

The Ancient Secrets



Computer Vision

Previously
On

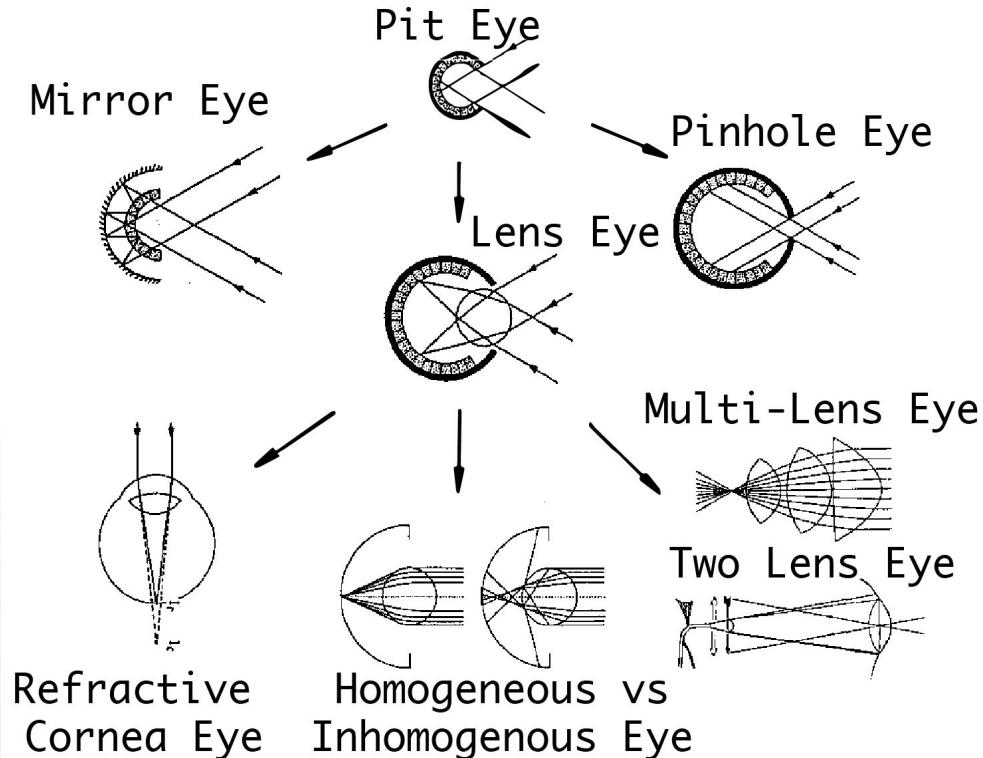


Ancient Secrets
of Computer Vision

Vision is good!

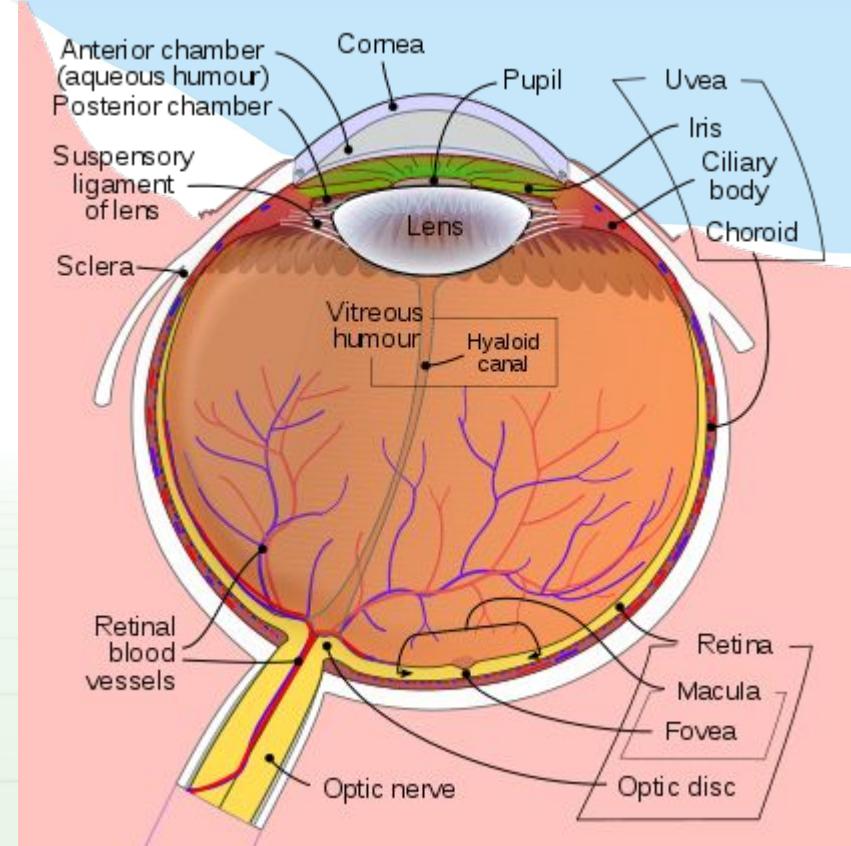
Simple eyes: 28 of 33 animal phyla

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



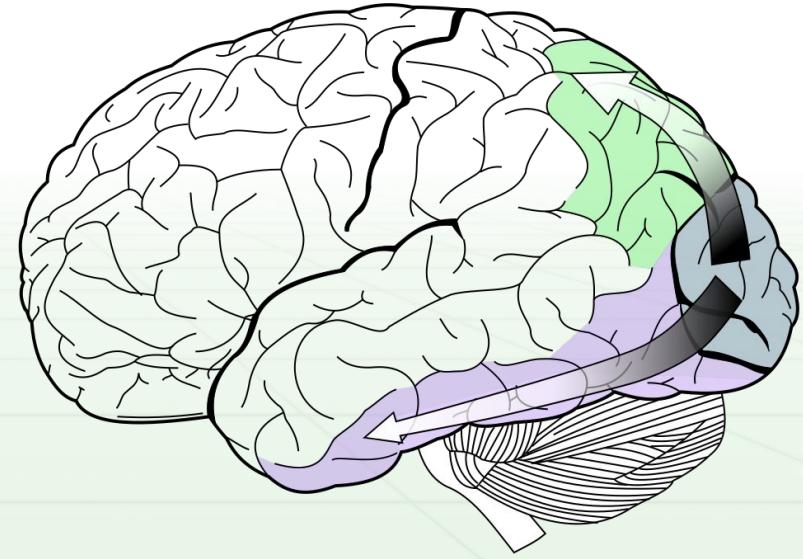
Human eyes

- 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

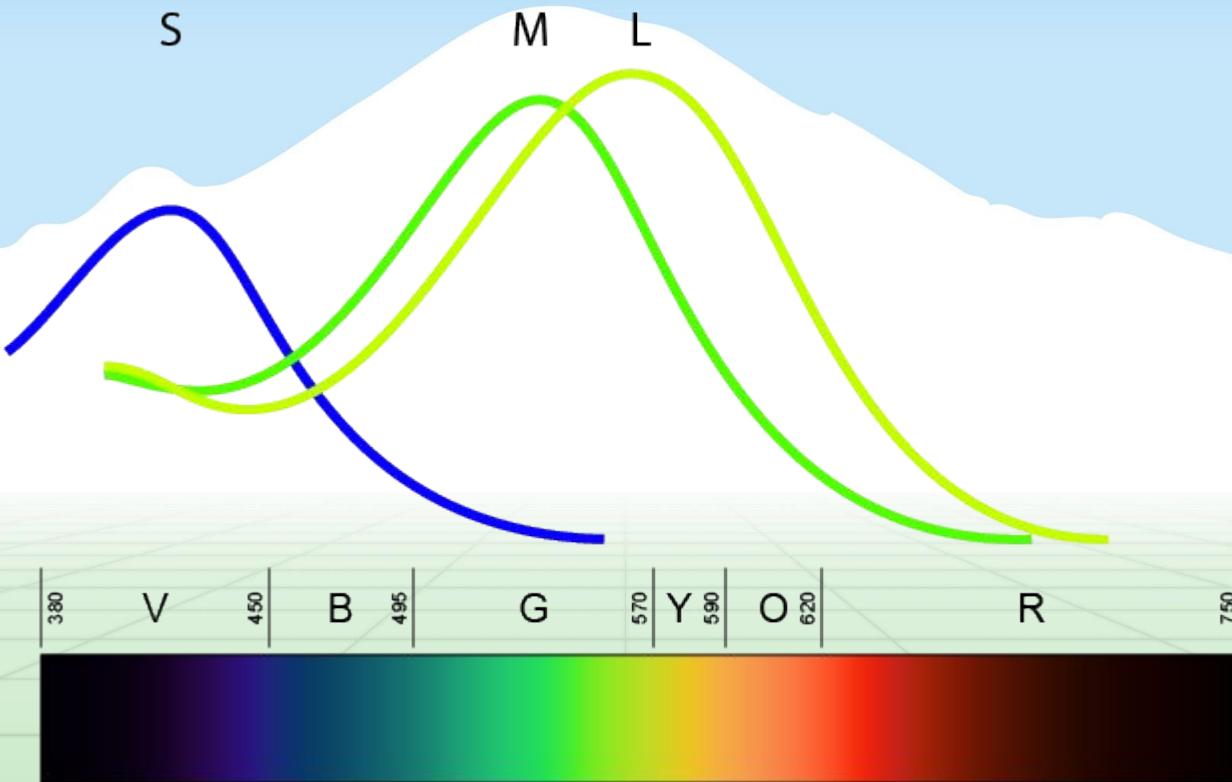


Ventral/dorsal split

- 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!

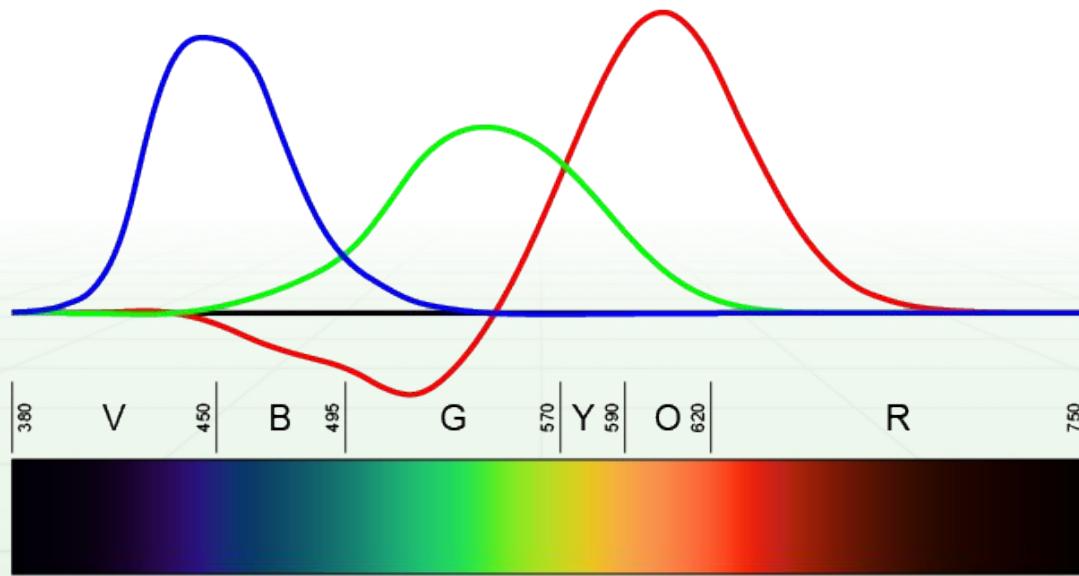


Rods and Cones: Color!



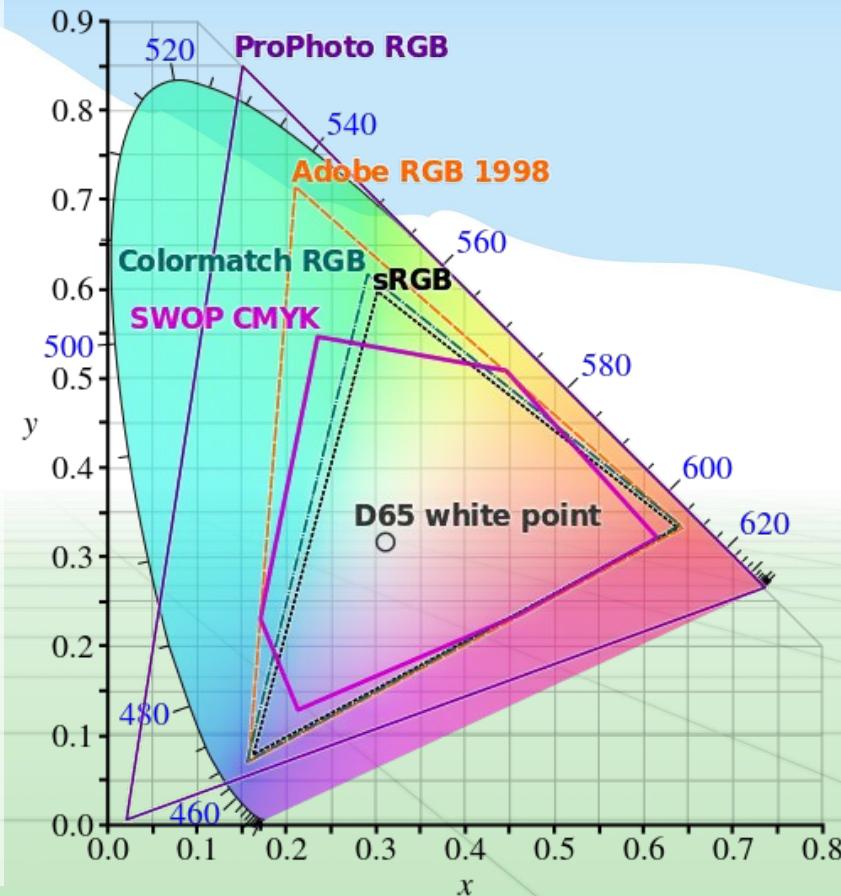
CIE 1931 color matching

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

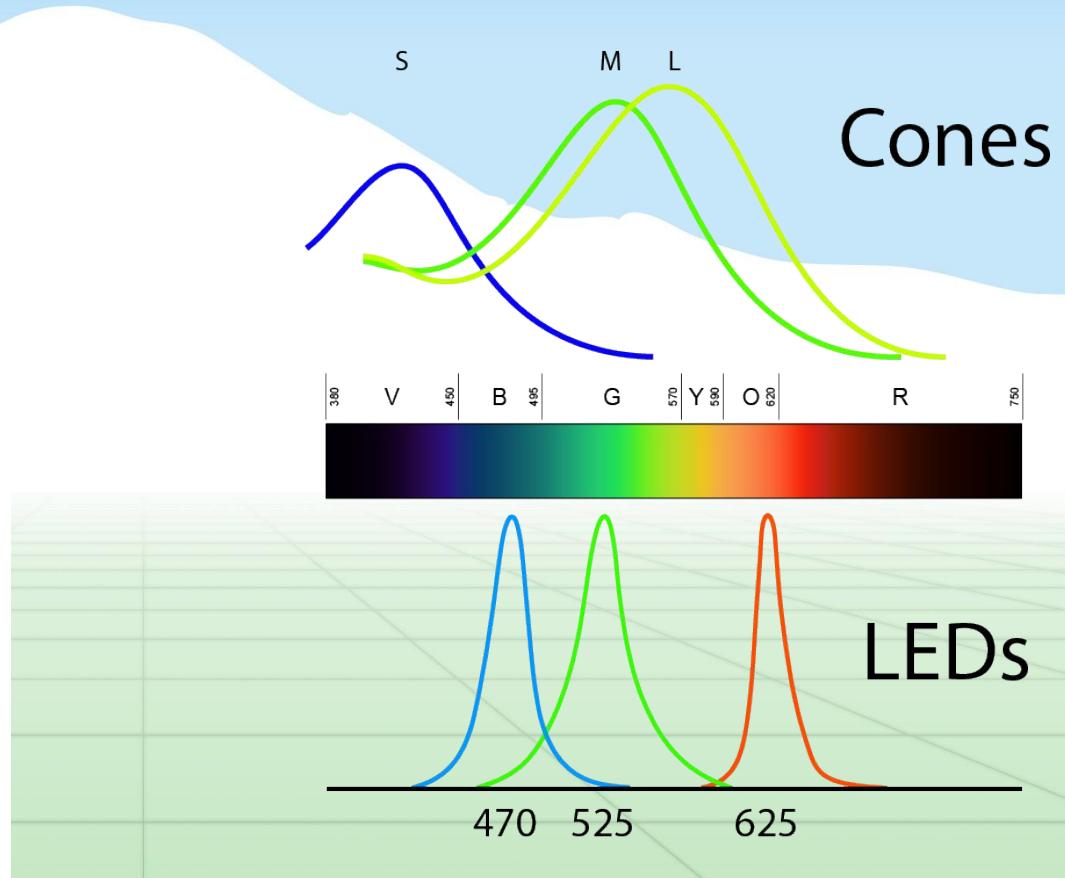
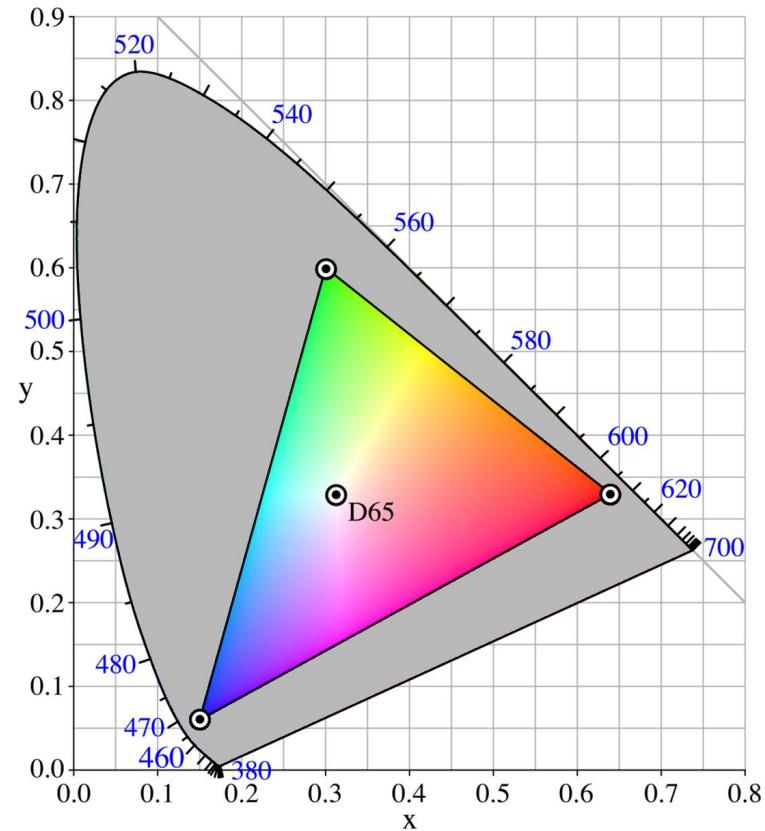


Can make a “map” of color

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



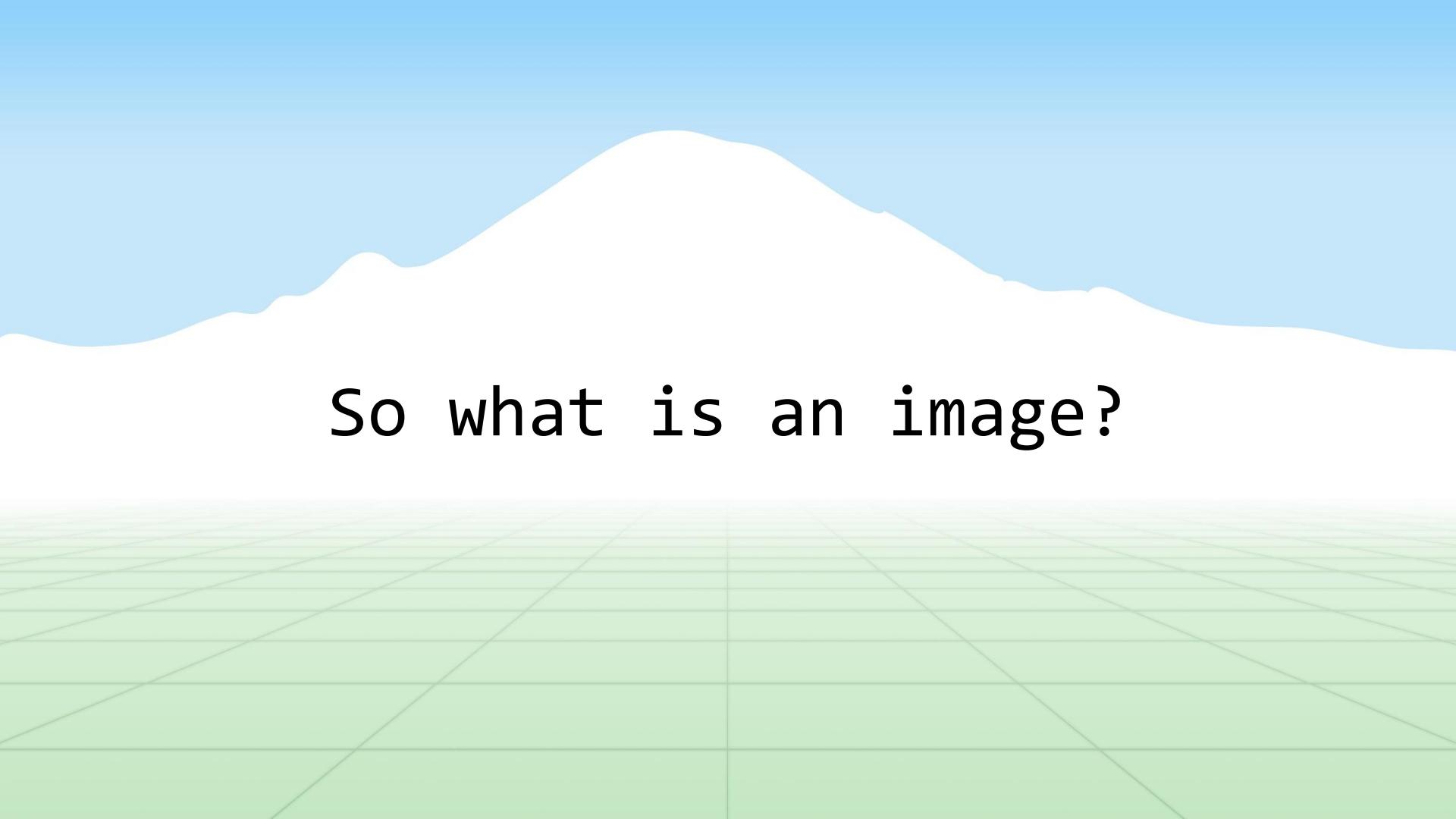
sRGB: most widely used colorspace



Chapter Three

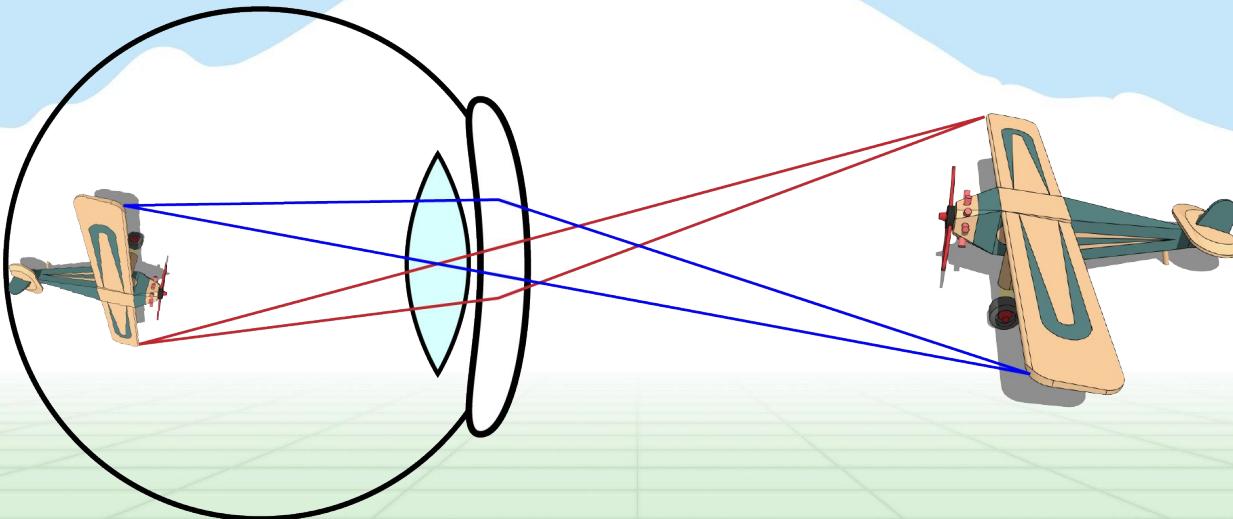


Image Basics

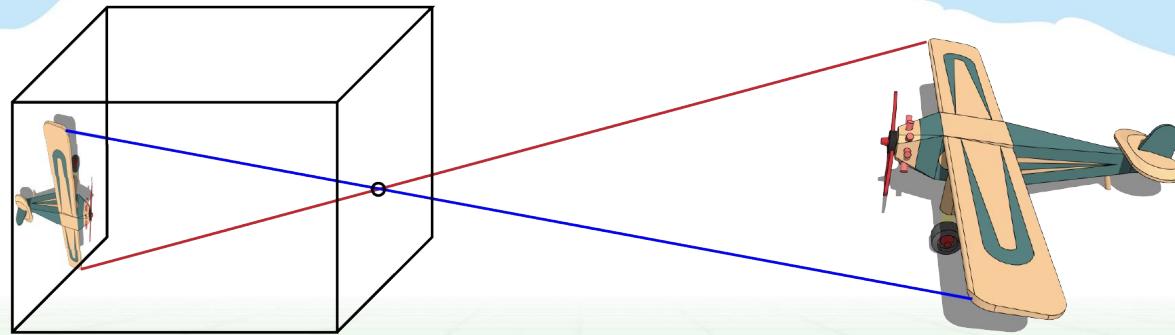


So what is an image?

Eyes: projection onto retina



Model: pinhole camera



Model: pinhole camera

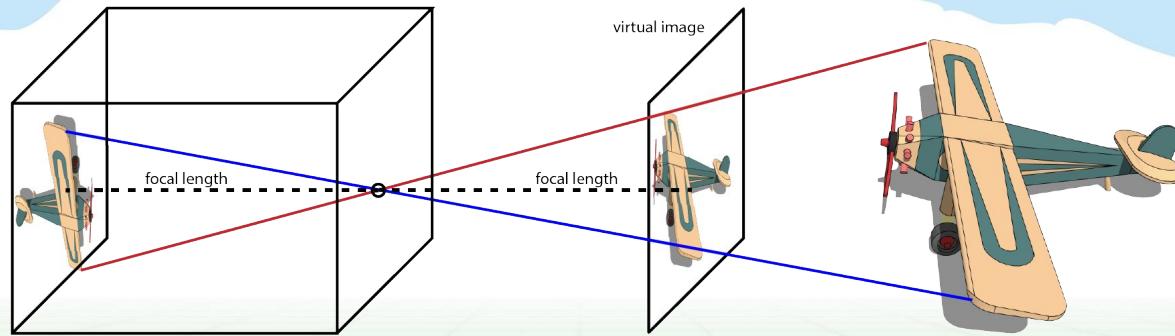


Image: 3d -> 2d projection of the world

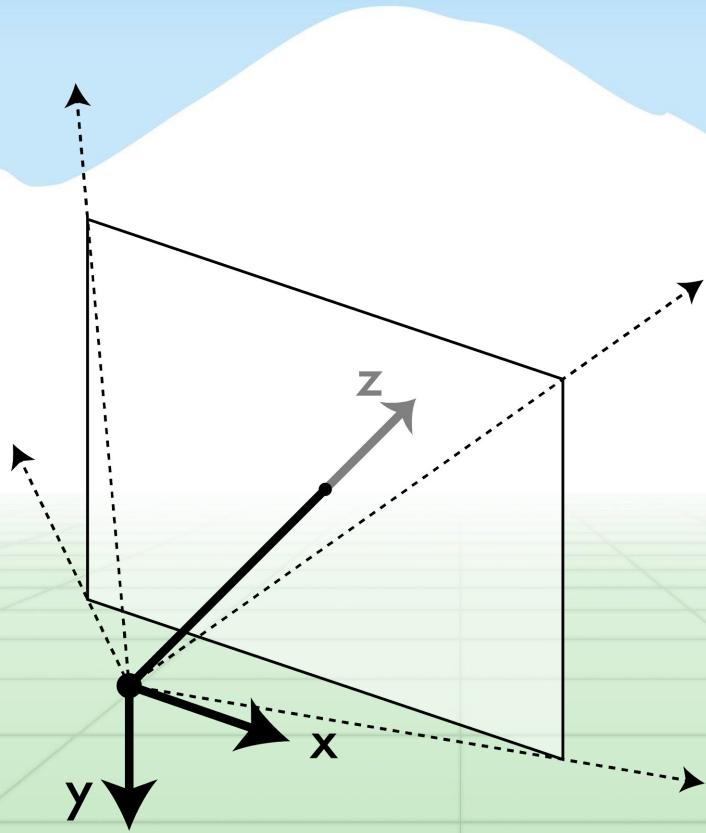


Image: 3d -> 2d projection of the world

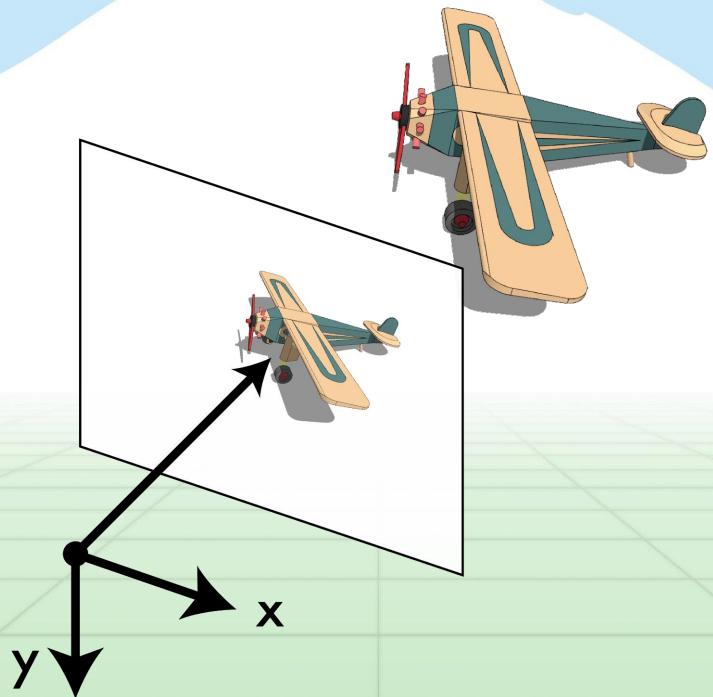


Image: 3d -> 2d projection of the world

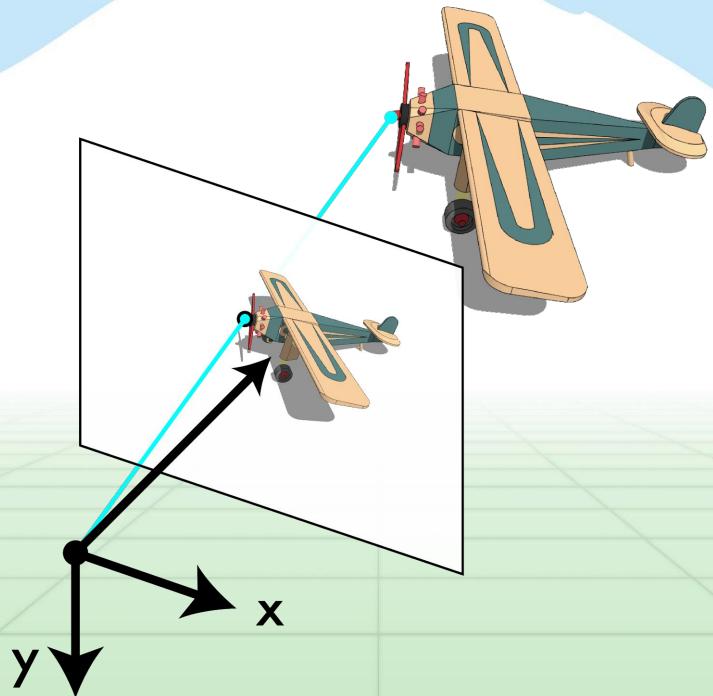


Image: 3d -> 2d projection of the world

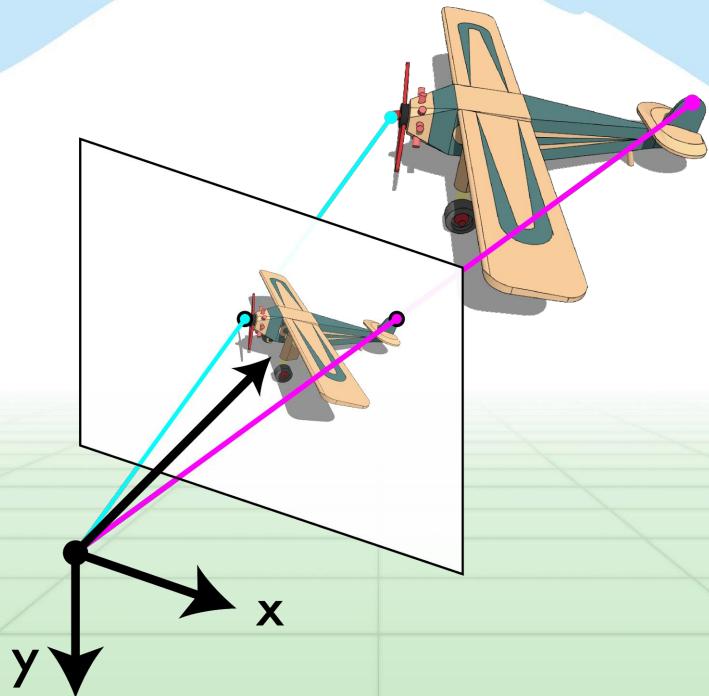


Image: 3d -> 2d projection of the world

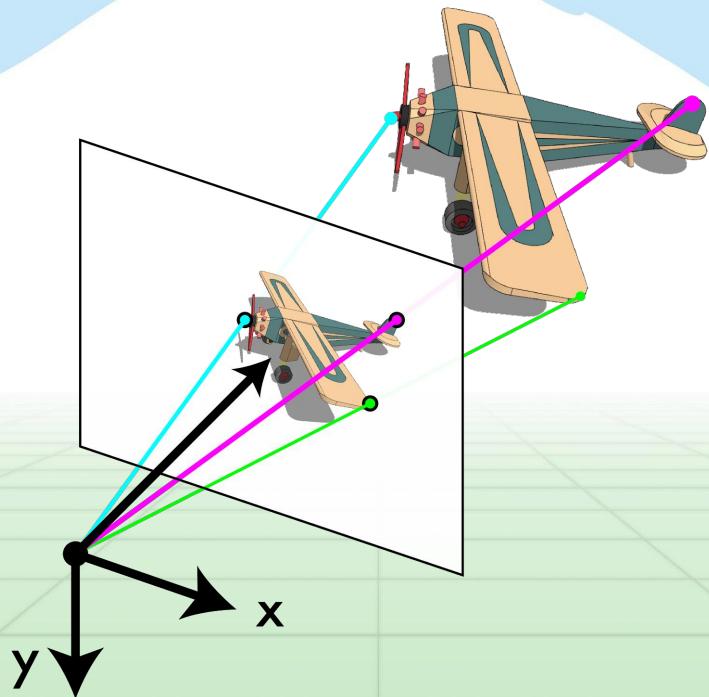
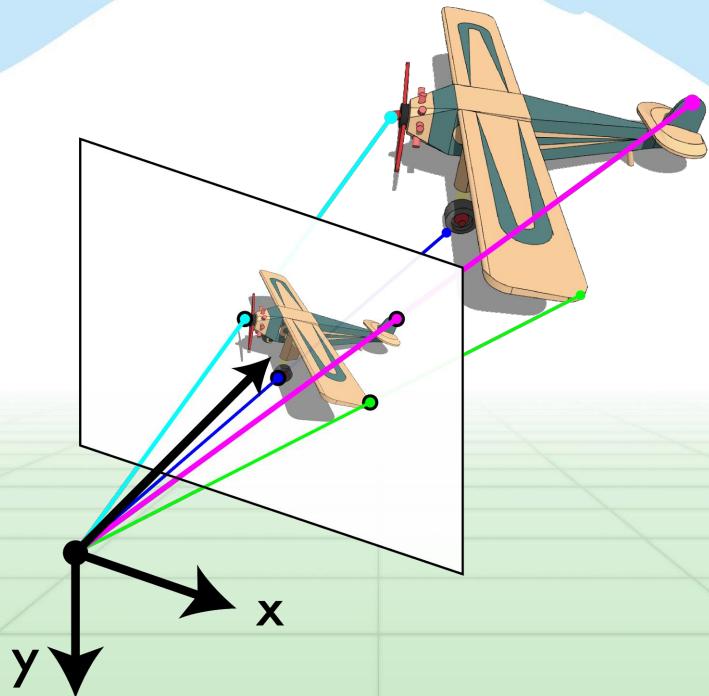
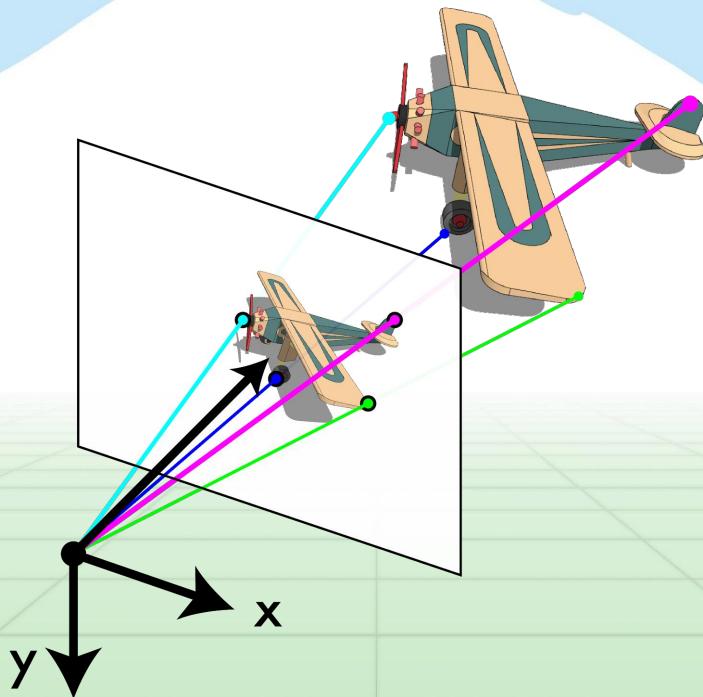


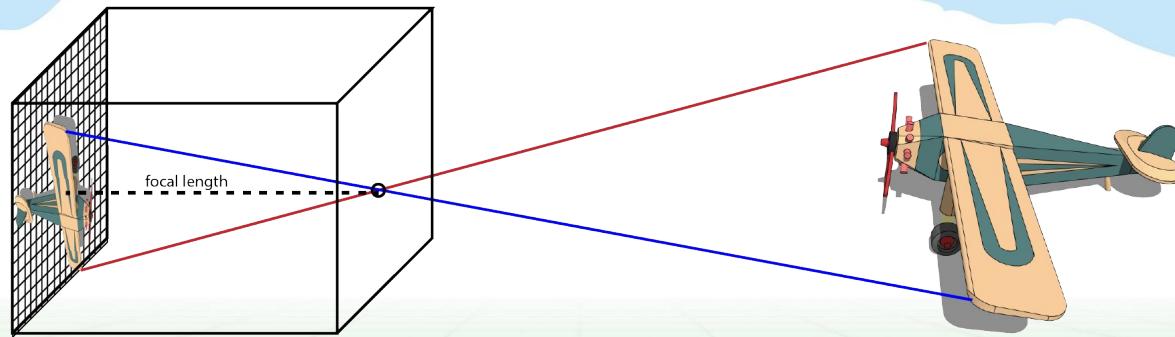
Image: 3d -> 2d projection of the world



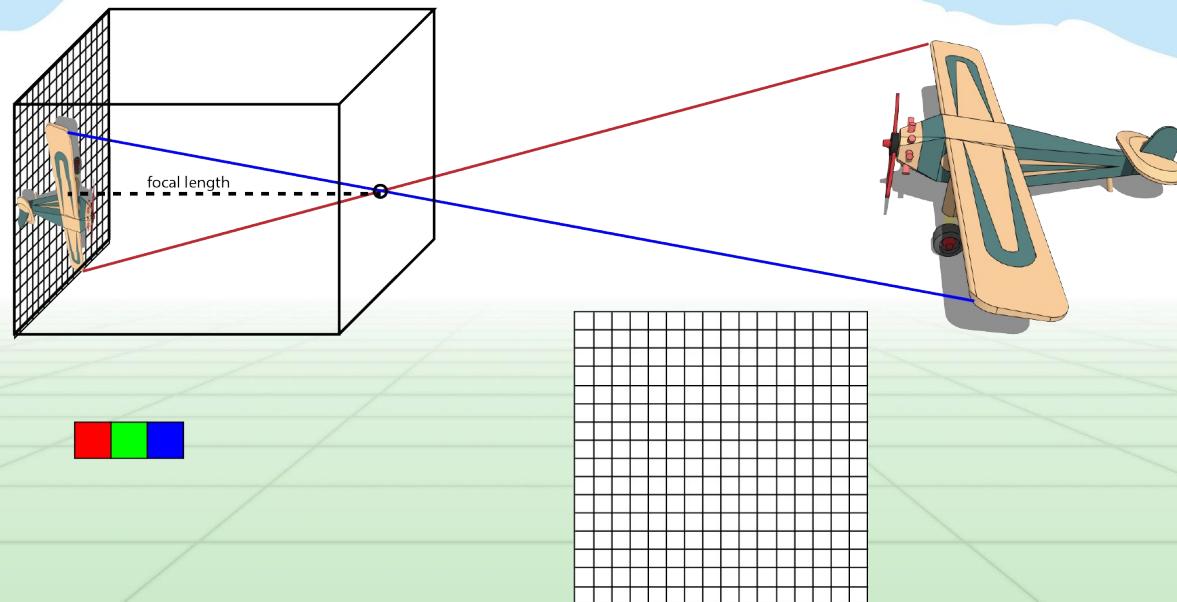
At each point we record incident light



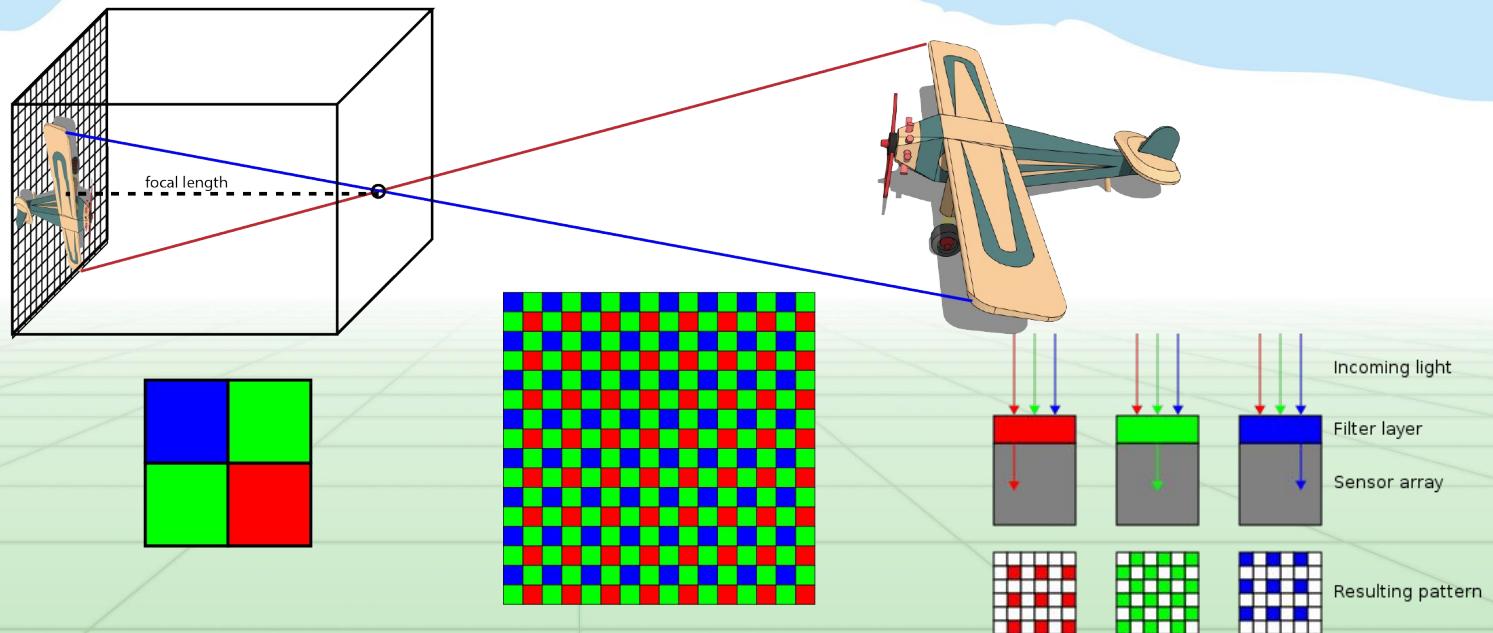
At each point we record incident light



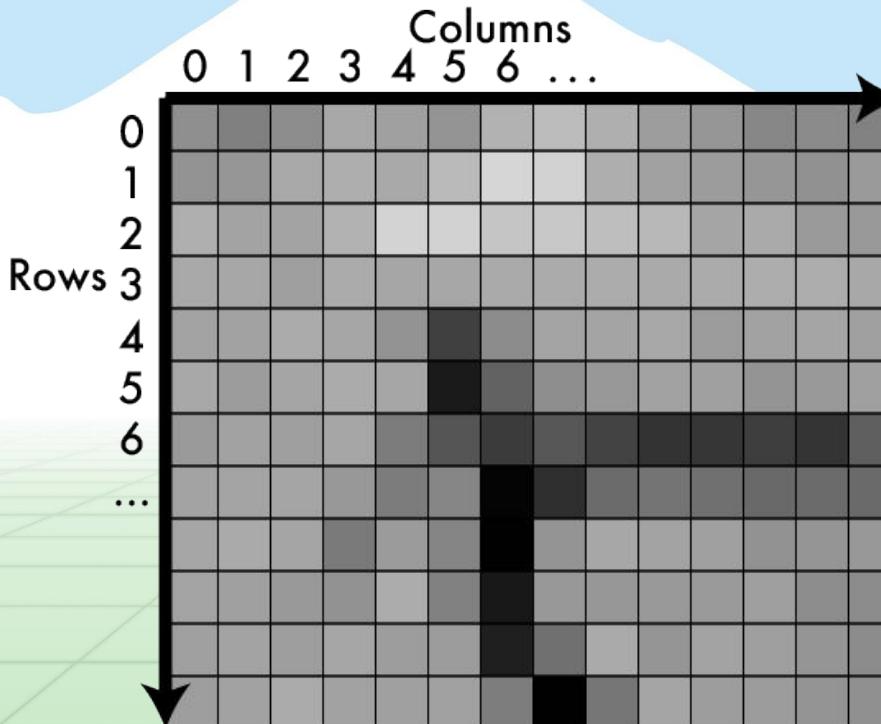
How do we record color?



Bayer pattern for CMOS sensors



An image is a matrix of light



Values in matrix = how much light

		Columns													
		0	1	2	3	4	5	6	...						
Rows	0	100	102	107	102	132	146	136	156	148	122	115	104	105	103
	1	100	102	107	102	132	146	136	156	148	122	115	104	105	103
	2	100	102	107	102	132	146	136	156	148	122	115	104	105	103
	3	100	102	107	102	132	146	136	156	148	122	115	104	105	103
	4	100	102	107	102	132	146	136	156	148	122	115	104	105	103
	5	100	102	107	102	132	30	60	156	148	122	115	104	105	103
	6	100	102	107	102	132	40	20	50	32	20	20	24	30	62
	...	100	102	107	102	132	71		156	51	57	57	58	62	58
		100	102	107	102	132	69		156	148	122	115	104	105	103
		100	102	107	102	132	89	12	156	148	122	115	104	105	103
		100	102	107	102	132	146	13	45	148	122	115	104	105	103
		100	102	107	102	132	146	46		42	122	115	104	105	103

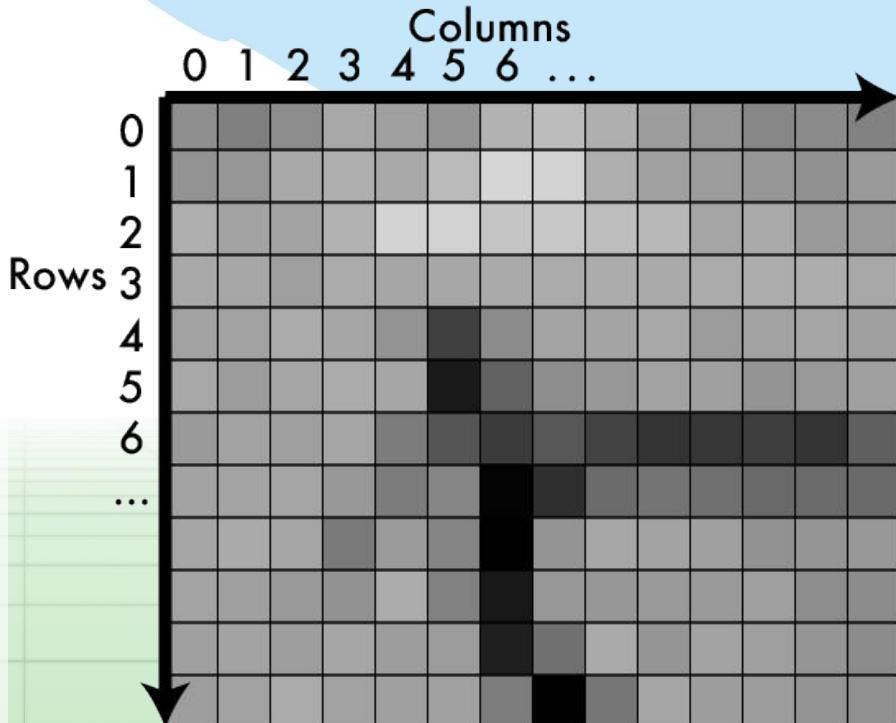
Values in matrix = how much light

- 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

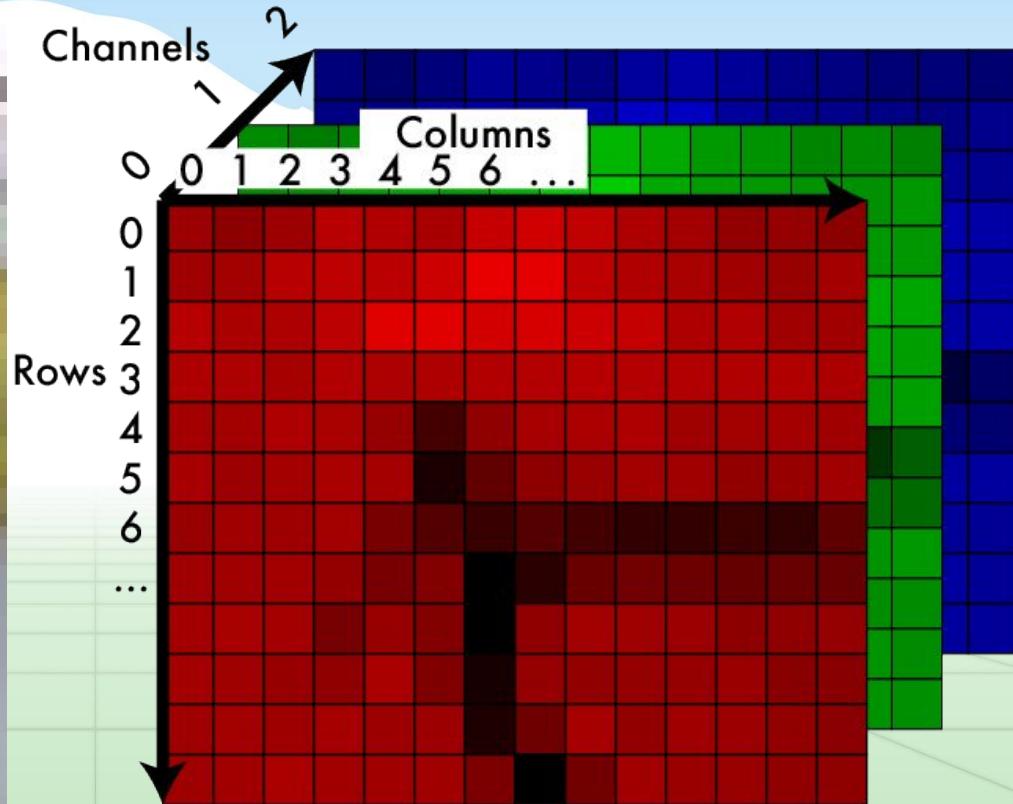
	Columns														
	0	1	2	3	4	5	6	...							
0	100	102	107	102	132	146	136	156	148	122	115	104	105	103	→
1	100	102	107	102	132	146	136	156	148	122	115	104	105	103	
2	100	102	107	102	132	146	136	156	148	122	115	104	105	103	
3	100	102	107	102	132	146	136	156	148	122	115	104	105	103	
4	100	102	107	102	132	146	136	156	148	122	115	104	105	103	
5	100	102	107	102	132	30	60	156	148	122	115	104	105	103	
6	100	102	107	102	132	40	20	50	32	20	20	24	30	62	
...	100	102	107	102	132	71		156	51	57	57	58	62	58	
	100	102	107	102	132	69		156	148	122	115	104	105	103	
	100	102	107	102	132	89	12	156	148	122	115	104	105	103	
	100	102	107	102	132	146	13	45	148	122	115	104	105	103	
	100	102	107	102	132	146	46		42	122	115	104	105	103	

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



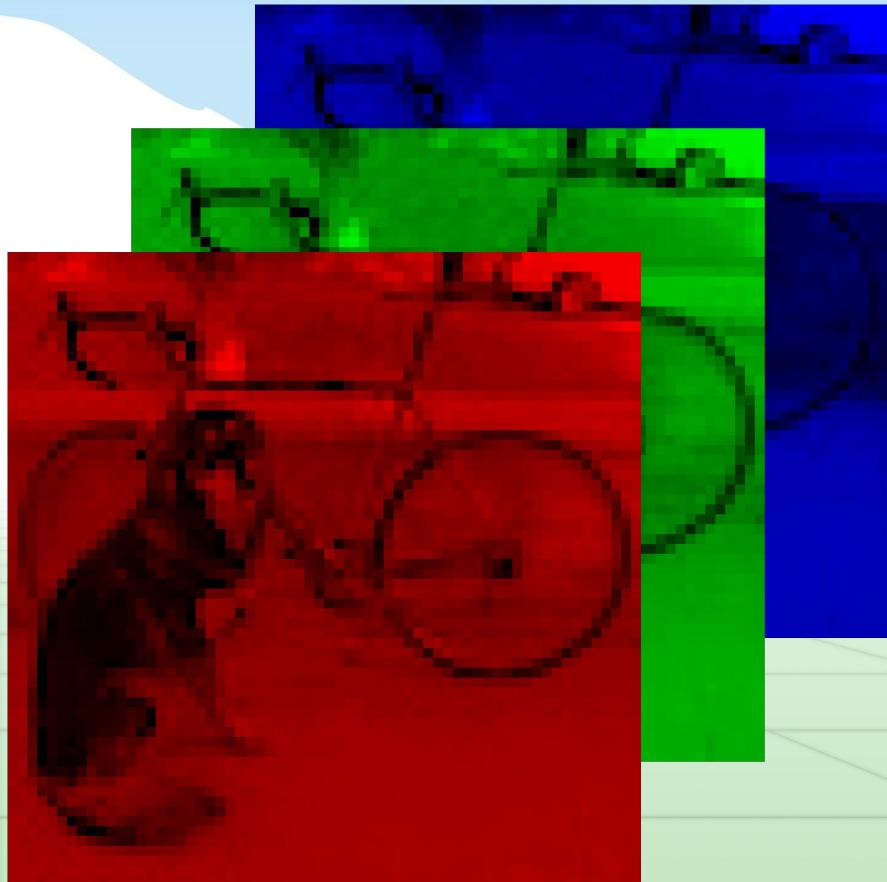
Color image: 3d tensor in colorspace



RGB information in separate “channels”

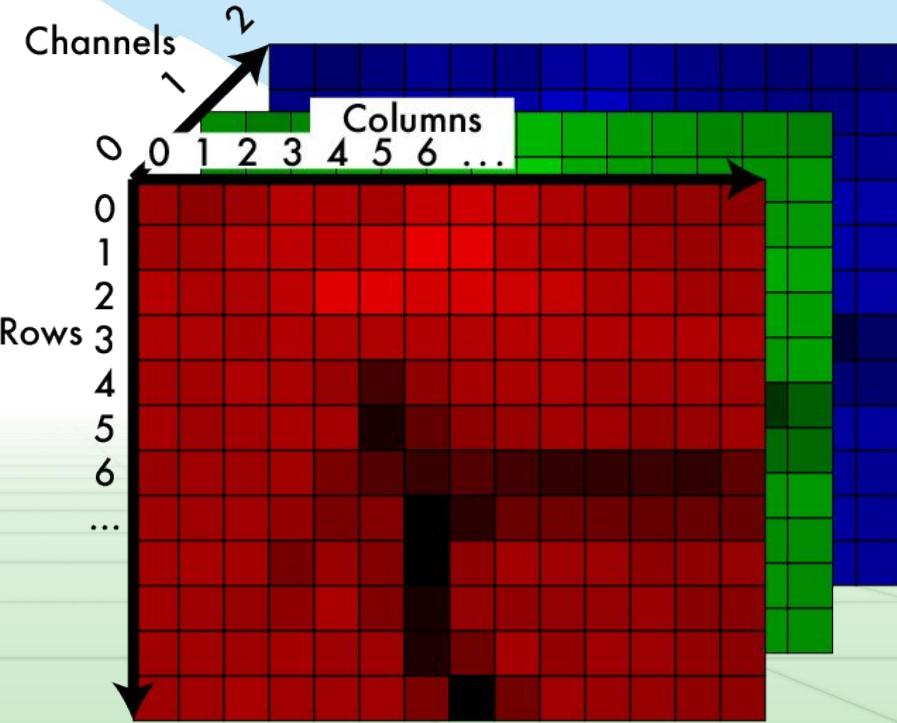
Remember: we can match “real” colors using a mix of primaries.

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

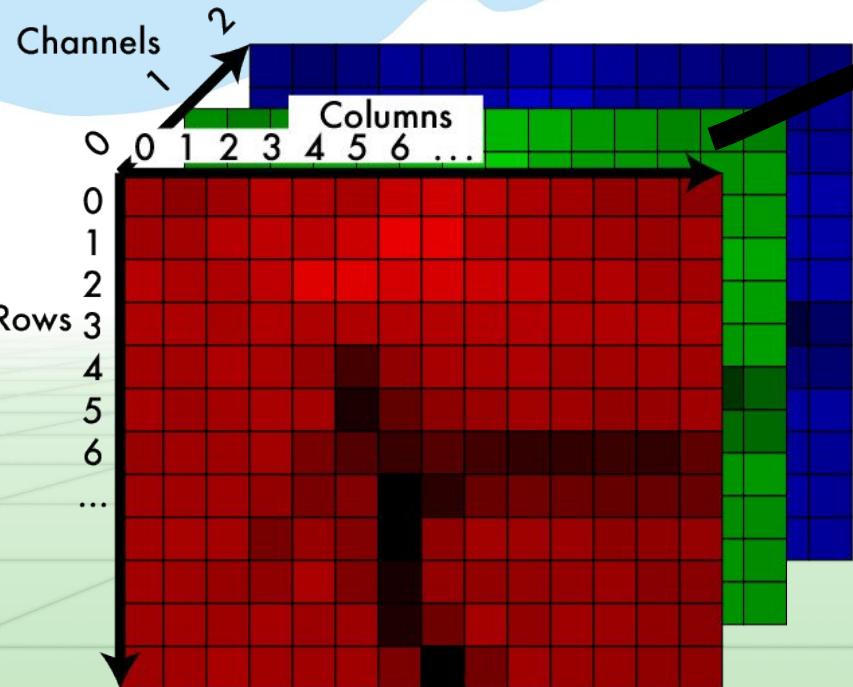


Addressing pixels

- 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:
 - $1920 \times 1080 \times 3$ image:
 - 1920 px wide
 - 1080 px tall
 - 3 channels

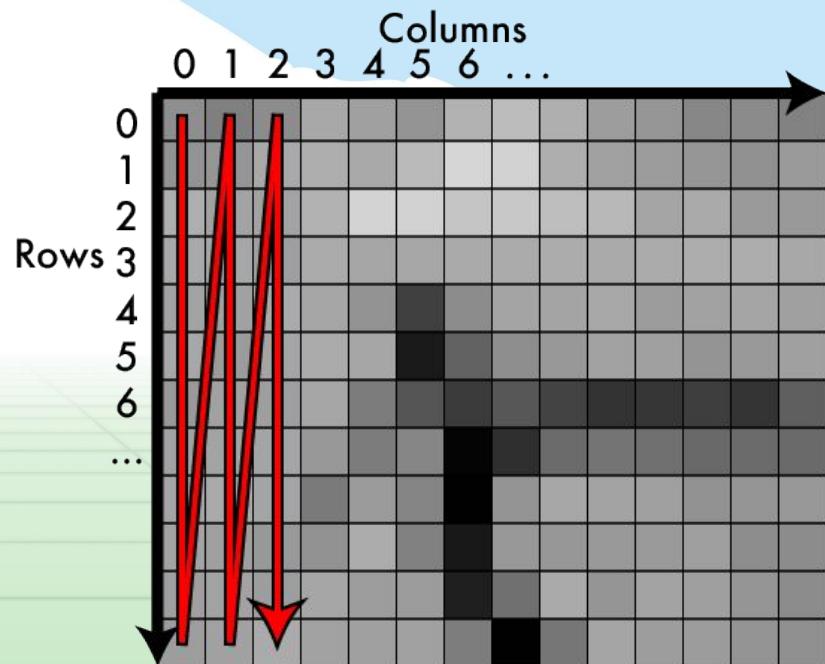
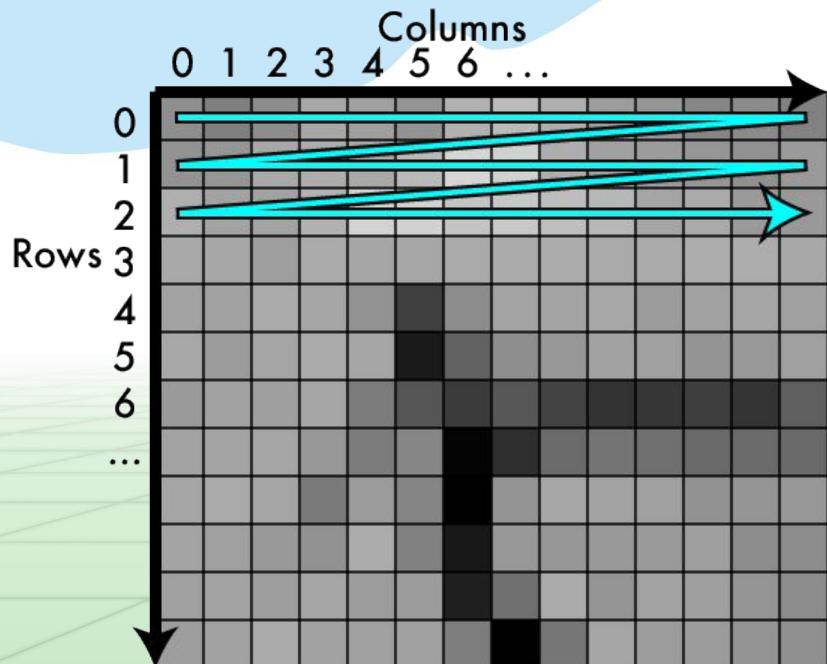


How do we store them?



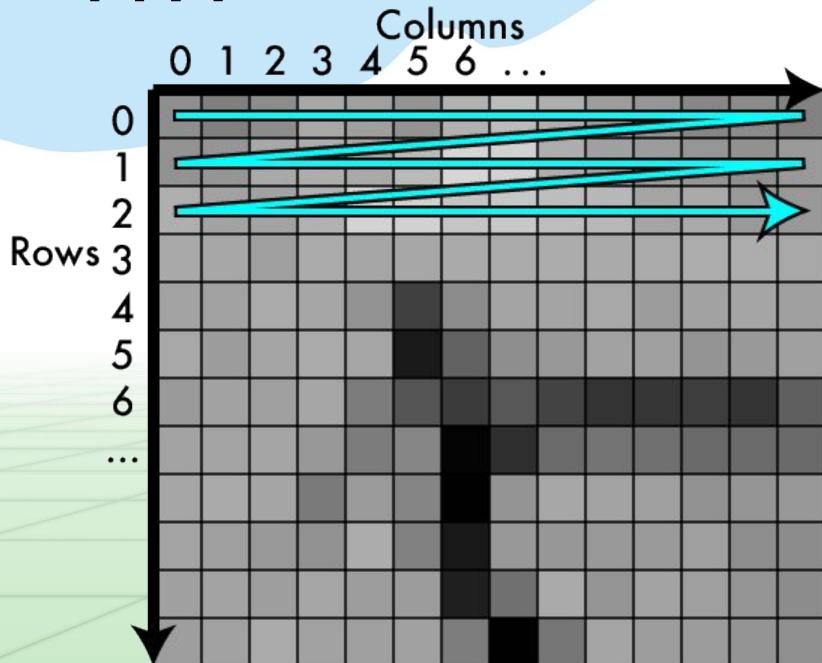
129	131	152	159	135	163	142	82	182	...
-----	-----	-----	-----	-----	-----	-----	----	-----	-----

Storage: row major vs column major

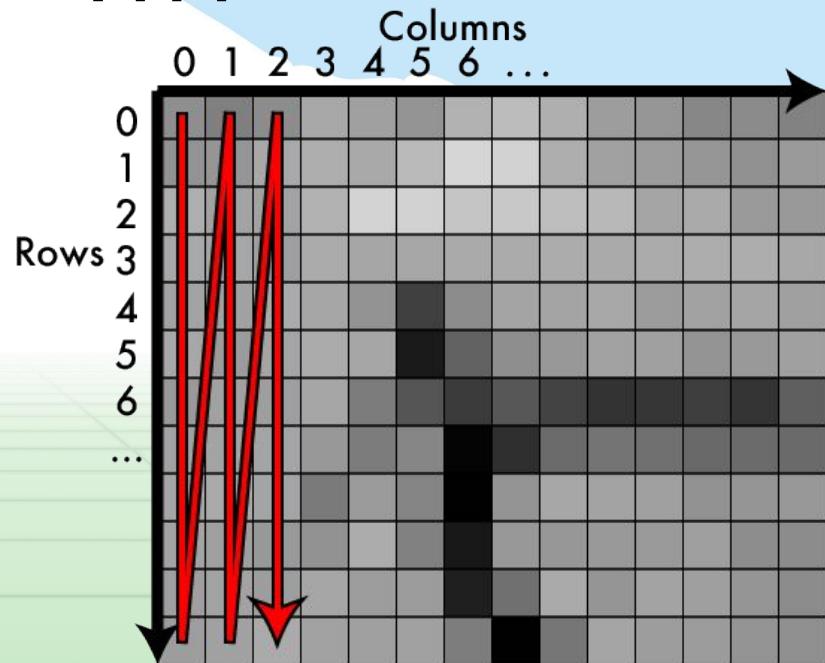


Storage: row major vs column major

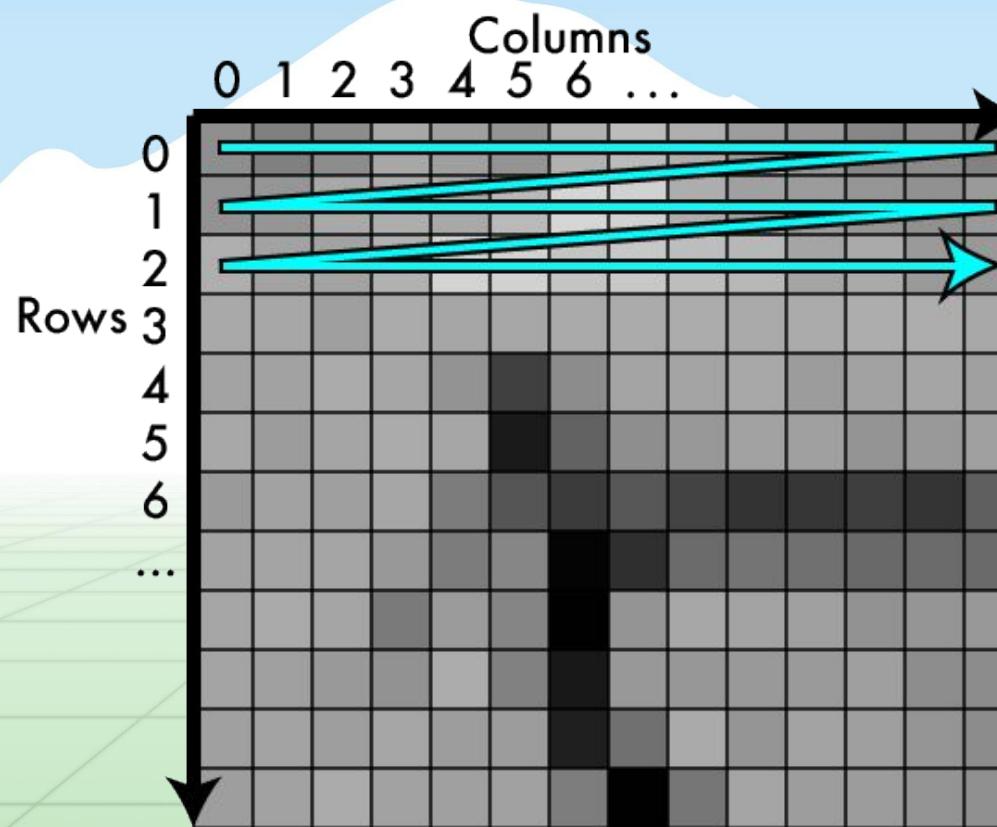
HW



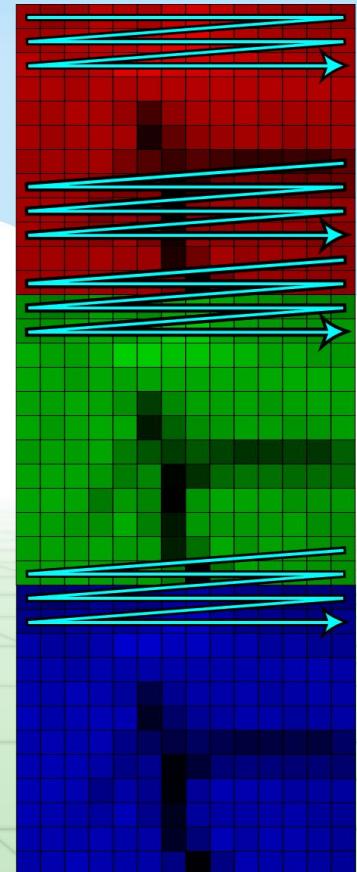
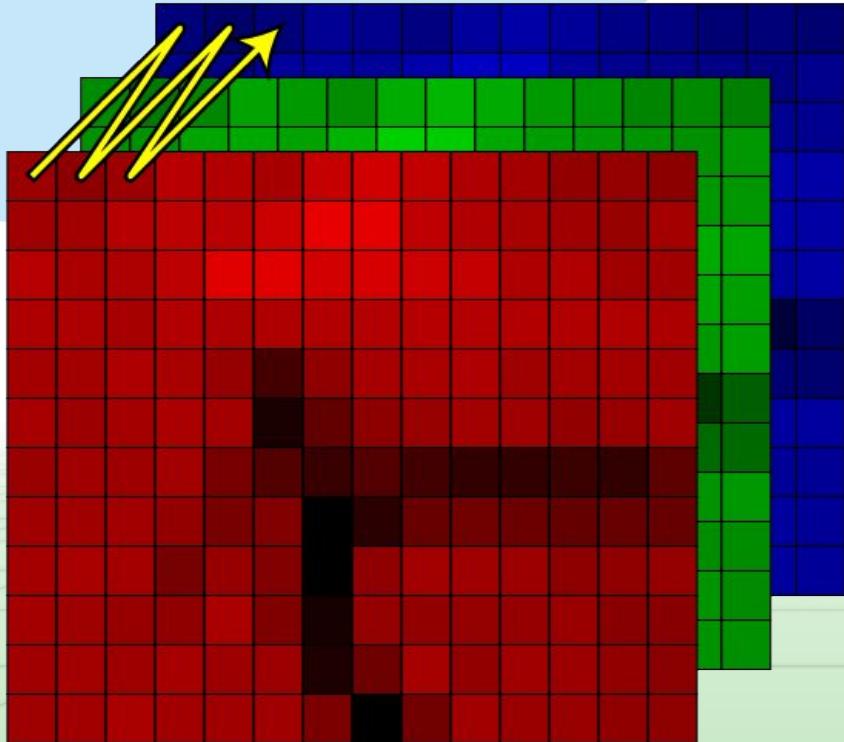
WH



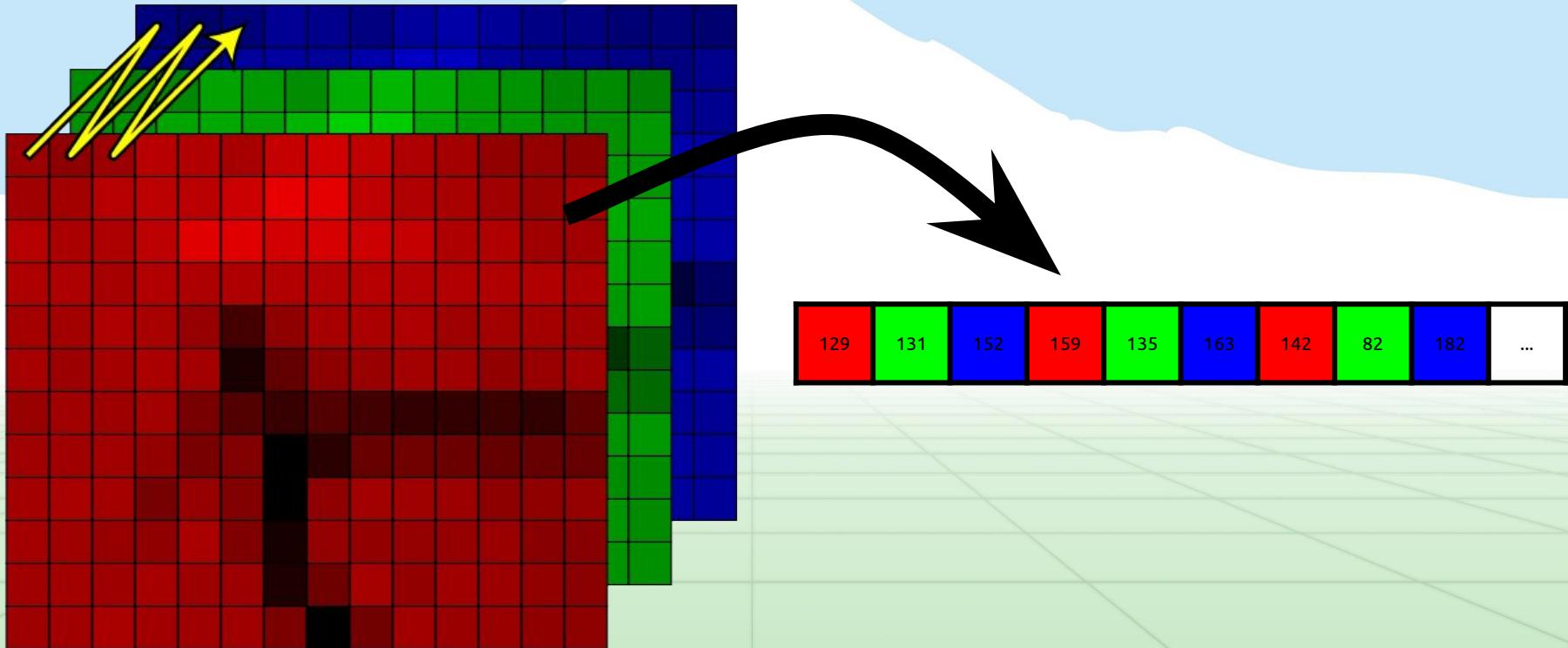
Typically use row-major or HW



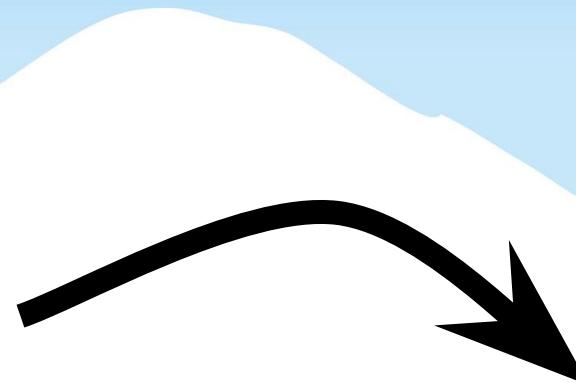
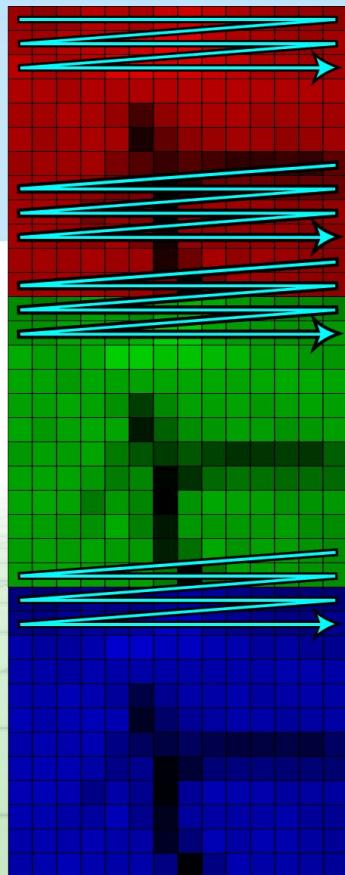
In 3d we have more choices!



HwC: channels interleaved



CHW: channels separated



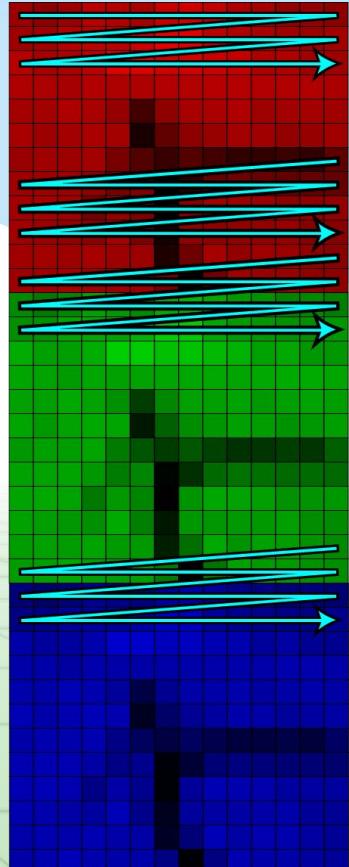
129	131	152	...	135	163	142	...	182	...
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

CHW Pop quiz

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

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

In groups, discuss for 2 minutes.



CHW Pop quiz

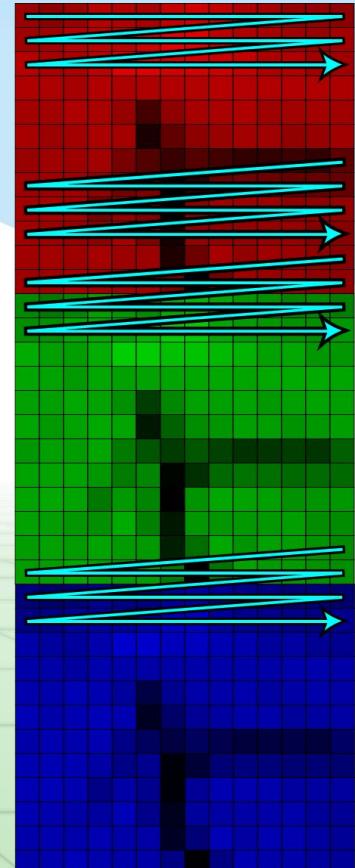
In an array for a $1920 \times 1080 \times 3$ image
what entry would contain the pixel
(15,192,2)?

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

$$x + y*W + z*W*H$$

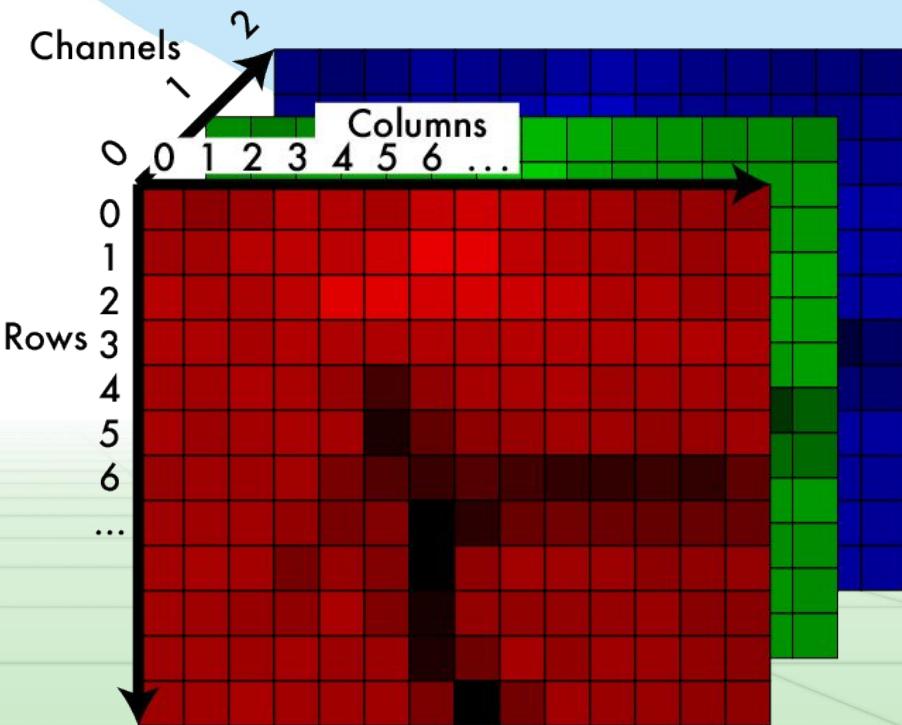
$$15 + 192*1920 + 2*1920*1080 = 4,515,855$$

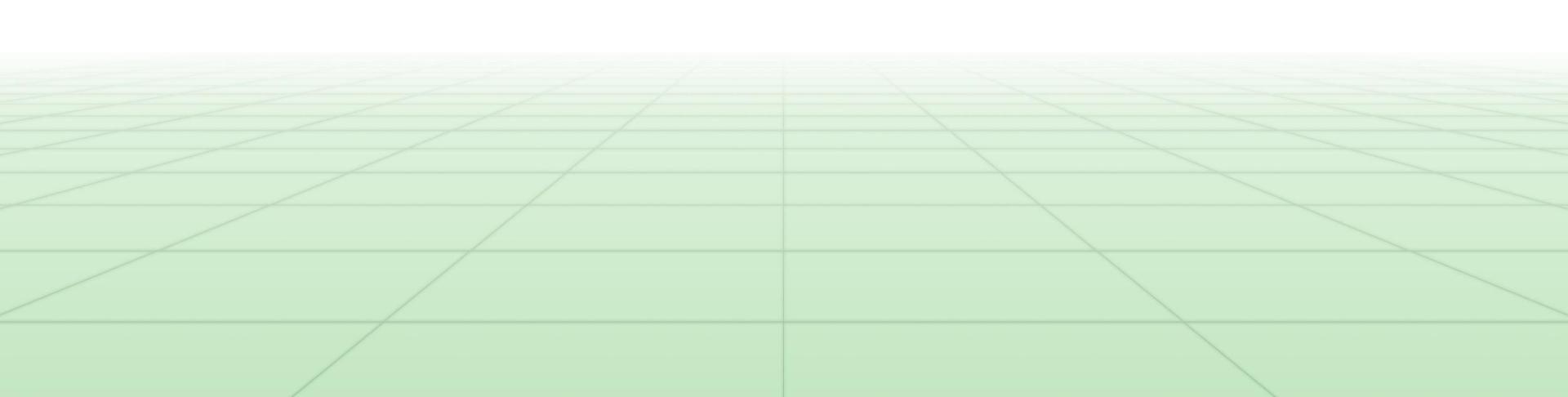
Remember, everything is 0 indexed
This isn't MATLAB 😊



In your homework

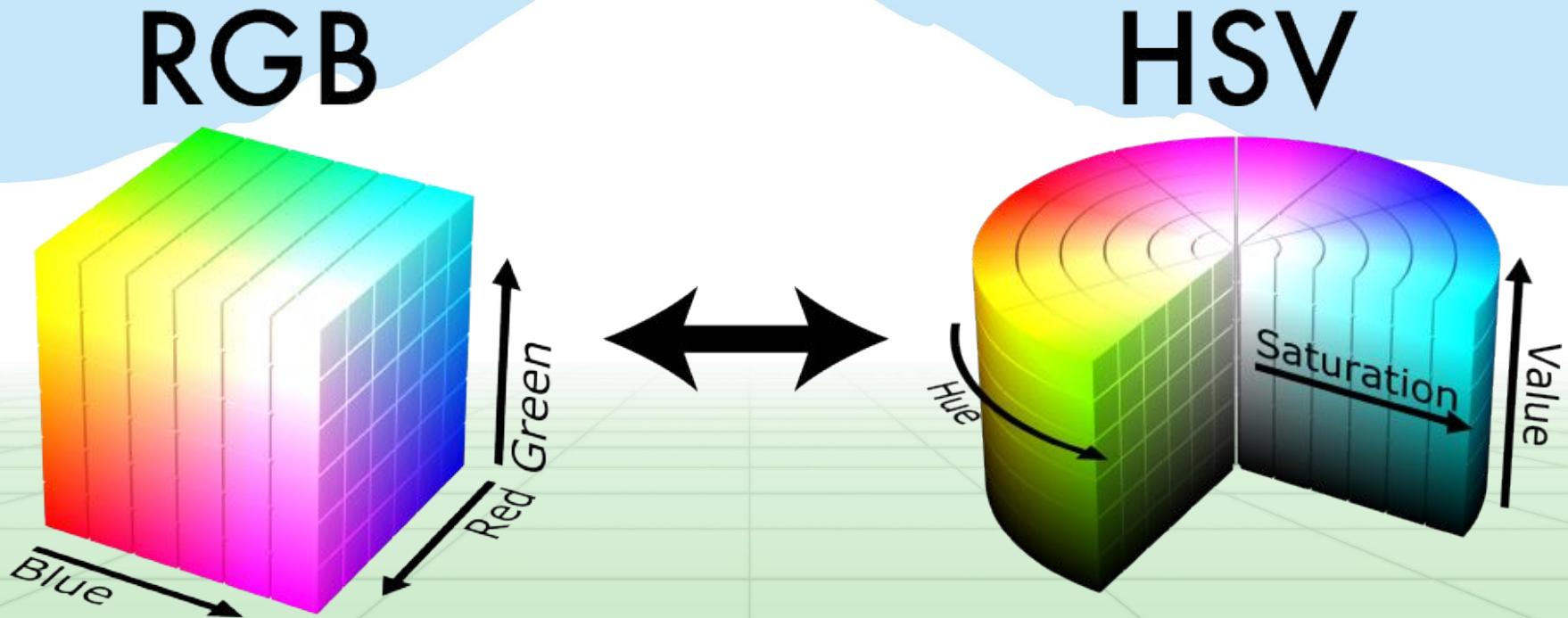
```
typedef struct {  
    int w,h,c;  
    float *data;  
} image;
```



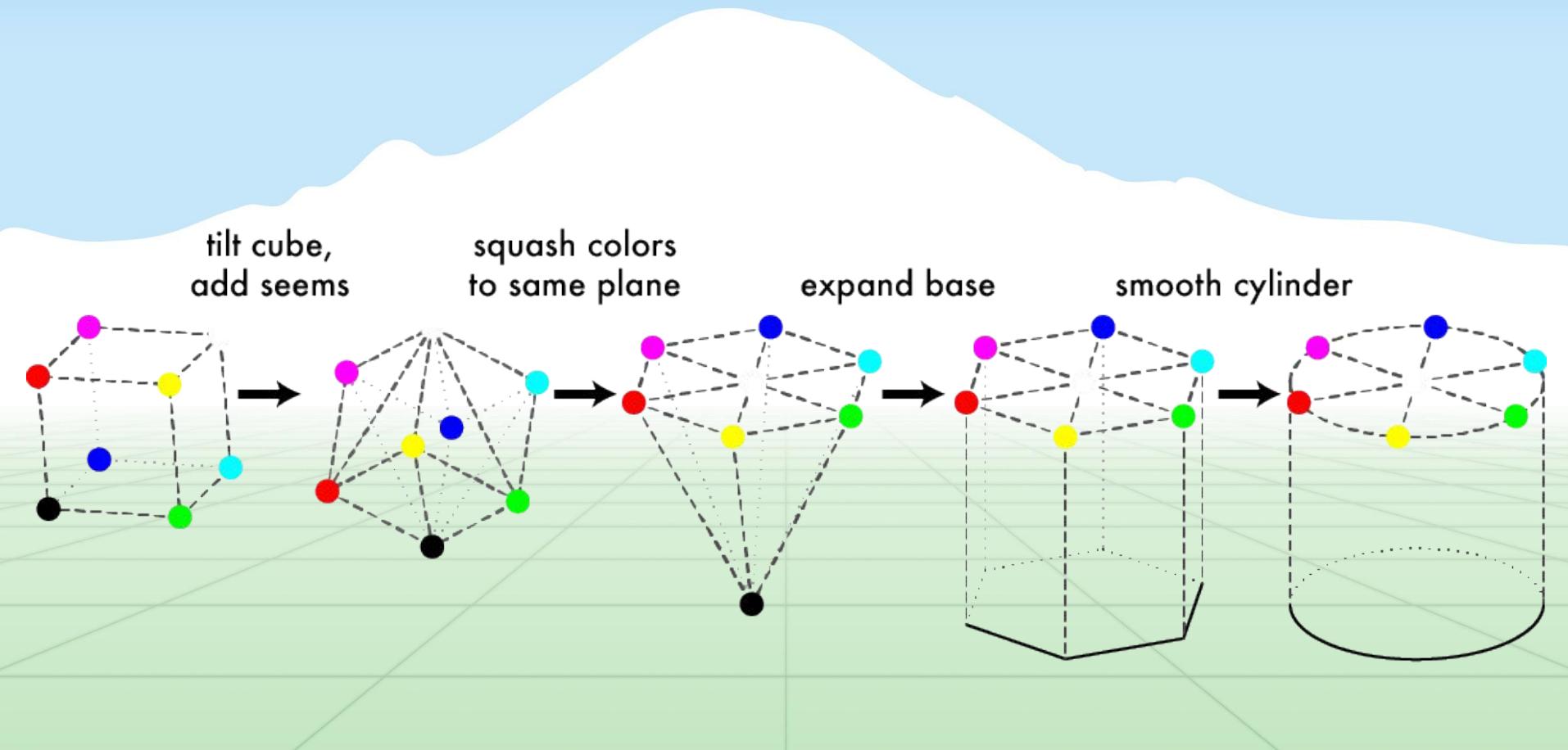


Fun with other colorspaces!

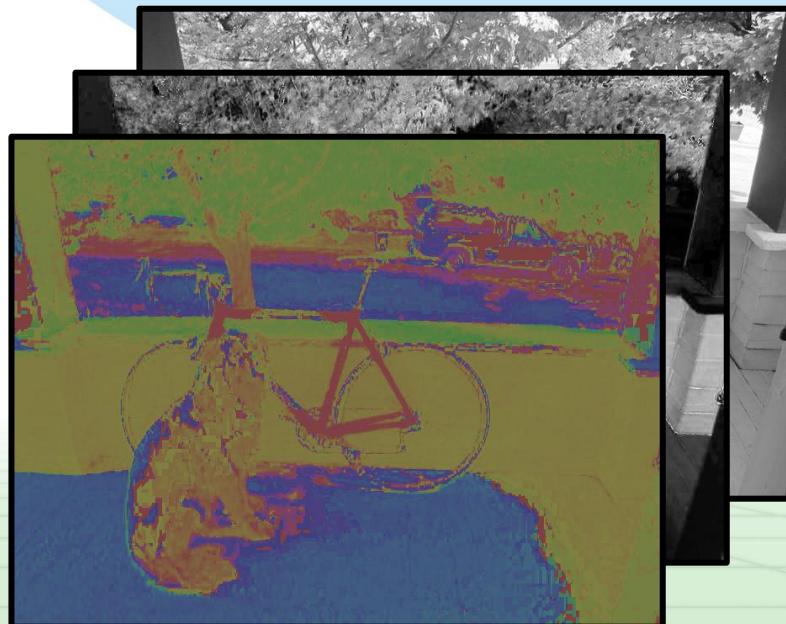
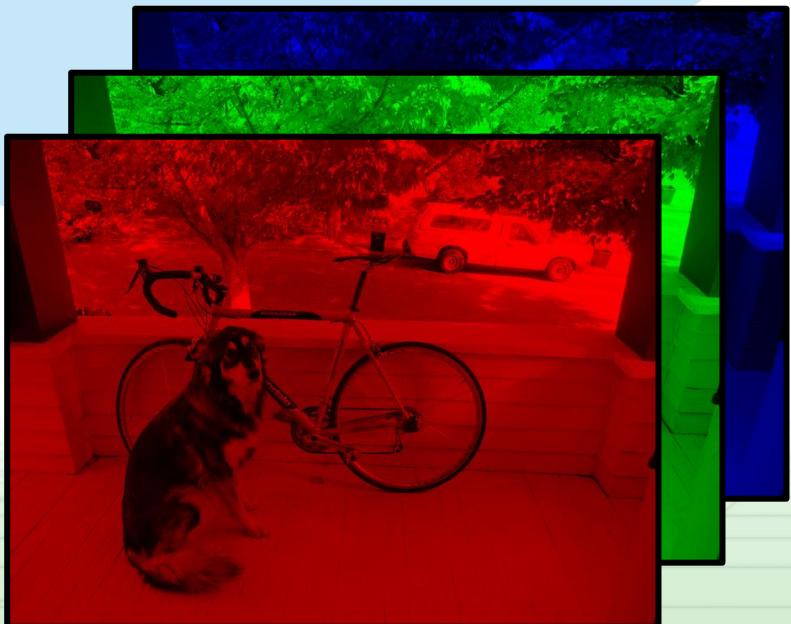
Other colorspaces are fun!



Geometric HSV to RGB:



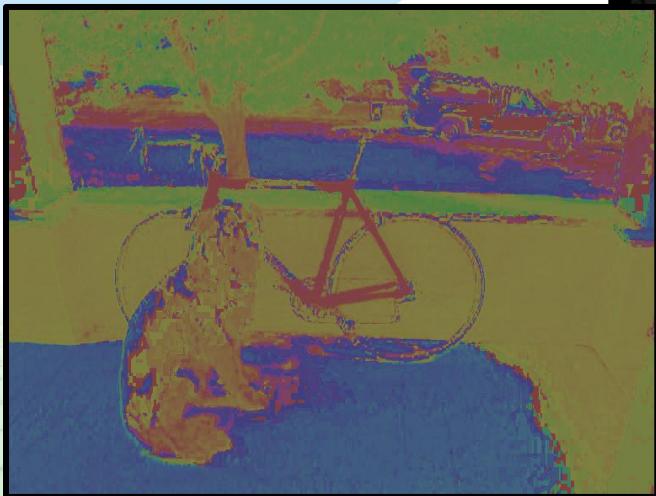
Still 3d tensor, different info



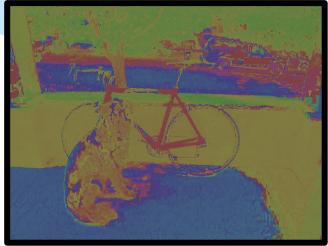
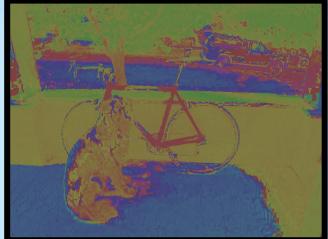
Hue

Saturation

Value



More saturation = intense colors



2x



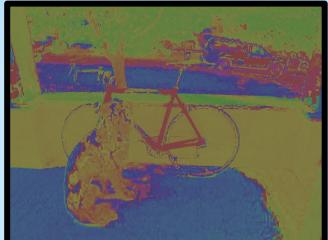
More value = lighter image



2x



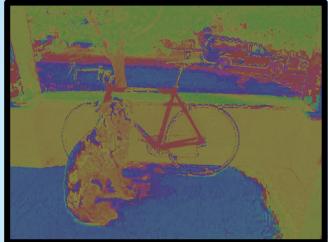
Shift hue = shift colors



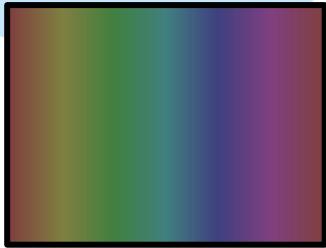
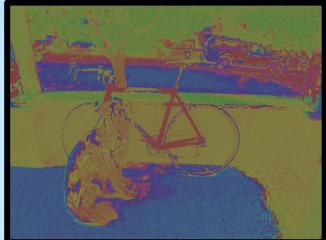
- .2



Set hue to your favorite color!



Or pattern...



Increase and threshold saturation

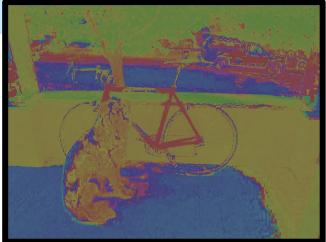
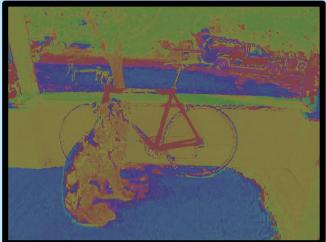






Image interpolation and resizing



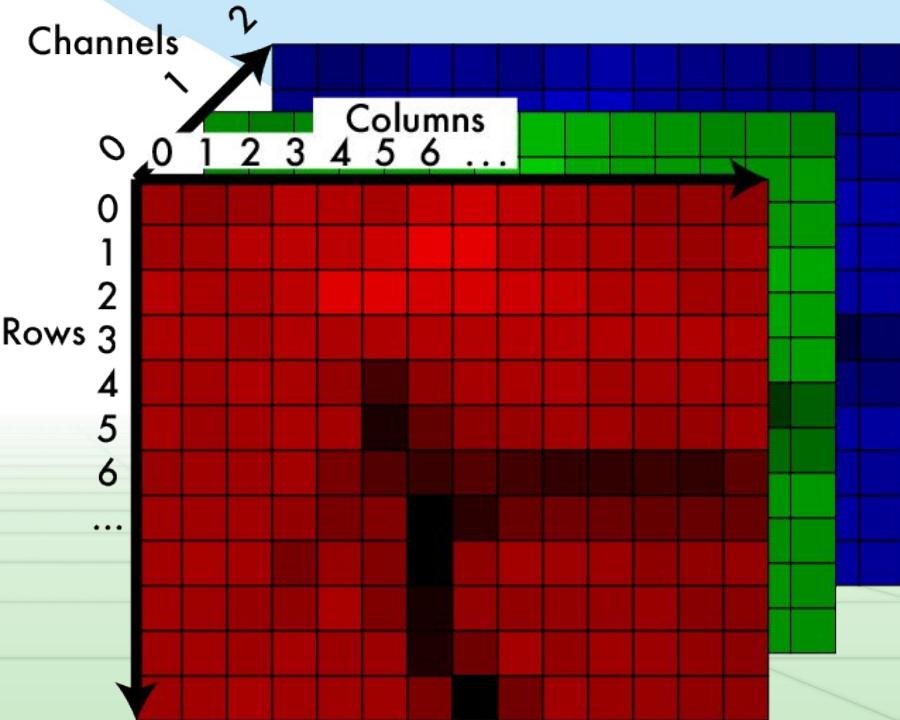
An image is kinda like a function

An image is a mapping from indices to pixel value:

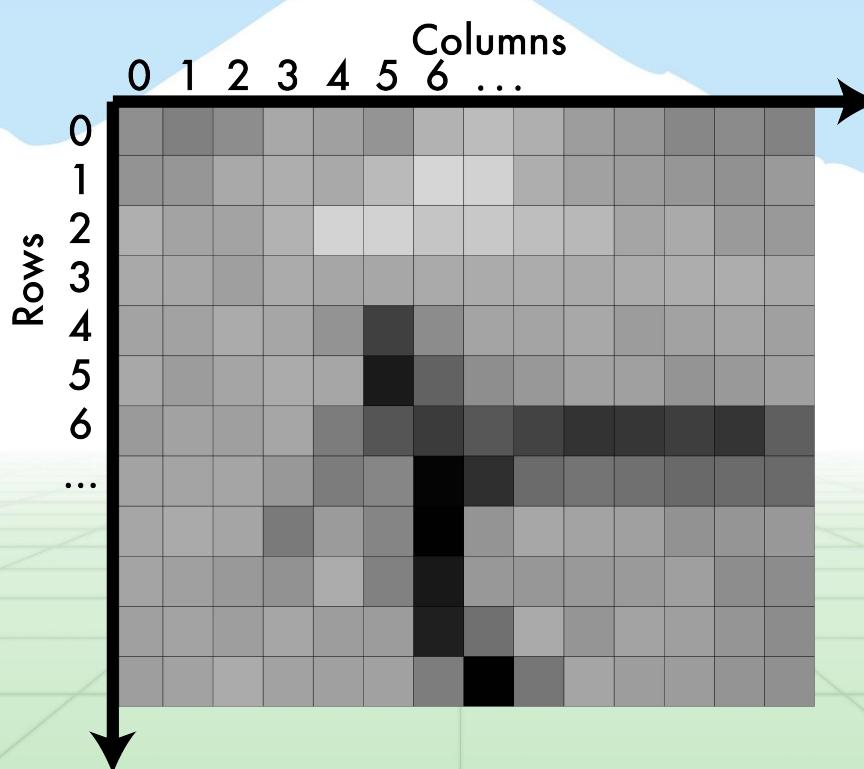
- $\text{Im}: \mathbb{I} \times \mathbb{I} \times \mathbb{I} \rightarrow \mathbb{R}$

We may want to pass in non-integers:

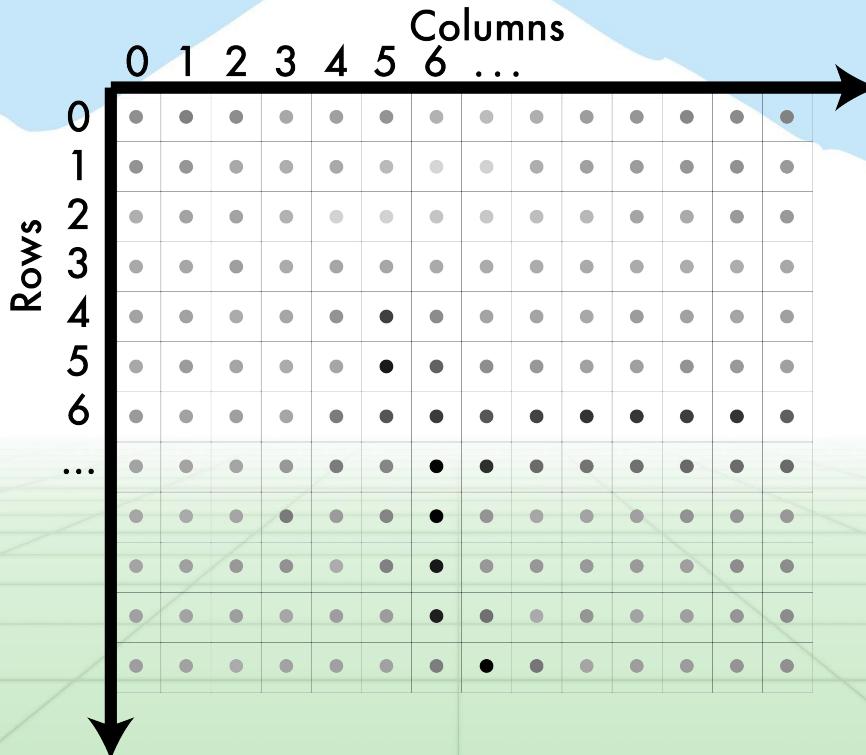
- $\text{Im}': \mathbb{R} \times \mathbb{R} \times \mathbb{I} \rightarrow \mathbb{R}$



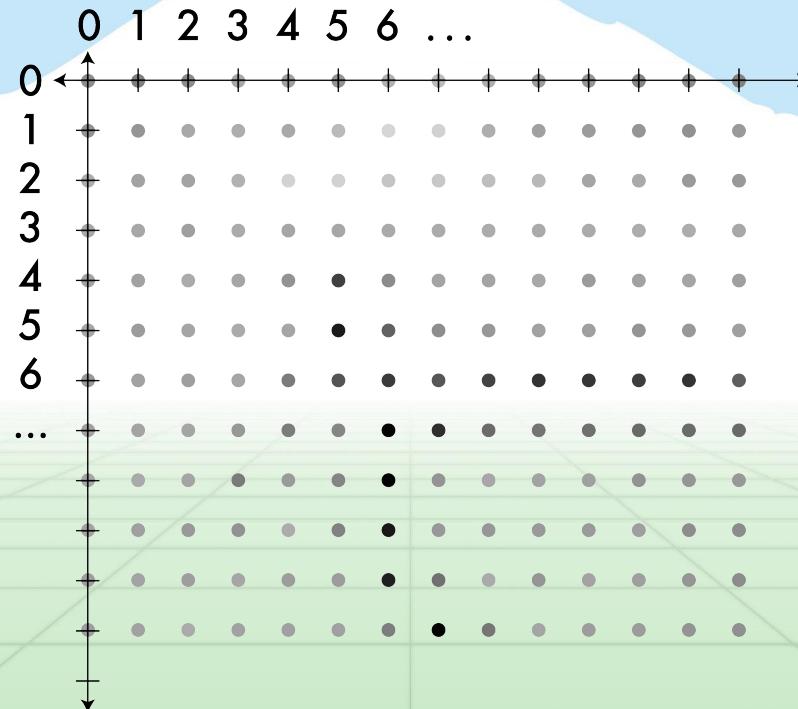
A note on coordinates in images



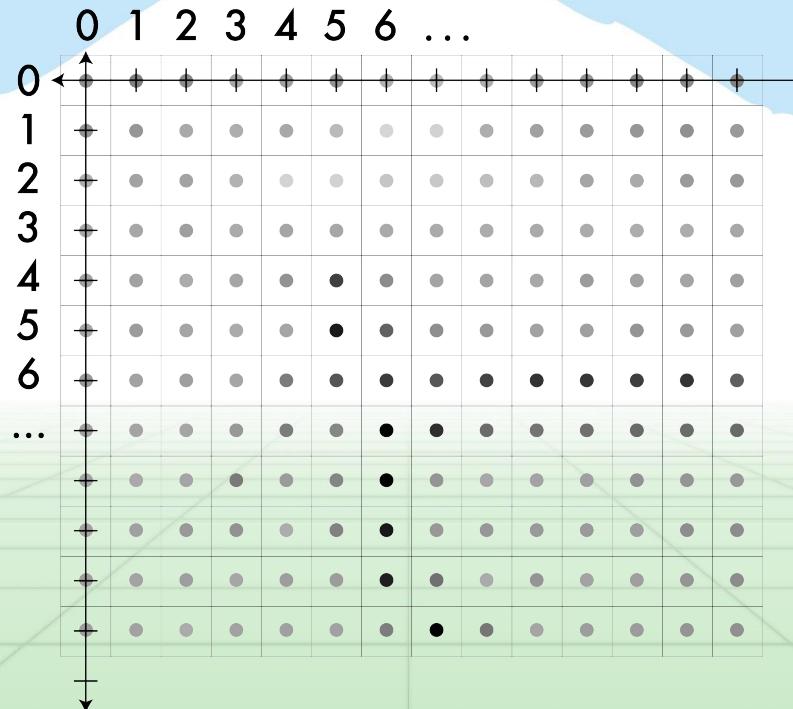
A note on coordinates in images



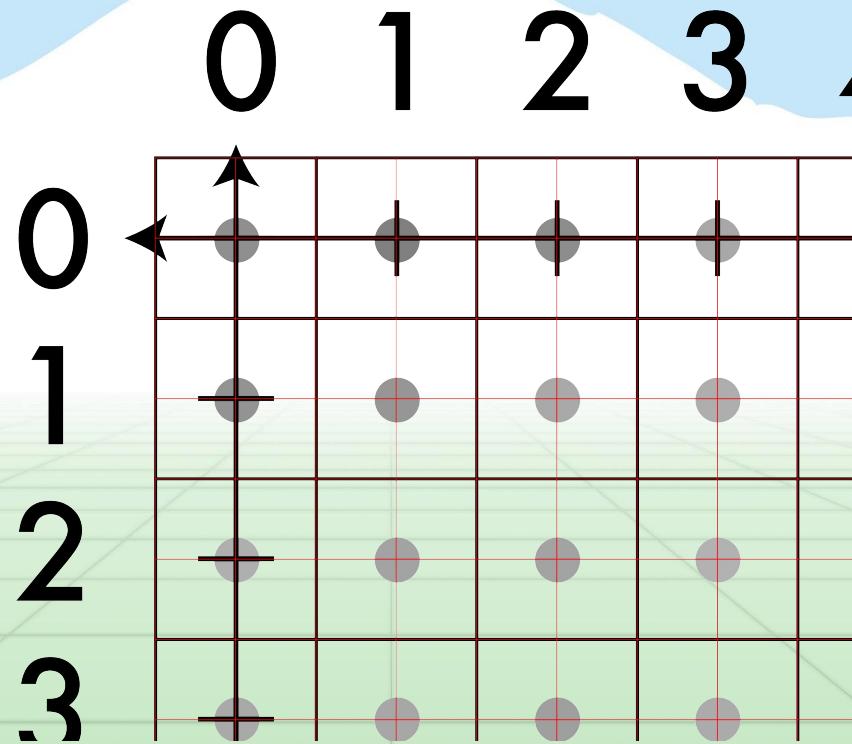
A note on coordinates in images



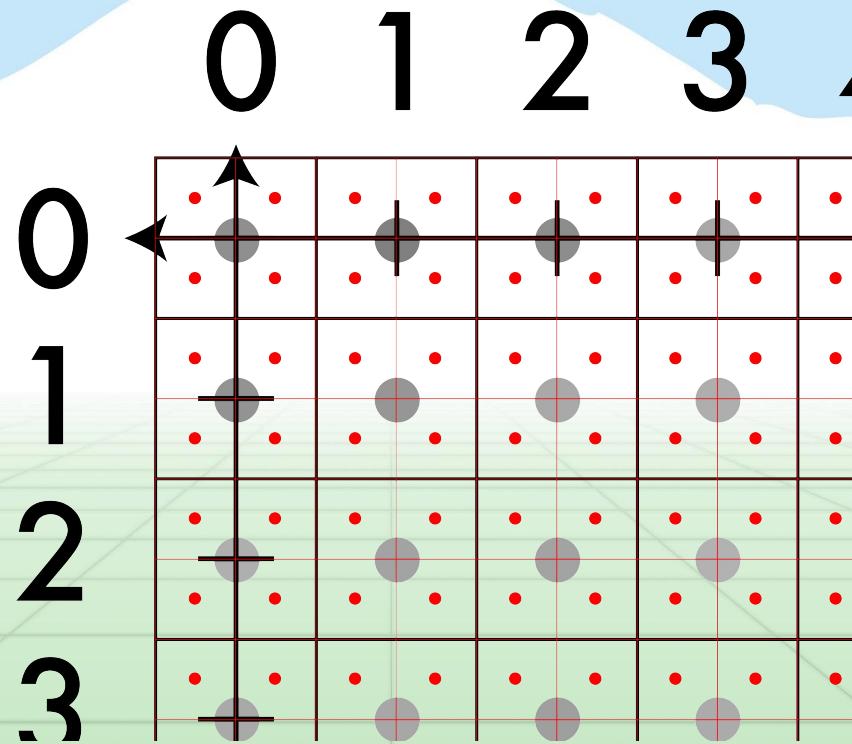
A note on coordinates in images



A note on coordinates in images

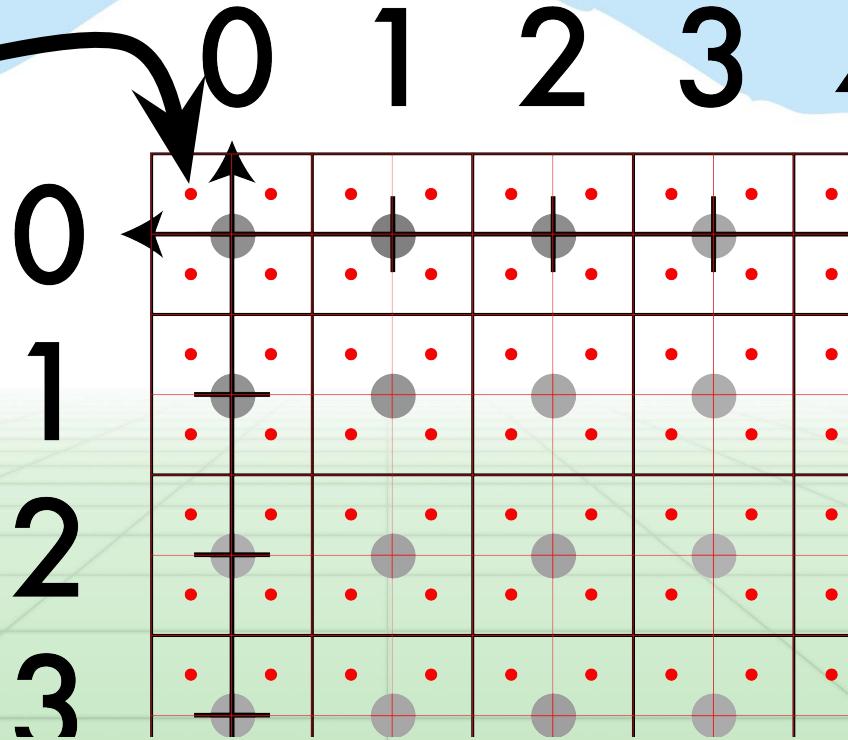


A note on coordinates in images



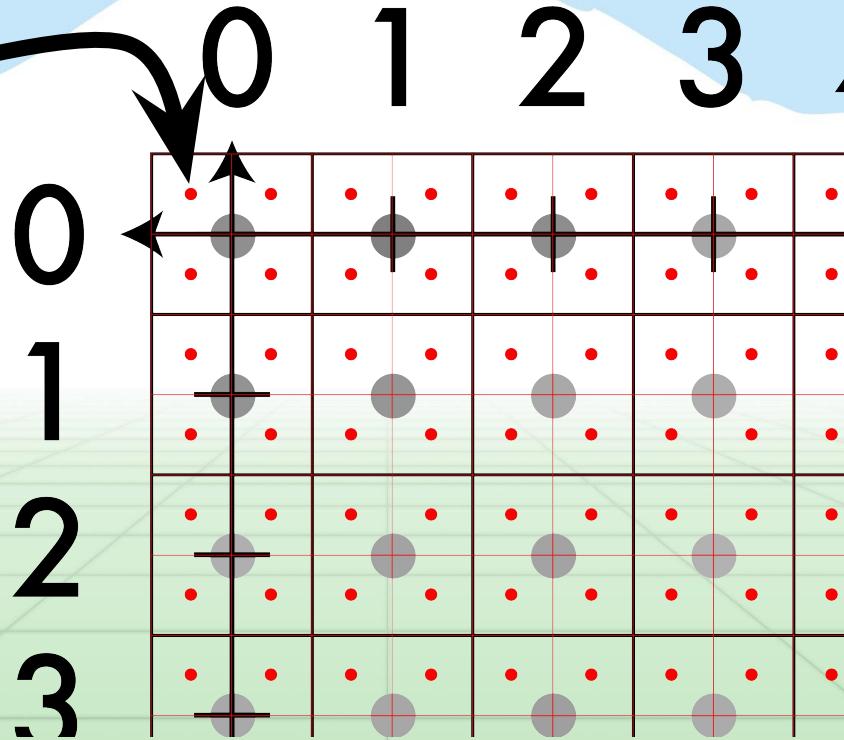
A note on coordinates in images

This point is:
 $(-.25, -.25)$



Just be careful, lots of pitfalls

This point is:
 $(-.25, -.25)$



Nearest neighbor: what it sounds like

$f(x,y,z) = \text{Im}(\text{round}(x), \text{round}(y), z)$

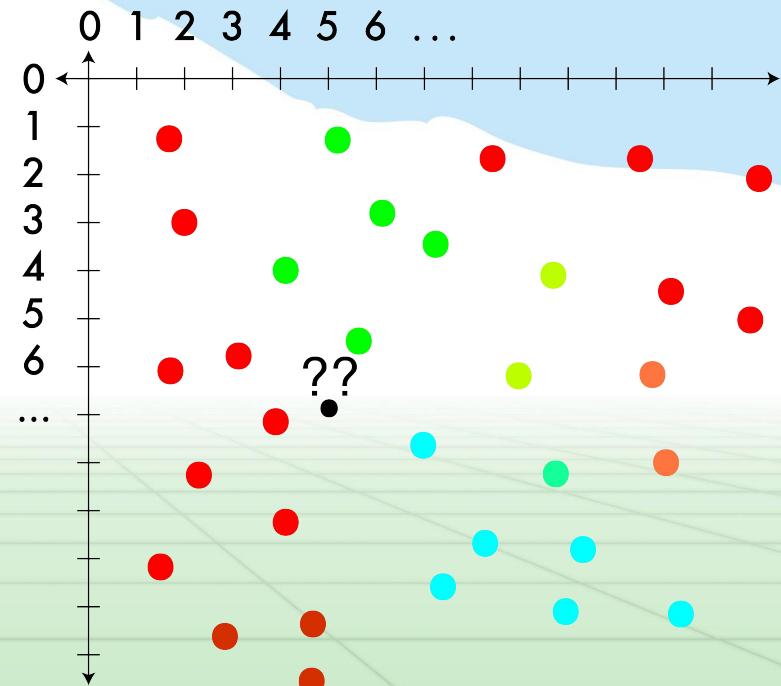
- Looks blocky
- Common pitfall:
Integer division
rounds down in C
- Note: z is still int



Triangle interpolation: for less structured image

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

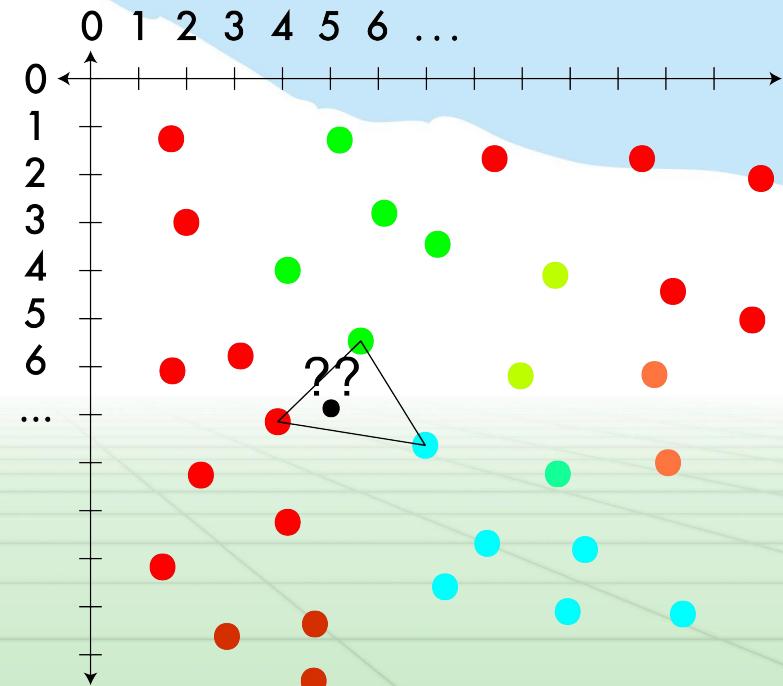
When you don't look for triangles!



Triangle interpolation: for less structured image

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

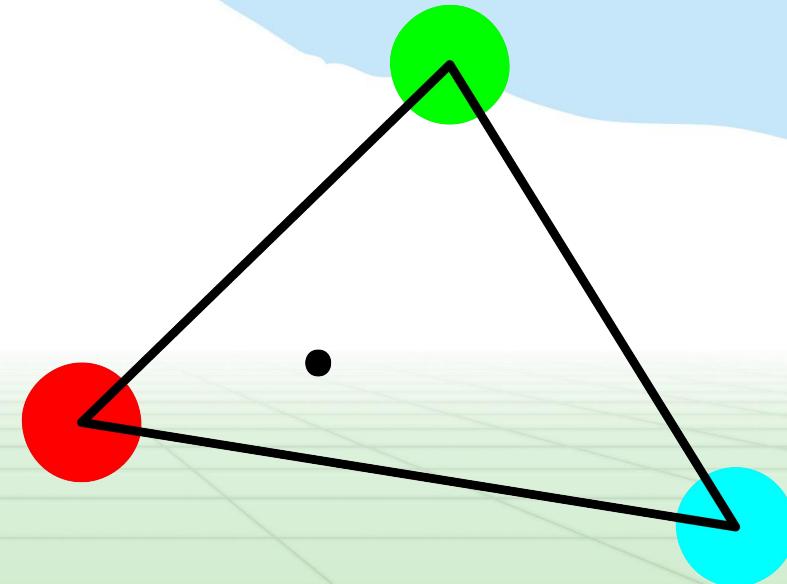
When you don't look for triangles!



Triangle interpolation: for less structured image

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

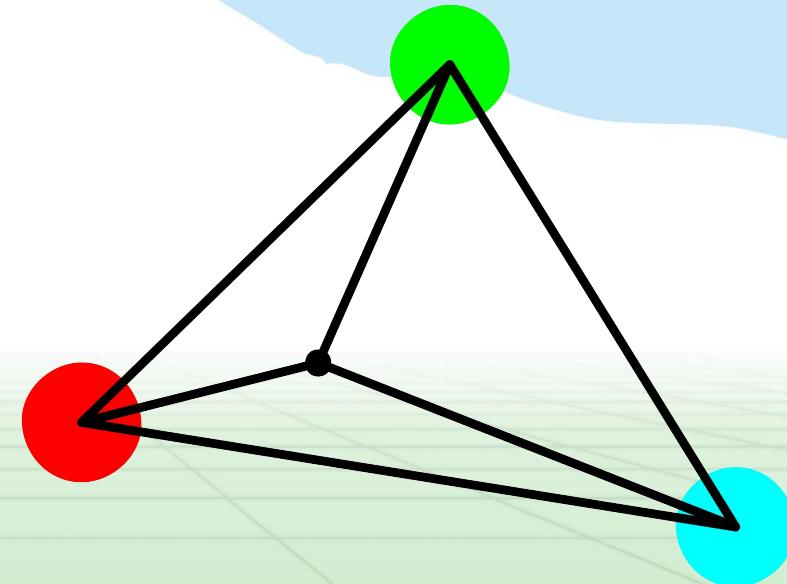
When you don't look for triangles!



Triangle interpolation: for less structured image

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

When you don't look for triangles!

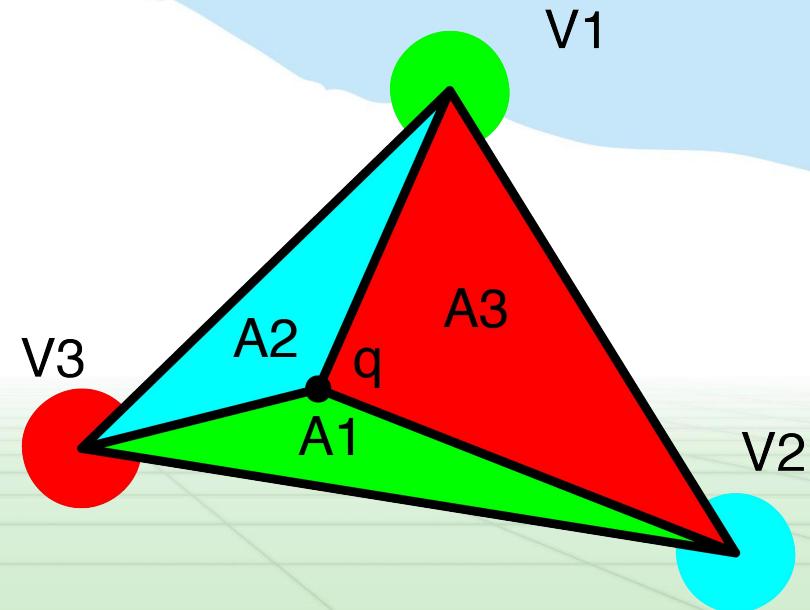


Triangle interpolation: for less structured image

Weighted sum using of triangles:

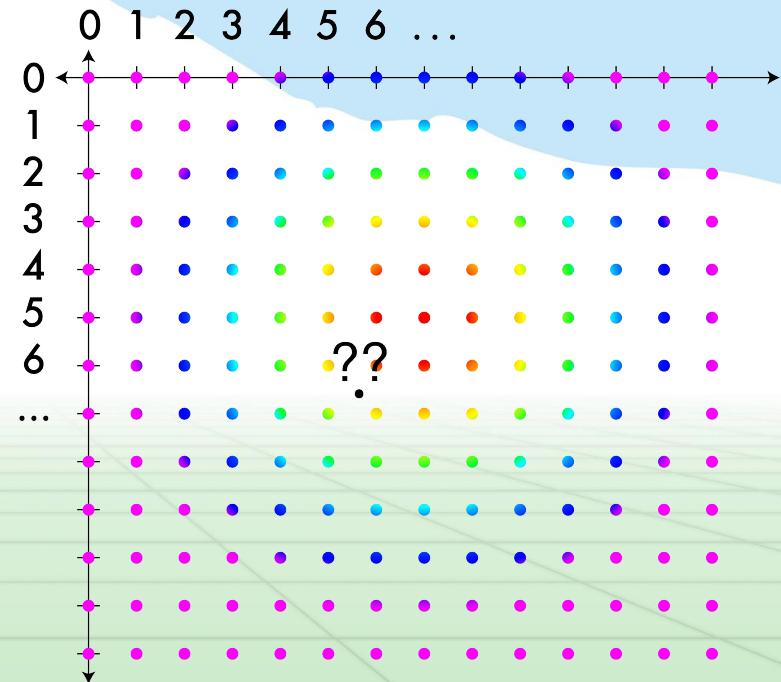
$$Q = V1 * A1 + V2 * A2 + V3 * A3$$

Should normalize this based on total area



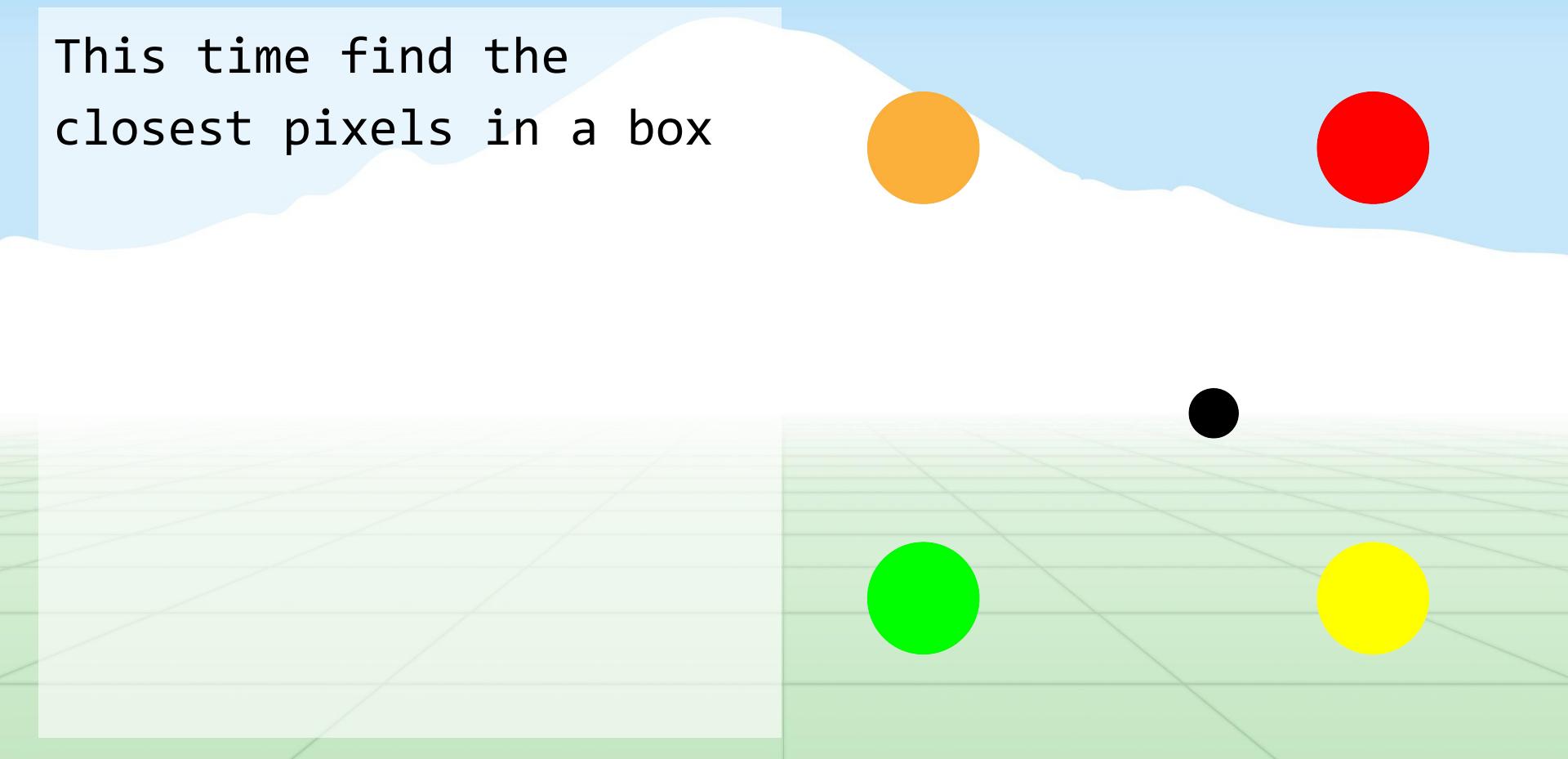
Bilinear interpolation: for grids, pretty good

This time find the
closest pixels in a box



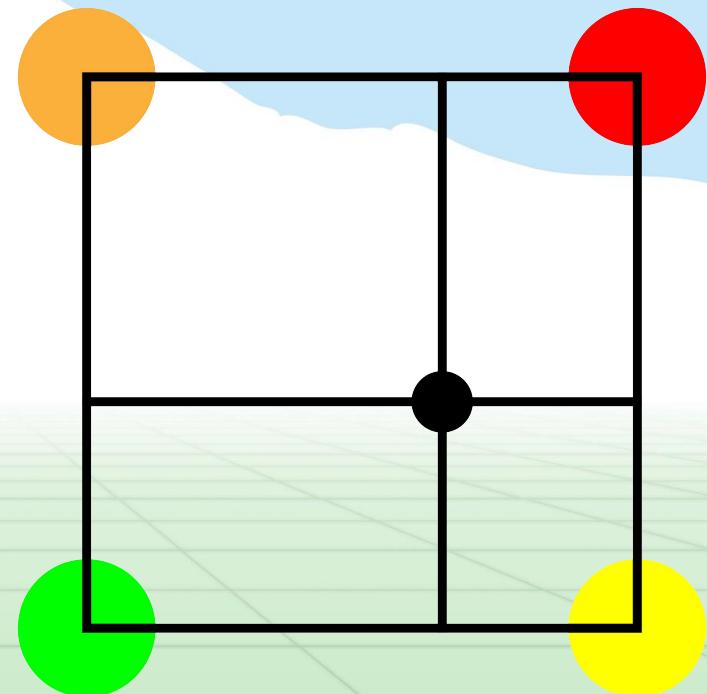
Bilinear interpolation: for grids, pretty good

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

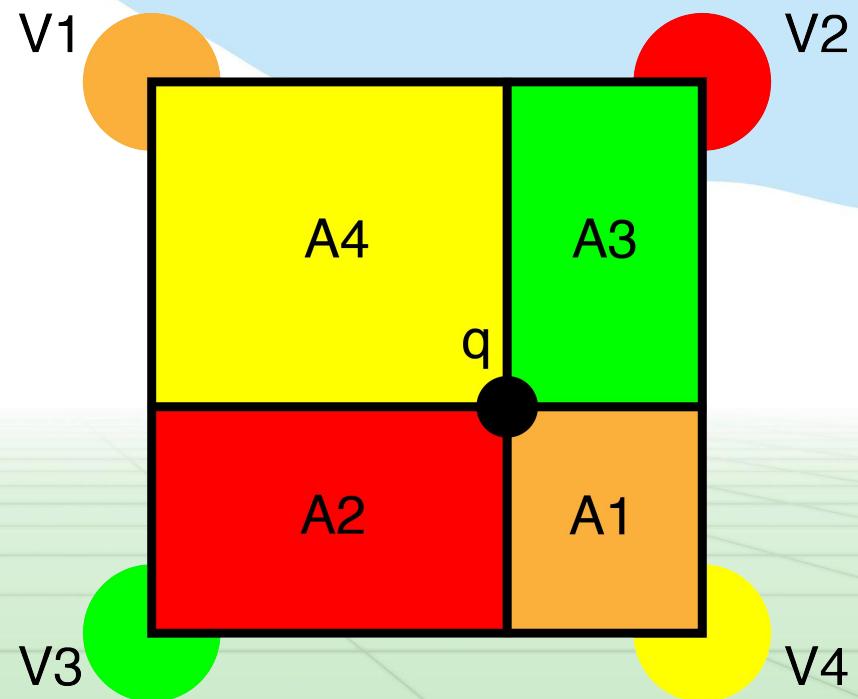
This time find the closest pixels in a box

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?



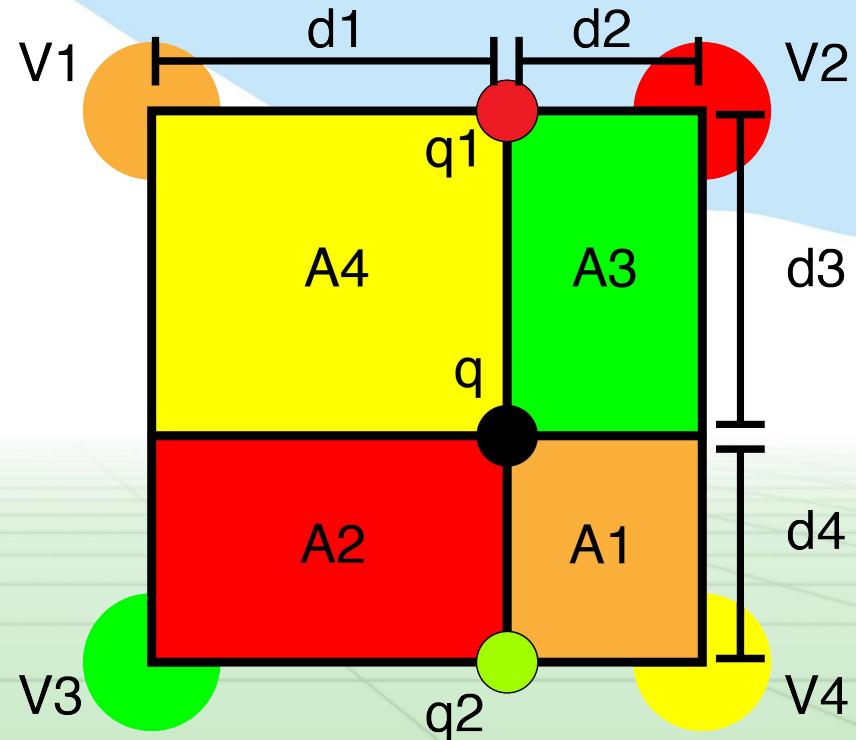
Bilinear interpolation: for grids, pretty good

Alternatively, linear
interpolation of linear
interpolates

$$q_1 = V1 \cdot d_2 + V2 \cdot d_1$$

$$q_2 = V3 \cdot d_2 + V4 \cdot d_1$$

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$



Bilinear interpolation: for grids, pretty good

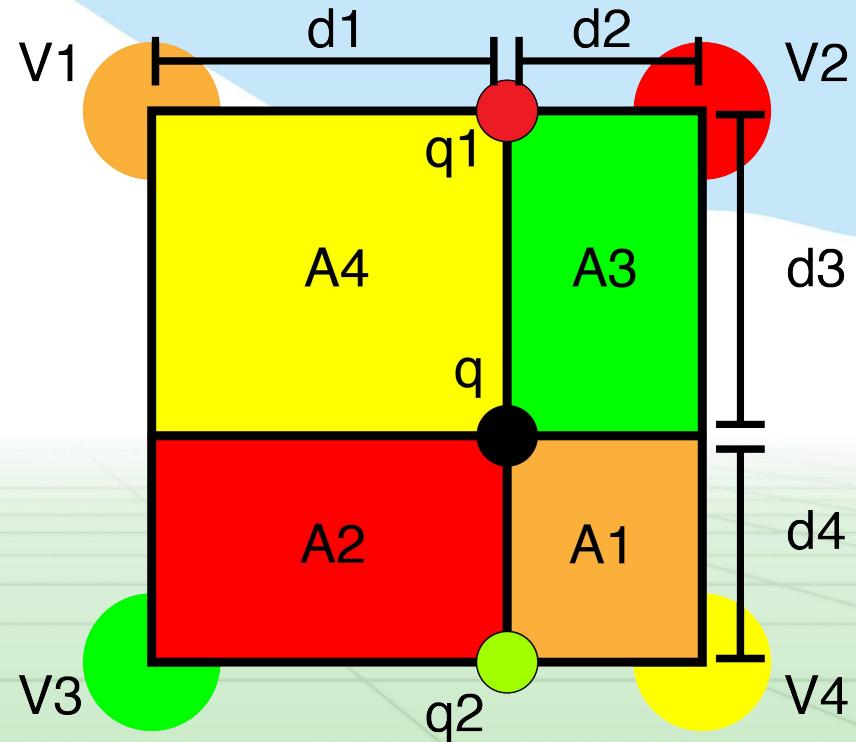
$$q_1 = V_1 \cdot d_2 + V_2 \cdot d_1$$

$$q_2 = V_3 \cdot d_2 + V_4 \cdot d_1$$

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

Equivalent:

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$



Bilinear interpolation: for grids, pretty good

$$q_1 = V_1 \cdot d_2 + V_2 \cdot d_1$$

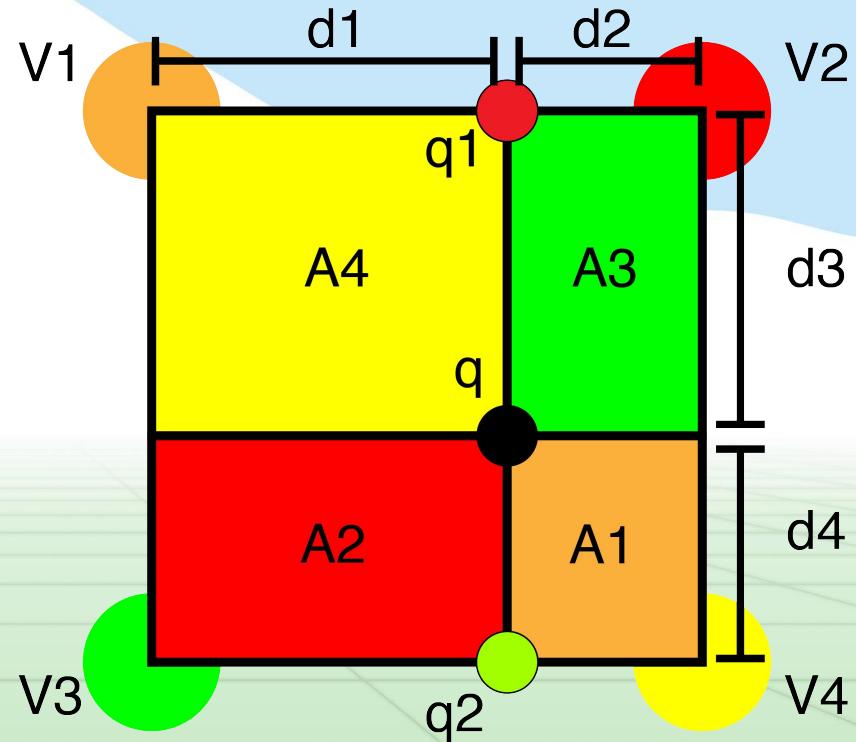
$$q_2 = V_3 \cdot d_2 + V_4 \cdot d_1$$

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

Equivalent:

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

$$q = (V_1 \cdot d_2 + V_2 \cdot d_1) \cdot d_4 + (V_3 \cdot d_2 + V_4 \cdot d_1) \cdot d_3 \text{ (subst)}$$



Bilinear interpolation: for grids, pretty good

$$q_1 = V_1 \cdot d_2 + V_2 \cdot d_1$$

$$q_2 = V_3 \cdot d_2 + V_4 \cdot d_1$$

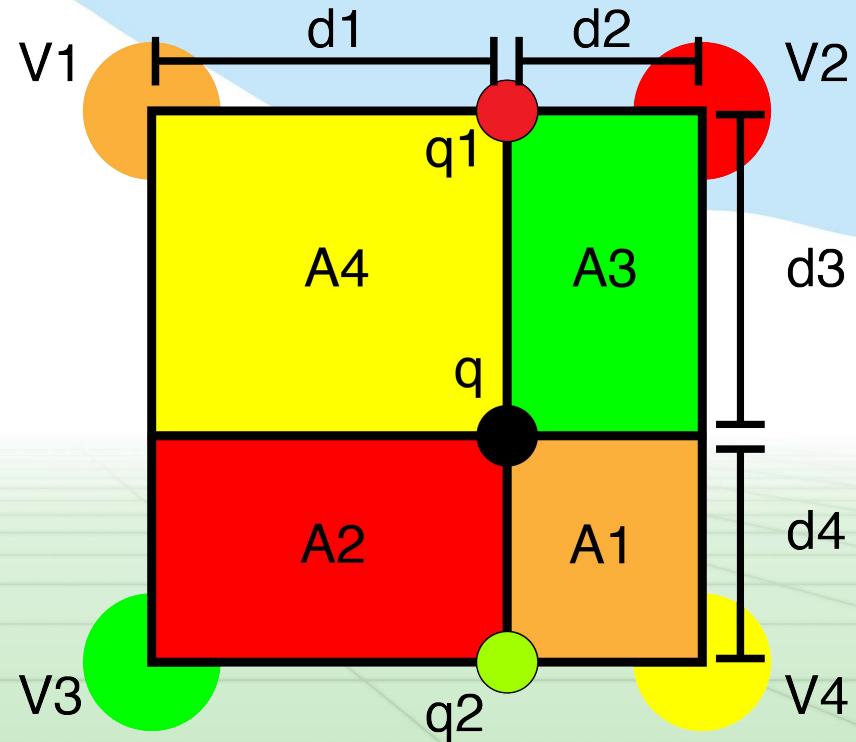
$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

Equivalent:

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

$$q = (V_1 \cdot d_2 + V_2 \cdot d_1) \cdot d_4 + (V_3 \cdot d_2 + V_4 \cdot d_1) \cdot d_3 \text{ (subst)}$$

$$q = V_1 \cdot d_2 \cdot d_4 + V_2 \cdot d_1 \cdot d_4 + V_3 \cdot d_2 \cdot d_3 + V_4 \cdot d_1 \cdot d_3 \text{ (distribution)}$$



Bilinear interpolation: for grids, pretty good

$$q_1 = V_1 \cdot d_2 + V_2 \cdot d_1$$

$$q_2 = V_3 \cdot d_2 + V_4 \cdot d_1$$

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

Equivalent:

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

$$q = (V_1 \cdot d_2 + V_2 \cdot d_1) \cdot d_4 + (V_3 \cdot d_2 + V_4 \cdot d_1) \cdot d_3 \text{ (subst)}$$

$$q = V_1 \cdot d_2 \cdot d_4 + V_2 \cdot d_1 \cdot d_4 + V_3 \cdot d_2 \cdot d_3 + V_4 \cdot d_1 \cdot d_3 \text{ (distribution)}$$

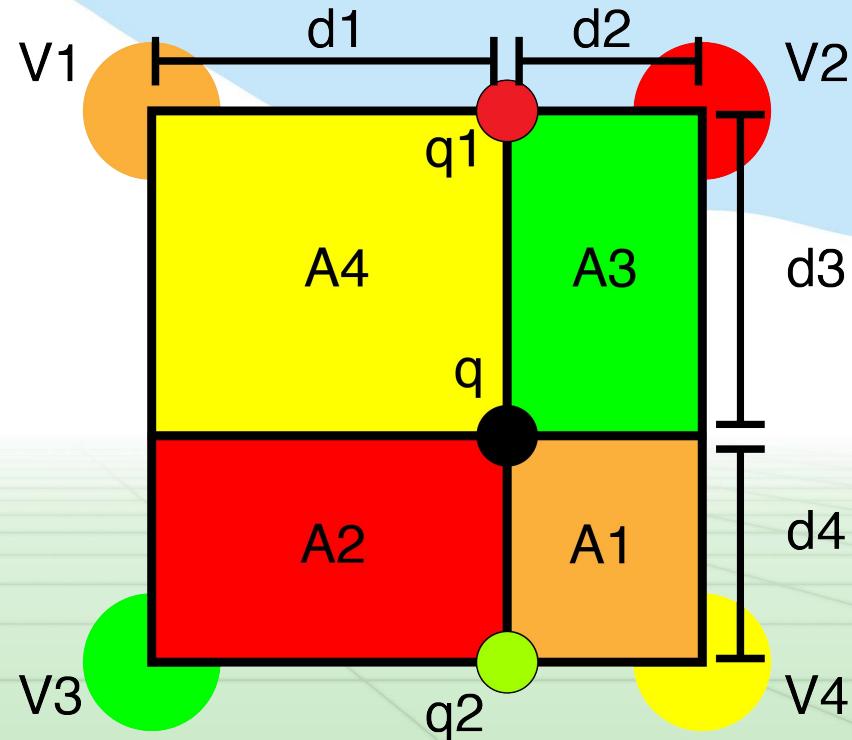
Recall:

$$A_1 = d_2 \cdot d_4$$

$$A_2 = d_1 \cdot d_4$$

$$A_3 = d_2 \cdot d_3$$

$$A_4 = d_1 \cdot d_3$$



Bilinear interpolation: for grids, pretty good

$$q_1 = V_1 \cdot d_2 + V_2 \cdot d_1$$

$$q_2 = V_3 \cdot d_2 + V_4 \cdot d_1$$

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

Equivalent:

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

$$q = (V_1 \cdot d_2 + V_2 \cdot d_1) \cdot d_4 + (V_3 \cdot d_2 + V_4 \cdot d_1) \cdot d_3 \text{ (subst)}$$

$$q = V_1 \cdot d_2 \cdot d_4 + V_2 \cdot d_1 \cdot d_4 + V_3 \cdot d_2 \cdot d_3 + V_4 \cdot d_1 \cdot d_3 \text{ (distribution)}$$

Recall:

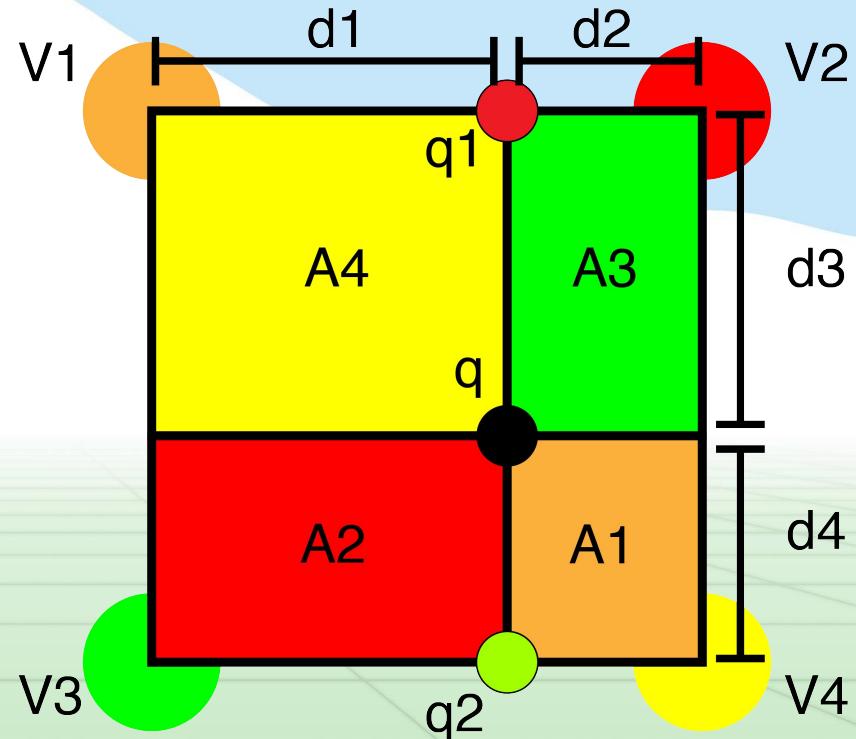
$$A_1 = d_2 \cdot d_4$$

$$A_2 = d_1 \cdot d_4$$

$$A_3 = d_2 \cdot d_3$$

$$A_4 = d_1 \cdot d_3$$

$$q = V_1 \cdot A_1 + V_2 \cdot A_2 + V_3 \cdot A_3 + V_4 \cdot A_4$$



Bilinear interpolation: for grids, pretty good

$$q_1 = V_1 \cdot d_2 + V_2 \cdot d_1$$

$$q_2 = V_3 \cdot d_2 + V_4 \cdot d_1$$

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

Equivalent:

$$q = q_1 \cdot d_4 + q_2 \cdot d_3$$

$$q = (V_1 \cdot d_2 + V_2 \cdot d_1) \cdot d_4 + (V_3 \cdot d_2 + V_4 \cdot d_1) \cdot d_3 \text{ (subst)}$$

$$q = V_1 \cdot d_2 \cdot d_4 + V_2 \cdot d_1 \cdot d_4 + V_3 \cdot d_2 \cdot d_3 + V_4 \cdot d_1 \cdot d_3 \text{ (distribution)}$$

Recall:

$$A_1 = d_2 \cdot d_4$$

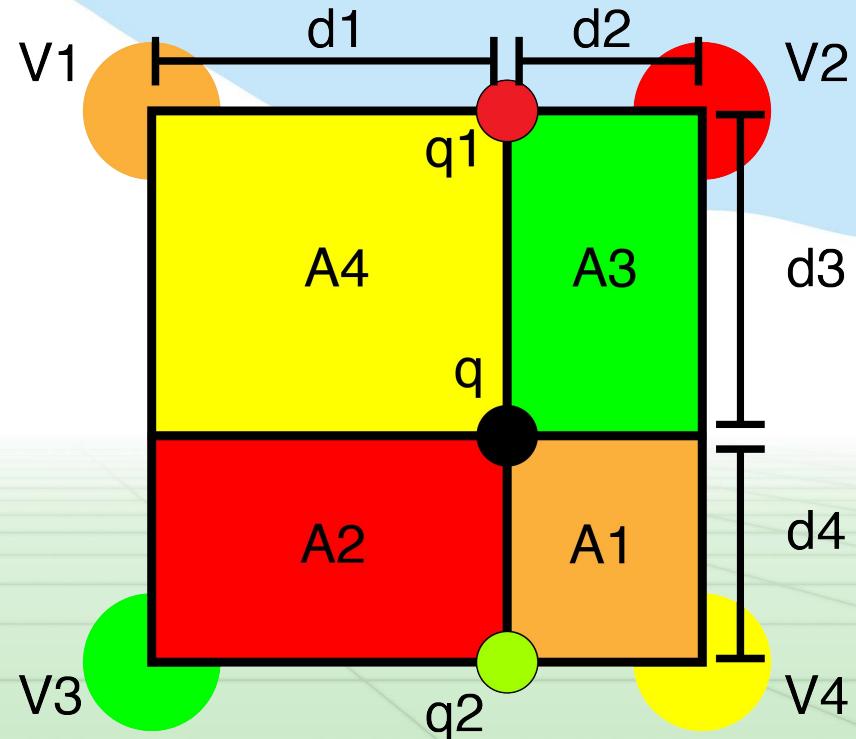
$$A_2 = d_1 \cdot d_4$$

$$A_3 = d_2 \cdot d_3$$

$$A_4 = d_1 \cdot d_3$$

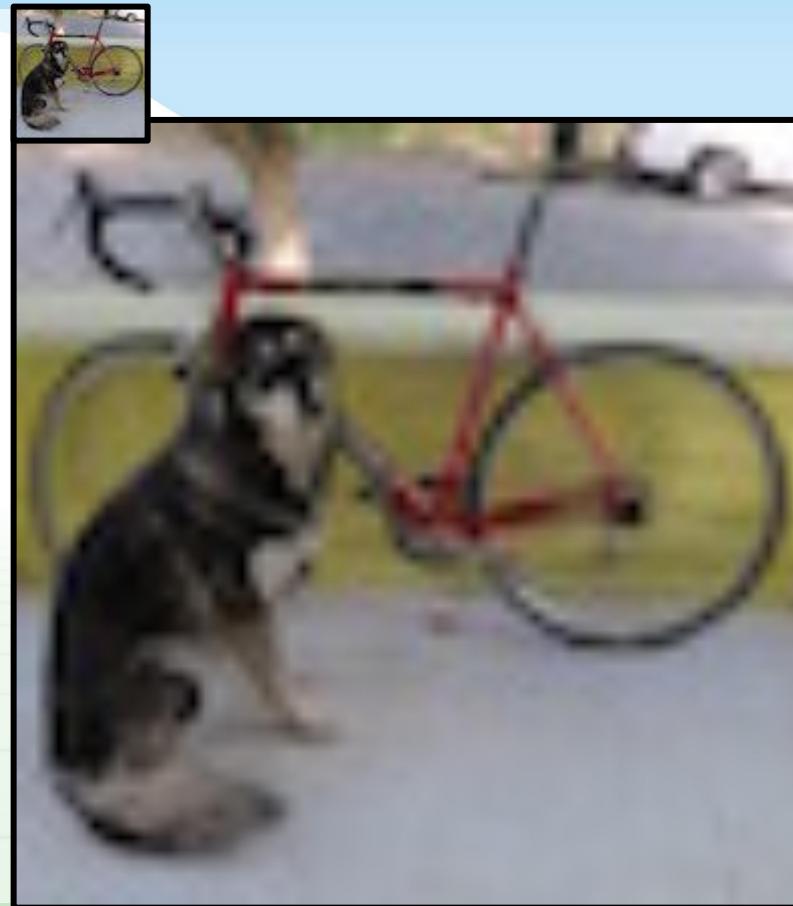
$$q = V_1 \cdot A_1 + V_2 \cdot A_2 + V_3 \cdot A_3 + V_4 \cdot A_4$$

yay!



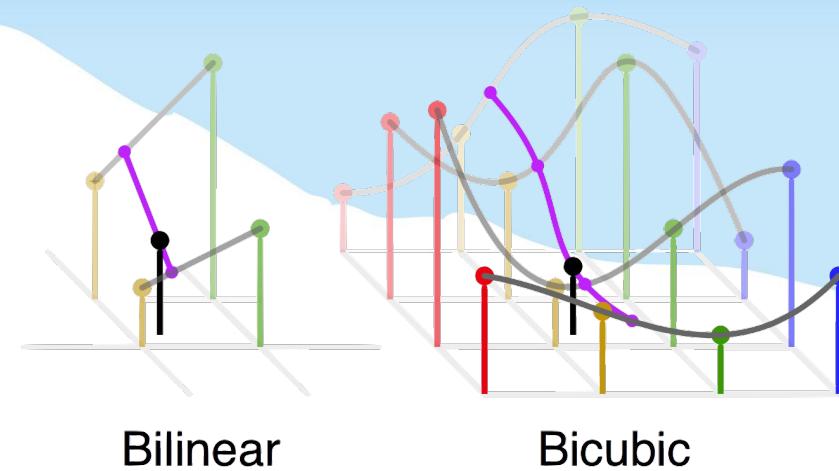
Bilinear interpolation: for grids, pretty good

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

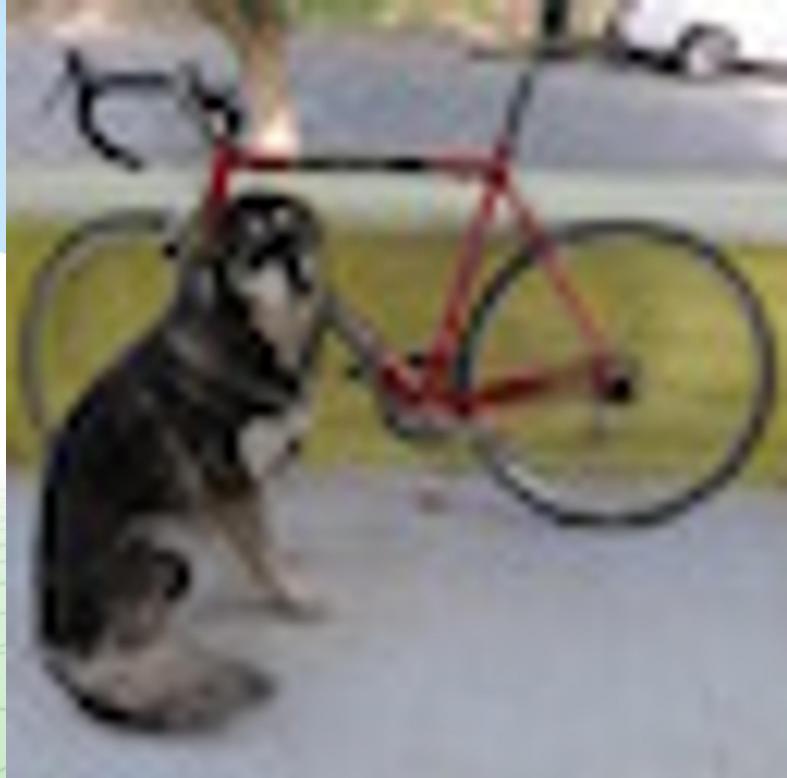


Bicubic sampling: more complex, maybe better?

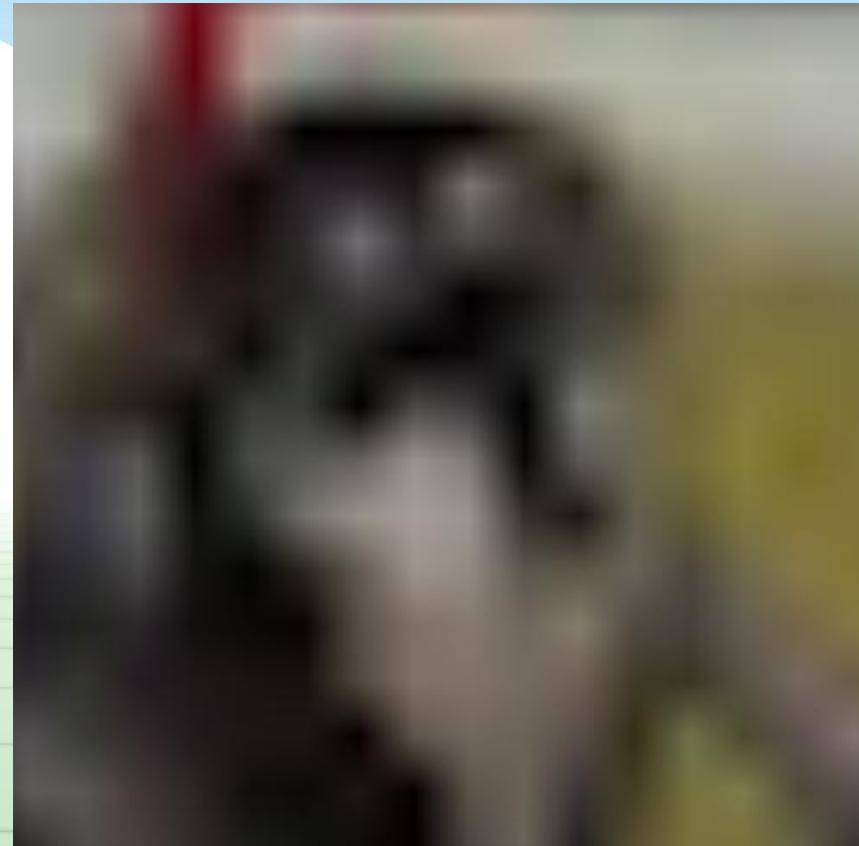
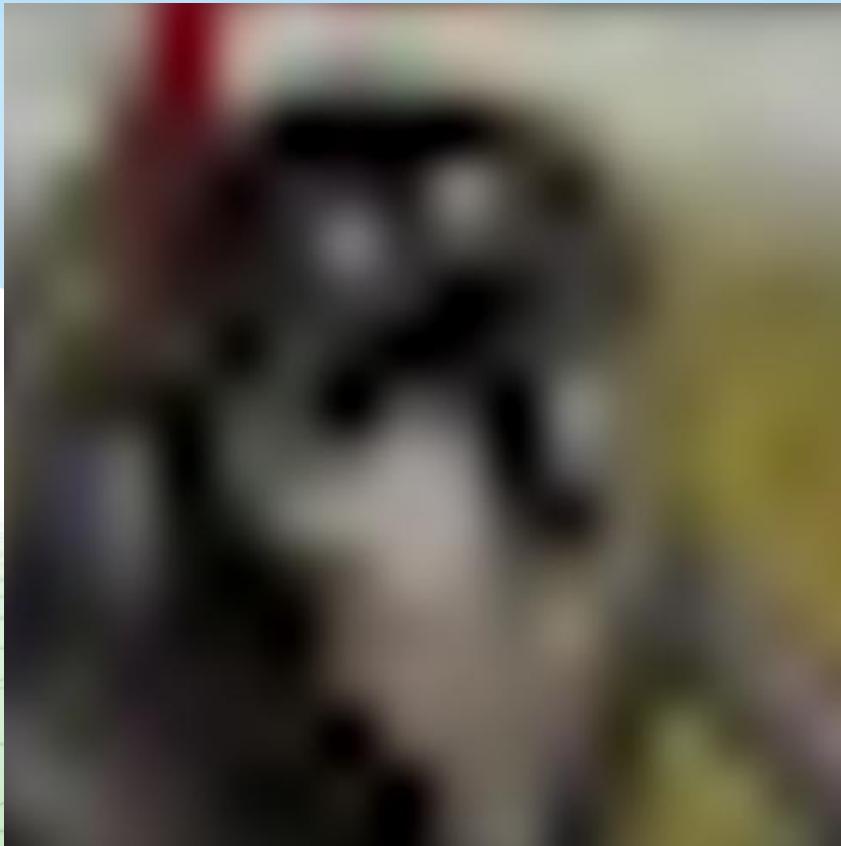
- A cubic interpolation of 4 cubic interpolations
- Smoother than bilinear, no “star”
- 16 nearest neighbors
- Fit 3rd order poly:
 - $f(x) = a + bx + cx^2 + dx^3$
- Interpolate along axis
- Fit another poly to interpolated values



Bicubic vs bilinear

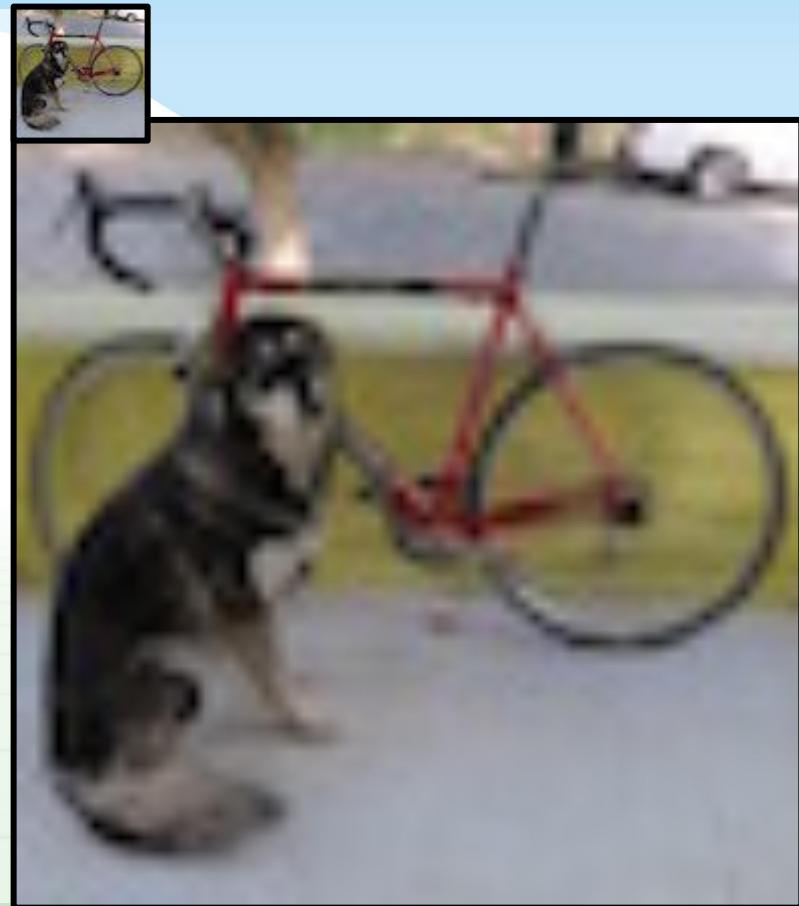


Bicubic vs bilinear



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!

