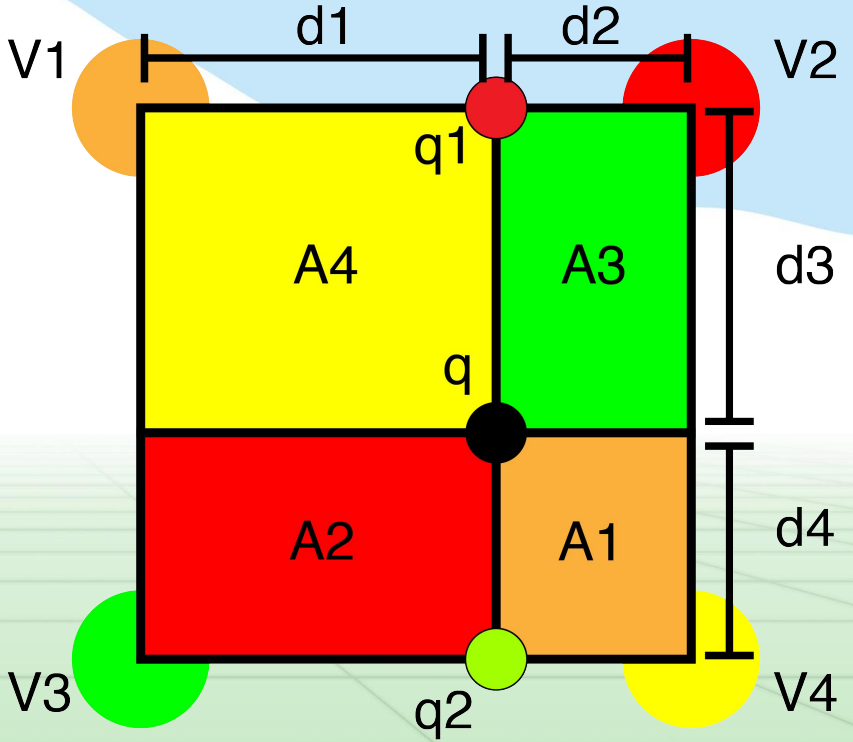
Equivalent:

```
q = q1*d4 + q2*d3
q = (V1*d2 + V2*d1)*d4 + (V3*d2 + V4*d1)*d3 (subst)
q = V1*d2*d4 + V2*d1*d4 + V3*d2*d3 + V4*d1*d3 (distribution)

Recall:
A1 = d2*d4
A2 = d1*d4
A3 = d2*d3
A4 = d1*d3
```

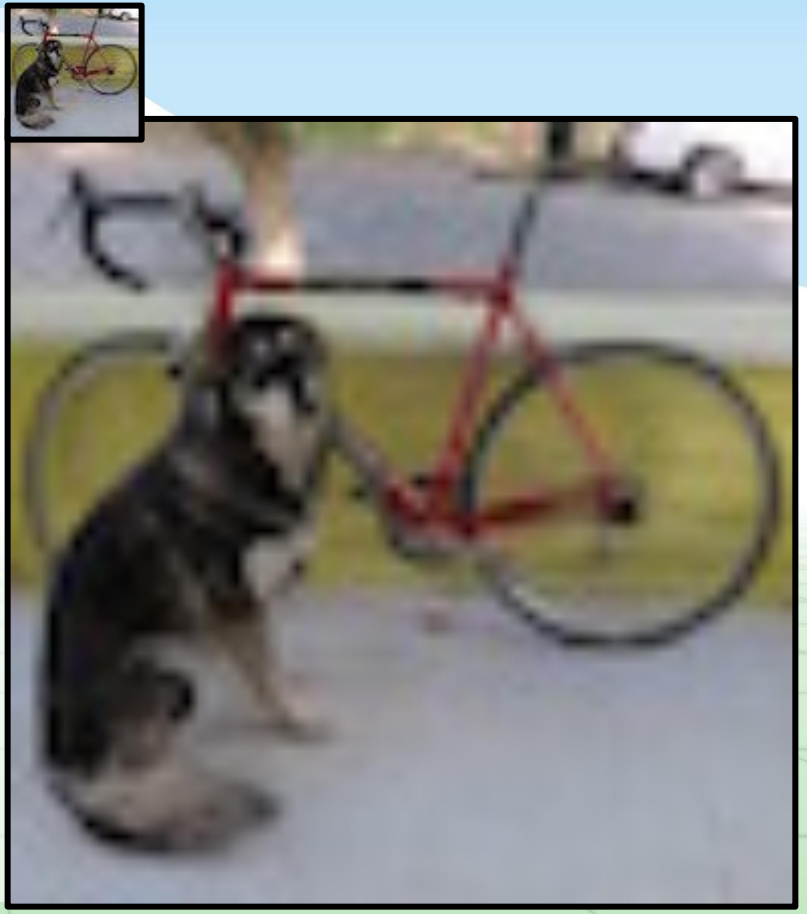
```
q = V1*A1 + V2*A2 + V3*A3 + V4*A4
```

yay!



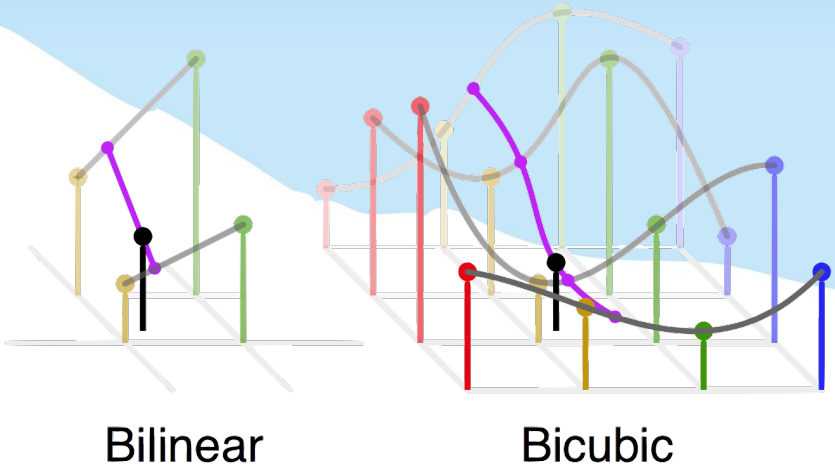
Bilinear interpolation: for grids, pretty good

- Smoother than NN
- More complex
  - 4 lookups
  - Some math
- Often the right tradeoff of speed vs final result



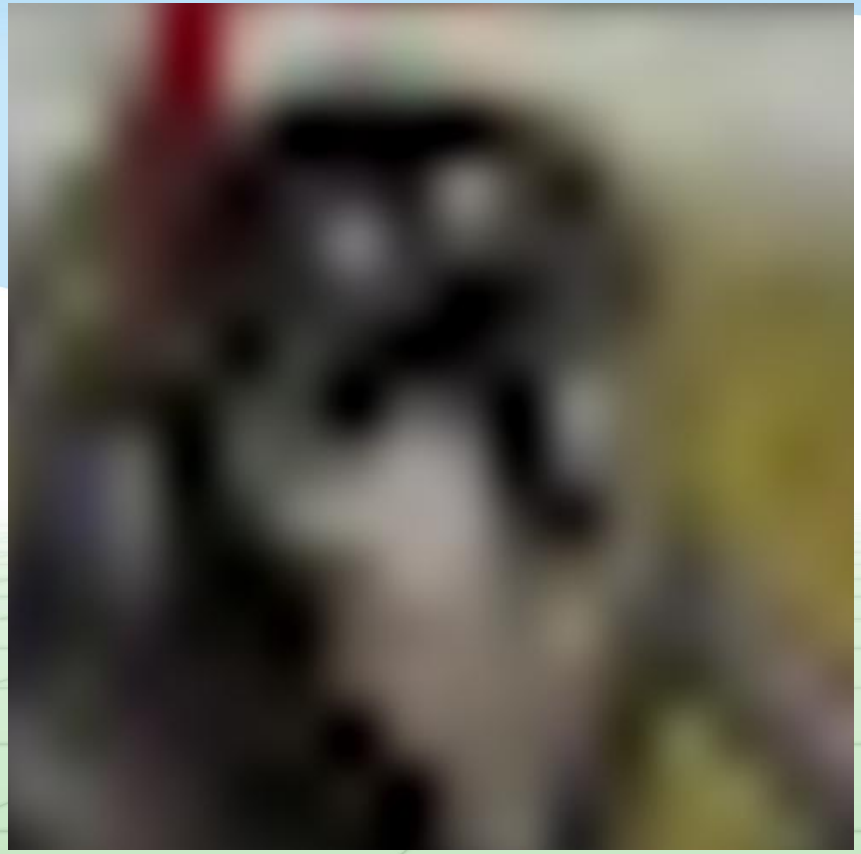
Bicubic sampling: more complex, maybe better?

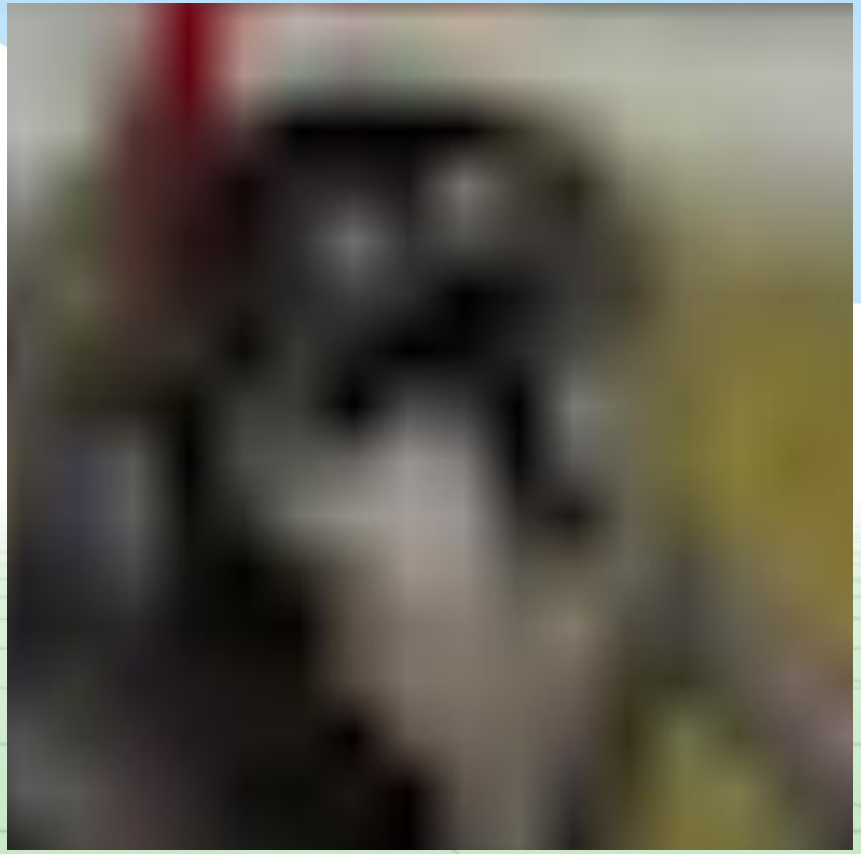
- A cubic interpolation of 4 cubic interpolations
- Smoother than bilinear, no “star”
- 16 nearest neighbors
- Fit 3rd order poly:
  - f(x) = a + bx + cx^2 + dx^3
- Interpolate along axis
- Fit another poly to interpolated values



Bicubic vs bilinear

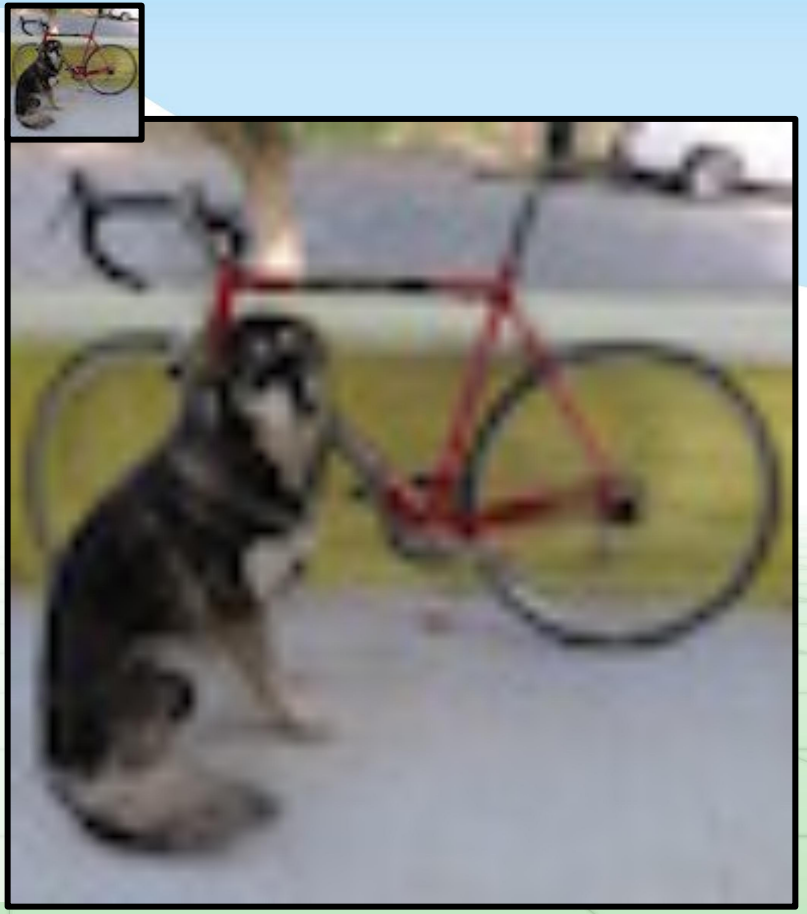
Bicubic vs bilinear





Resize algorithm:

- For each pixel in new image:
  - Map to old im coordinates
  - Interpolate value
  - Set new value in image



What about shrinking?

- NN and Bilinear only look at small area
- Lots of artifacting
- Staircase pattern on diagonal lines
- We'll fix this next class with filters!