Tutorial 1
CS3241 Computer Graphics (AY22/23)

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Question 1

To be able to display **realistic** images, our display devices need to be able to produce every frequency in the visible light spectrum.

True or false? Why? What are the advantages and disadvantages?

Three-Color Theory

To be **realistic to human**

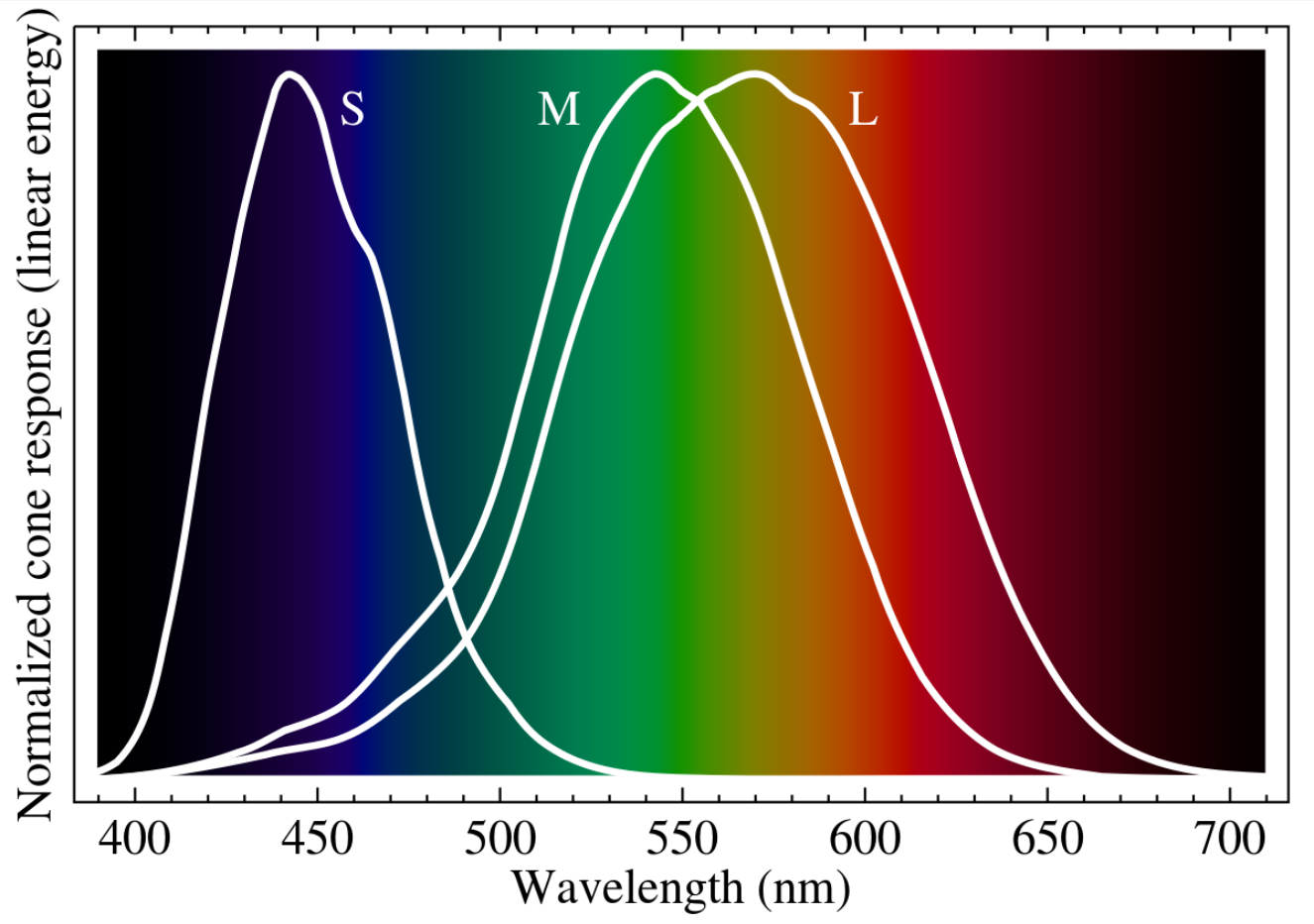
$\Rightarrow$ To be compatible with human visual system (L01, slide 35)

- Rods: Monochromatic
- **Cones**: Color sensitive to wavelengths
  - Long $\approx$ red
  - Medium $\approx$ green
  - Short $\approx$ blue

Proportion of the three gives us the sensation of different colors.

Cone sensitivity and Additive color theory

Single frequency = proportion of responses of each cone.



Additive Color Display

Pros

1. We don't have to produce light of every wavelength in vis. light spectrum for realism
2. We can see colors that are **NOT** on vis. light spectrum (e.g. **PURPLE**).
    - Visible colors are different combinations of amount of activity in RGB cones
    - Purple is not a specific wavelength but a combination of red and blue wavelengths (unlike violet which has its own wavelength)

Additive Color Display

Cons

Two different RGB values can produce the same color.

Q: What's an example of this?

A: There is no definitive inverse mapping of RGB to a wavelength, as it is display dependent.

https://physics.stackexchange.com/questions/248139/can-two-different-rgb-color-triplets-give-the-same-color

Question 2

Each pixel in a frame-buffer has 8 bits for each of the R, G and B channels. How many different colors can each pixel represent? Is this enough?

8 bits per channel (R, G, B): $2^{24} = \mathbf{16{,}777{,}216}$ colors.

32-bit color

In most graphical applications today, we have 4 channels:

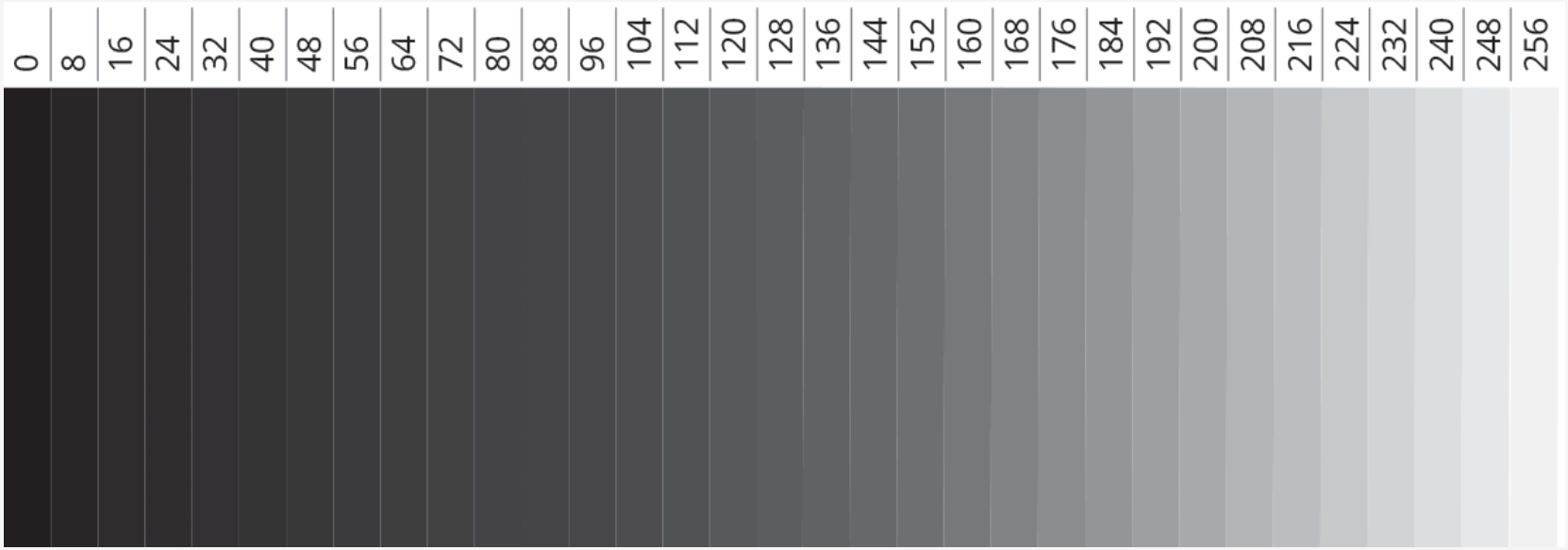
- R
- G
- B
- (not included in this question) A for Alpha (transparency)

Hence color has 32 bits: 2^{32} values (can be represented with an `int`)!
On color depth: https://computer.howstuffworks.com/monitor4.htm

32-bit color

Is this enough?

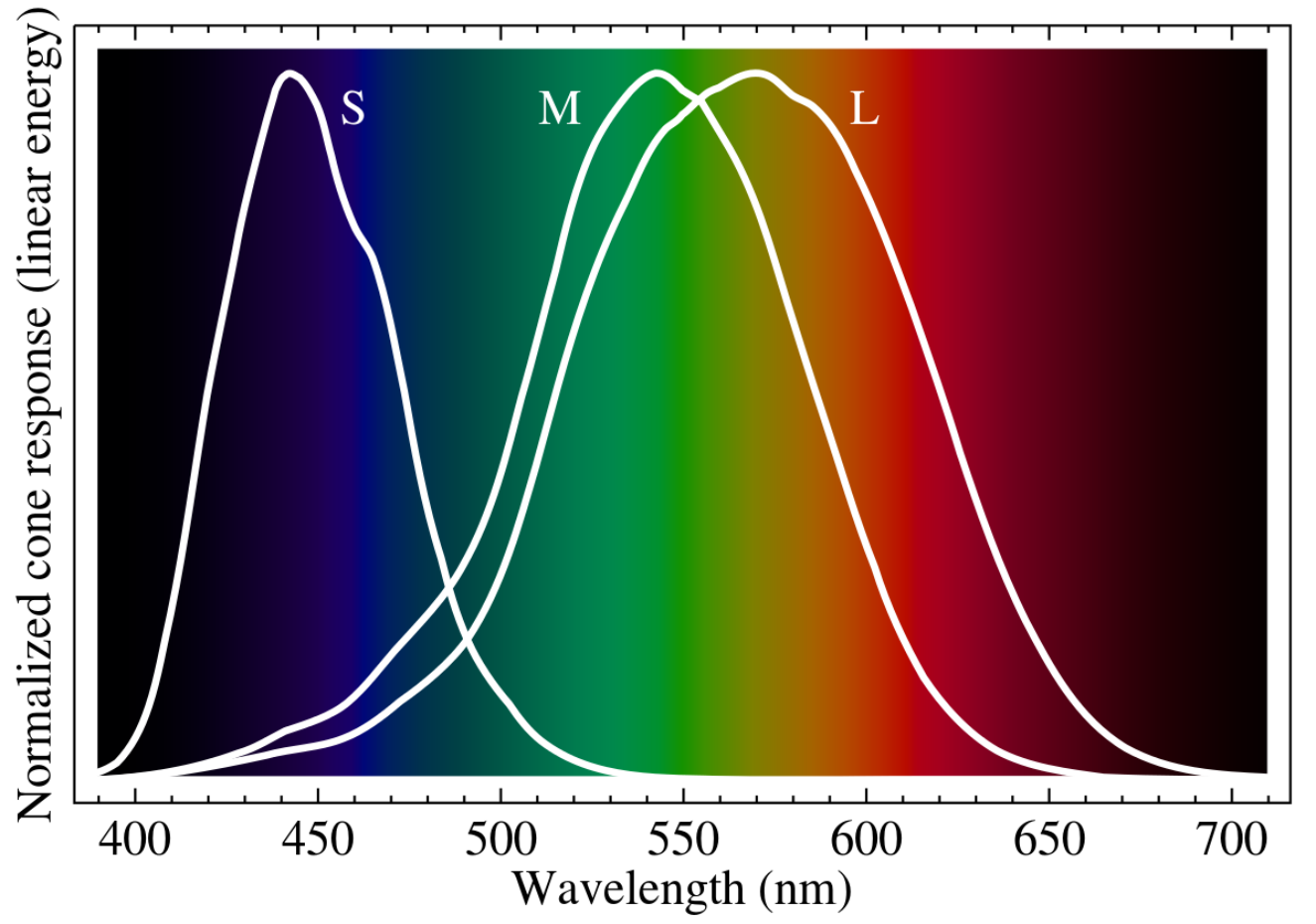
256 shades of gray: **banding artifacts**.



Use case decides if this is undesirable or not.

8-bit representation of color

On some systems, each pixel has only 8 bits (for all R, G, and B combined). How would you allocate the bits to the R, G and B primaries?



8-bit representation of color

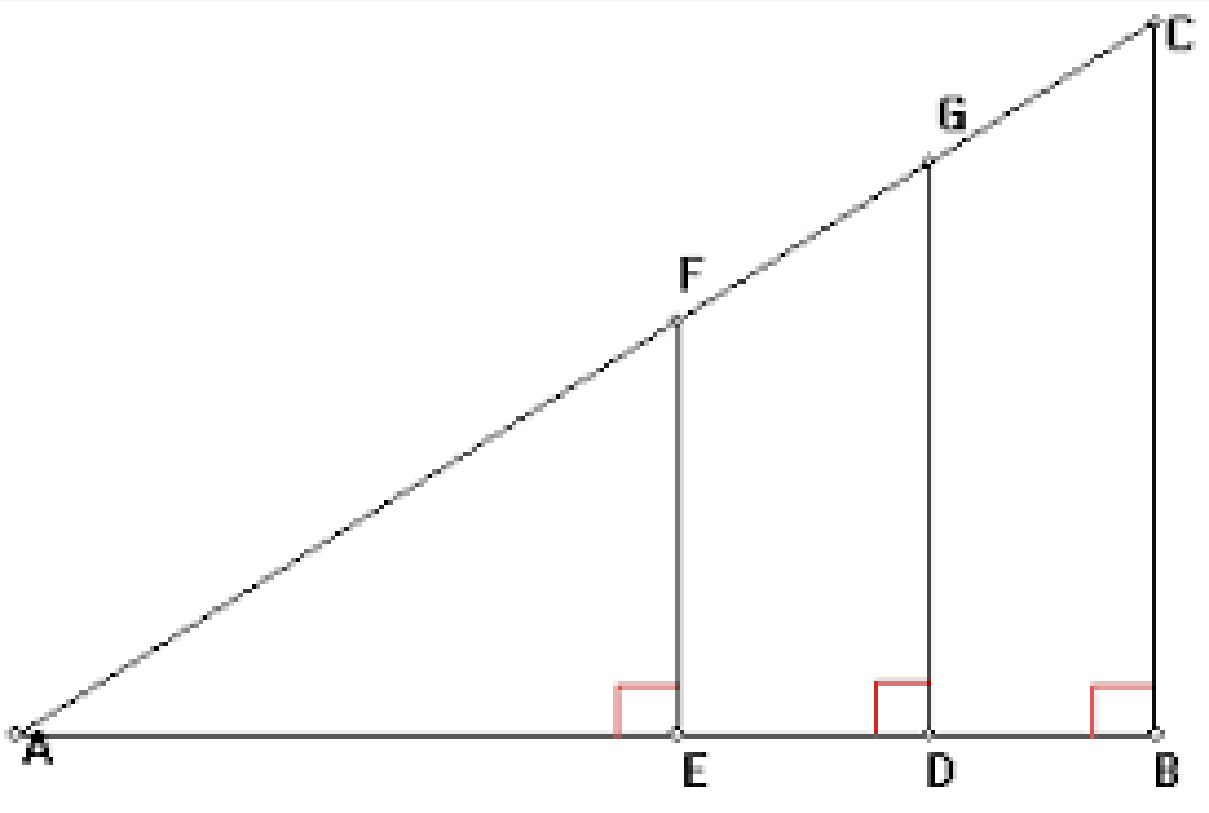
On some systems, each pixel has only 8 bits (for all R, G, and B combined). How would you allocate the bits to the R, G and B primaries?

> 3:3:2 for R:G:B. Our eyes are less sensitive to changes in blue, as you can see from the normalized cone response for high frequencies.

Question 3

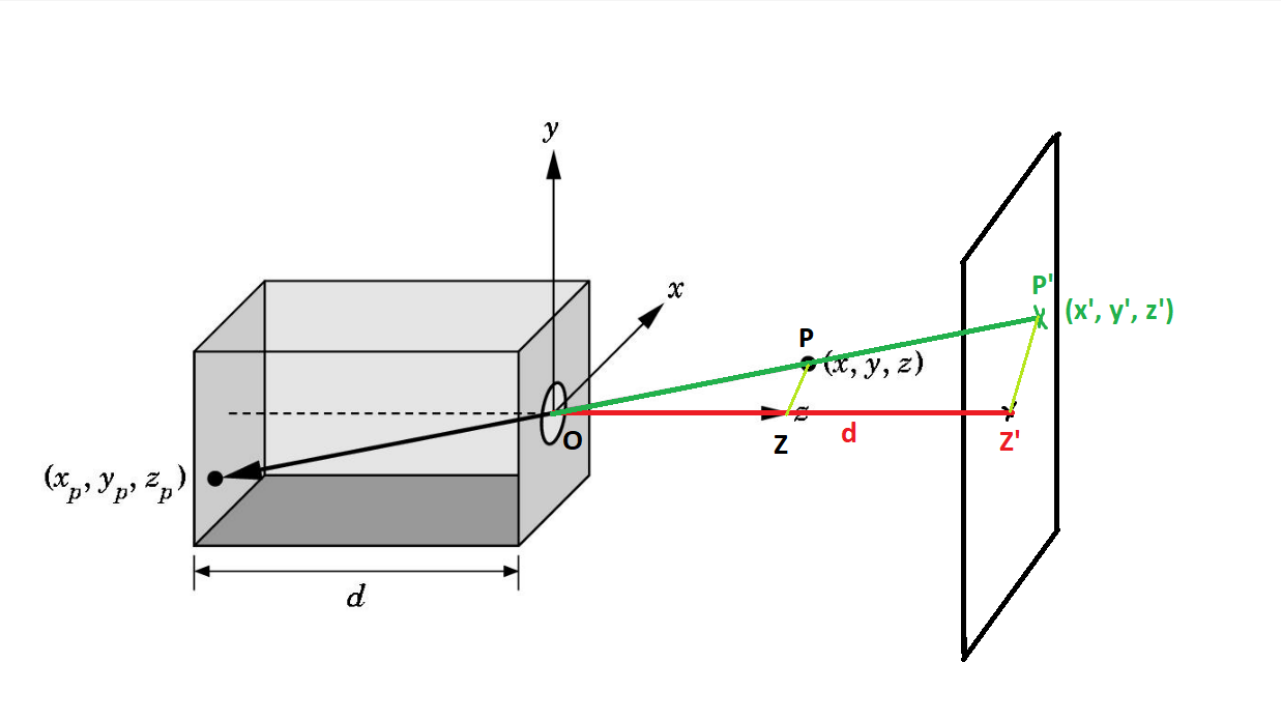
Referring to Lecture 1 Slide 31. If an imaginary image plane is d unit distance in front of the pinhole camera, what are the coordinates of the projection (on the imaginary image plane) of the 3D point (x, y, z)?

Similar triangles



$$\frac{AE}{AD} = \frac{AF}{AG} = \frac{EF}{DG}$$

Perspective

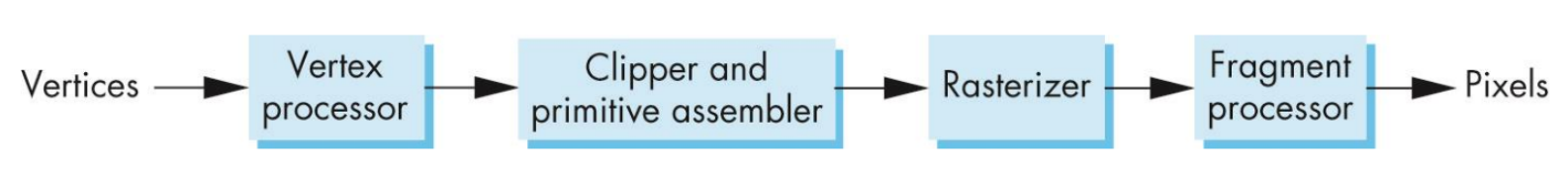


Notice that OPZ and $OP'Z'$ are similar triangles as their internal angles are identical.

$$\frac{x}{x'} = \frac{y}{y'} = \frac{z}{z'} \text{ and by definition } z' = d$$

Question 4

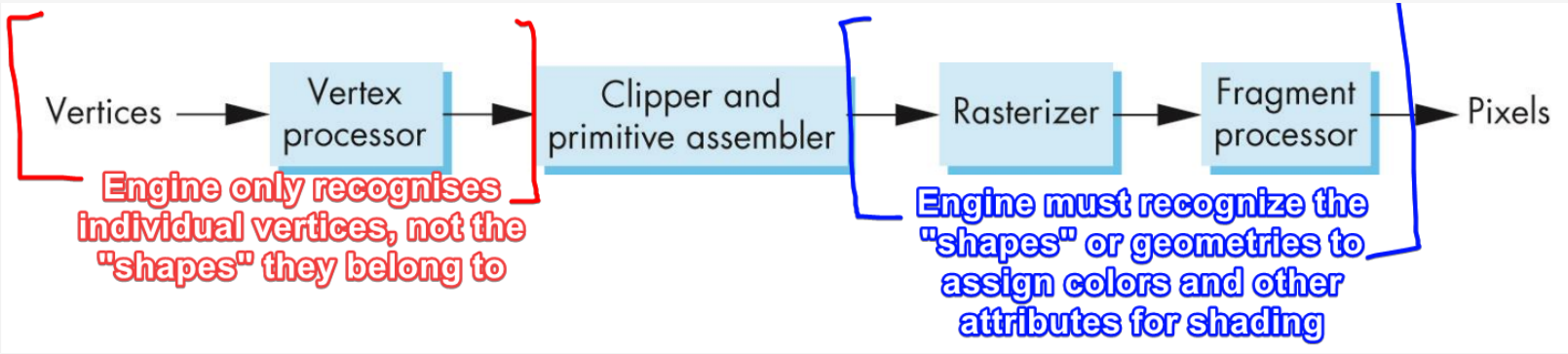
Why do we need a **primitive assembly** stage in the rendering pipeline architecture?

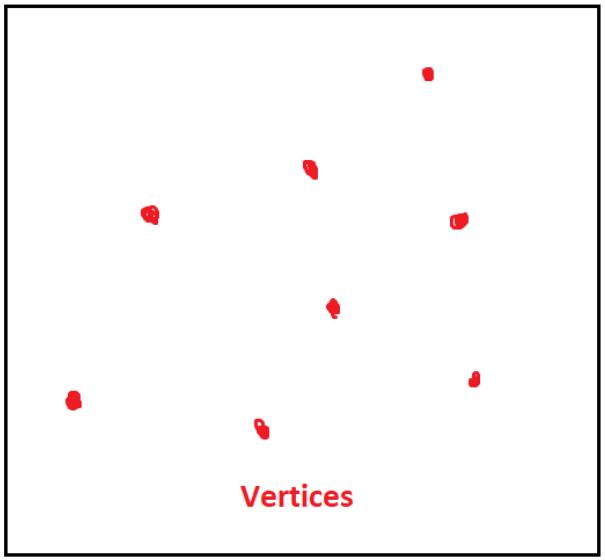


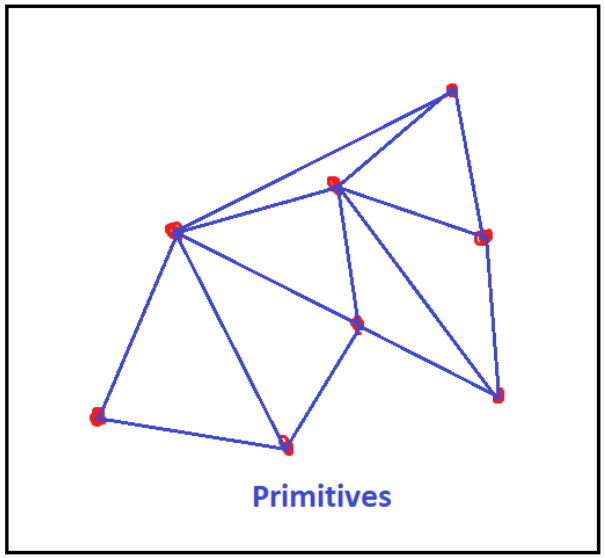
Primitive: One polygonal unit

Primitive Assembly

Rendering pipeline







Question 5

What does the rasterization stage (rasterizer) do in the rendering pipeline architecture?

Question 5

Describe what it does to a triangle that is supposed to be filled, and the three vertices have different color. Assume smooth shading is turned on.

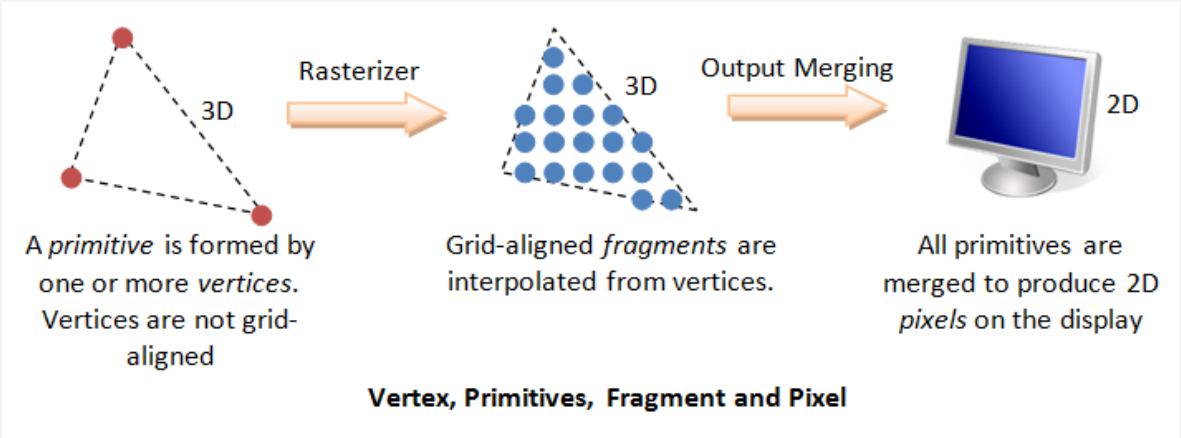
Rasterization

Rendering pipeline

(Lecture 1 Slide 40)

Assigning colors to pixels occupied by a primitive/polygon.

1. Each vertex has an attribute.
2. Each attribute is **interpolated** across the vertices.

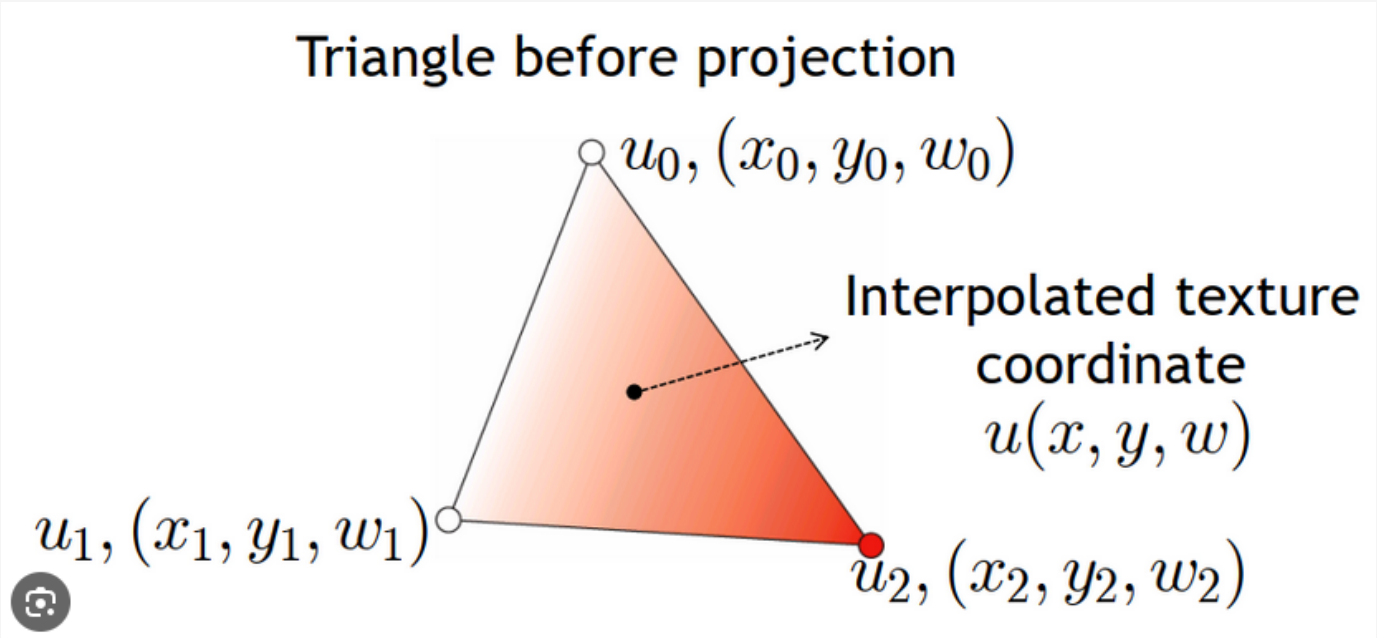


Rasterization

Which attributes can be interpolated?

- Position
- Colour
- Normals
- UV coordinates
- Anything else that vertices may describe

We use barycentric coordinates.

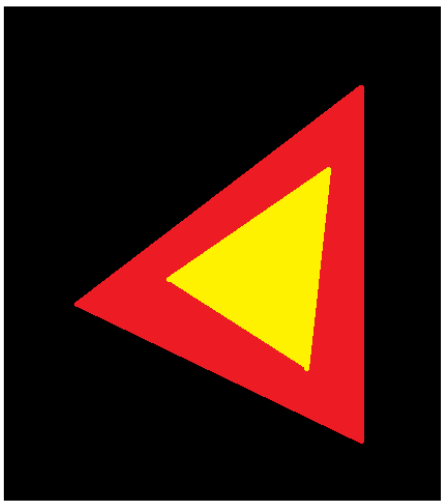


Question 6

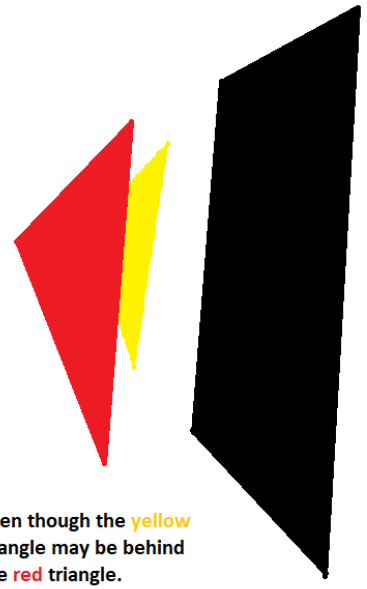
What is hidden-surface removal? When is it not necessary?

Hidden Surface Removal

After rasterization: we can have multiple fragments with the same pixel coordinates.



if i draw the yellow triangle to the screen after red:



even though the yellow triangle may be behind the red triangle.

The correct fragments to render are those that are **closest to the camera** at the same pixel coordinates.
We should discard or overwrite entire hidden surfaces/fragments.

Hidden Surface Removal

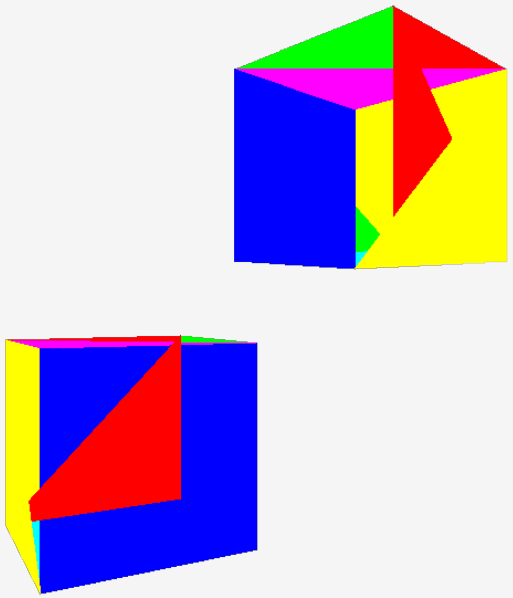
Hence if

1. we have no overlapping surfaces, or
2. we are already rendering from back to front

then we don't need hidden surface removal.

> HSR also has the added benefit of reducing rendering workload (remove pixels/whole surfaces from rendering pipeline).

Some hidden surface removal techniques



Question 7

Which of the two following program fragments is more efficient? Why?

A

```
double v[3*N][3];
...
for ( int i = 0; i < 3*N; i+=3 )
{
   glBegin(GL_TRIANGLE);
      glVertex3dv( v[i] );
      glVertex3dv( v[i+1] );
      glVertex3dv( v[i+2] );
   glEnd();
}
```

B

```
double v[3*N][3];
...
glBegin(GL_TRIANGLE);
   for ( int i = 0; i < 3*N; i+=3 )
   {
      glVertex3dv( v[i] );
      glVertex3dv( v[i+1] );
      glVertex3dv( v[i+2] );
   }
glEnd();
```

Can the same optimization be done for the case of `GL_POLYGON`?

Calls to glBegin and glEnd

A

```
double v[3*N][3];
...
for ( int i = 0; i < 3*N; i+=3 )
{
   glBegin(GL_TRIANGLE);
      glVertex3dv( v[i] );
      glVertex3dv( v[i+1] );
      glVertex3dv( v[i+2] );
   glEnd();
}
```

N times

B

```
double v[3*N][3];
...
glBegin(GL_TRIANGLE);
   for ( int i = 0; i < 3*N; i+=3 )
   {
      glVertex3dv( v[i] );
      glVertex3dv( v[i+1] );
      glVertex3dv( v[i+2] );
   }
glEnd();
```

once!

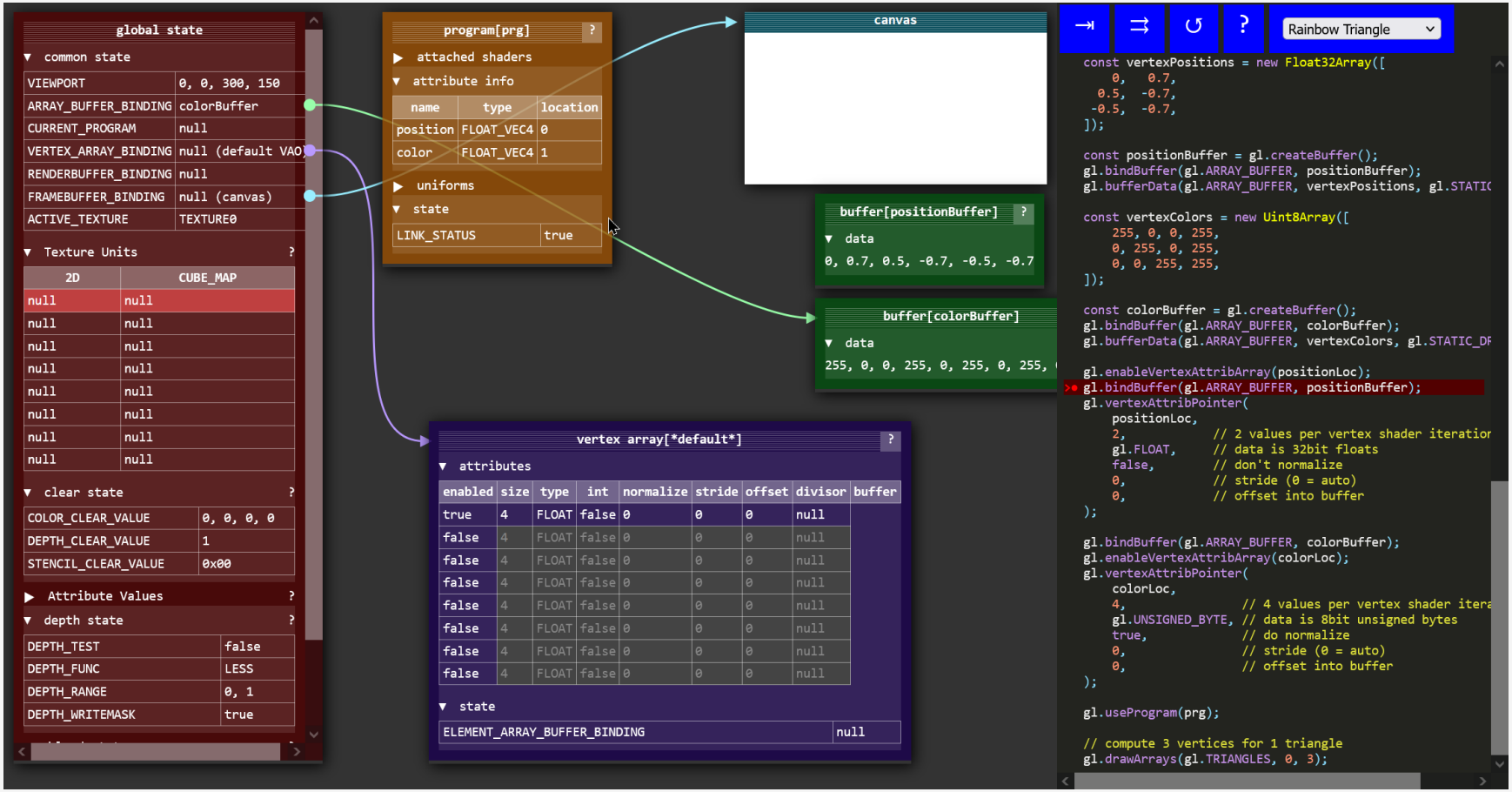
Note that OpenGL (together with mosts other graphics engines) is a **state machine**. Method B greatly reduces the number of state changes.

What about GL_POLYGON?

We can't do this with GL_POLYGON or we'll be defining one massive $3N$-vertex polygon.

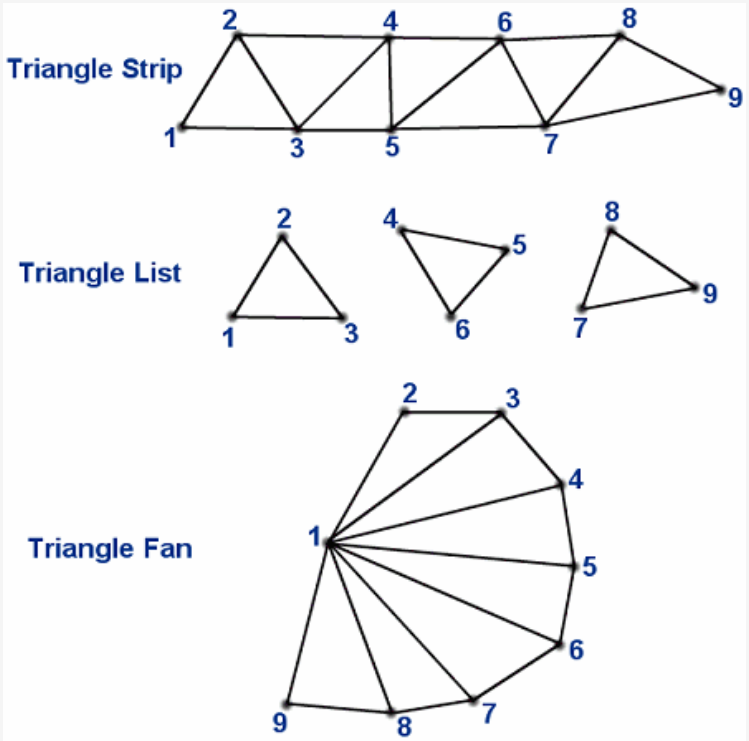
> `GL_POLYGON`
>
> Draws a single, convex polygon. Vertices 1 through N define this polygon.

WebGL State Machine visualizer/debugger tool



Question 8

OpenGL supports the GL_TRIANGLES primitive type. Why do you think that OpenGL also supports GL_TRIANGLE_FAN and GL_TRIANGLE_STRIP?



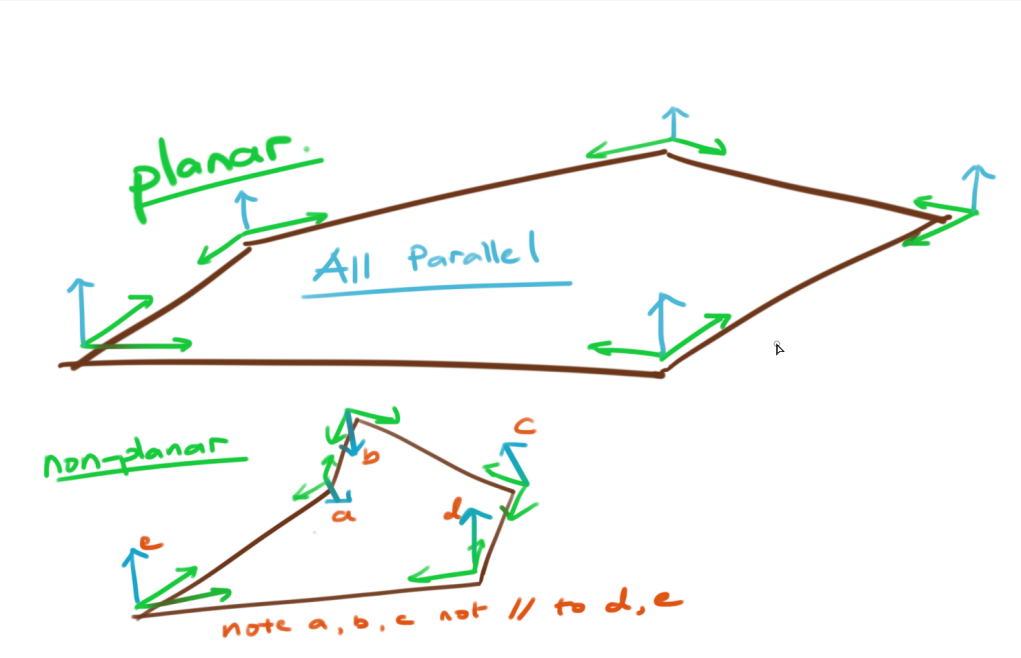
Comparison

Type	Vertices	Triangles
GL_TRIANGLES	3n	n
GL_TRIANGLE_FAN	n + 2	n
GL_TRIANGLE_STRIP	n + 2	n

Question 9

Devise a test to check whether a polygon in 3D space is planar.

Method from Tutorial answer



1. For each vertex, take the cross product of its two neighbouring edges.
2. Normalize the cross product.
3. Identify if all the cross products of each vertex are the same.

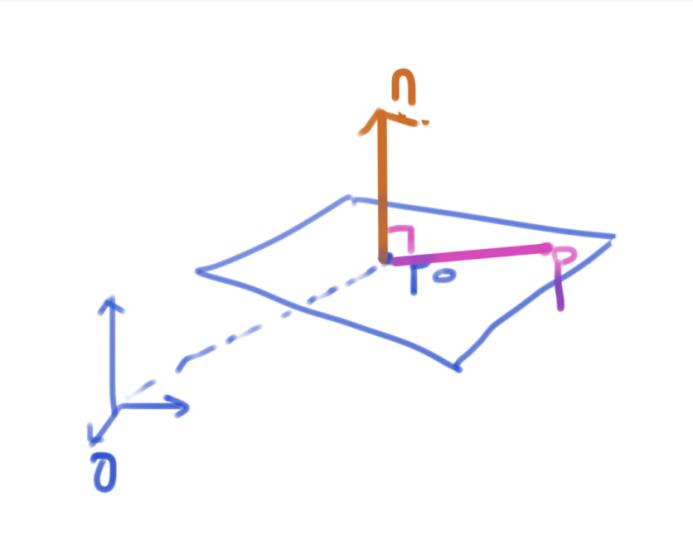
Slow because cross product computation is expensive.

Improved method

Note that a plane can be defined by the following equation:

$$n \cdot (p - p_0) = 0$$

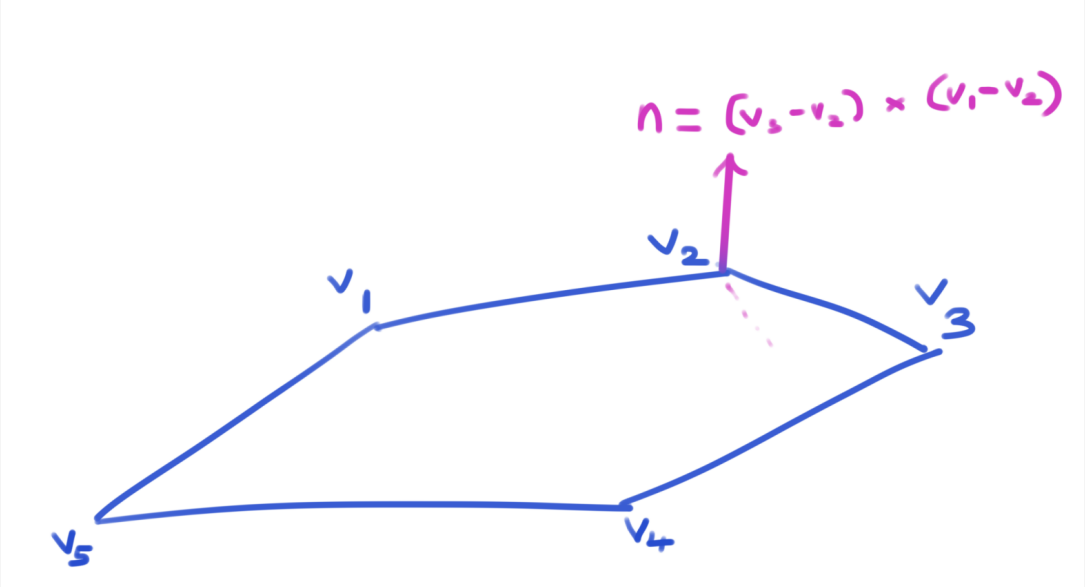
where n is the **normal of the plane**.



This is because dot product of two vectors is zero if and only if they are perpendicular!

Improved method

Hence let's set the normal of this polygon to be $(v_1 - v_2) \times (v_3 - v_2)$.



Improved Method

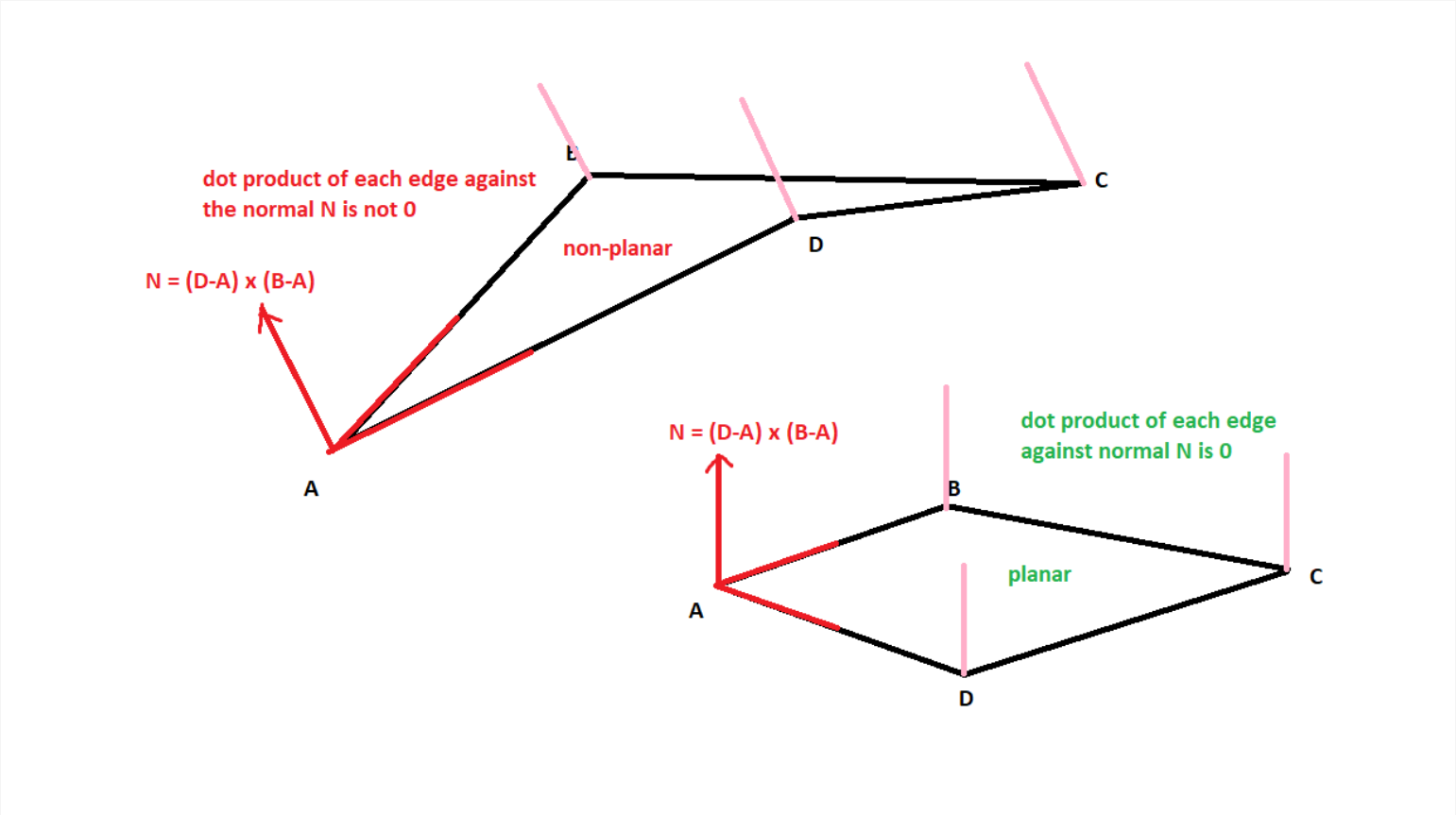
For each of the vertices $v_i \in \{v_1, v_2, v_3, \ldots, v_n\}$, if

$$n \cdot (v_i - v_2) = 0$$

then the polygon is planar.

Cross product involves more operations than dot product, so dot product is more efficient to compute. Asymptotically the runtime is still the same ($O(n)$).

Summary

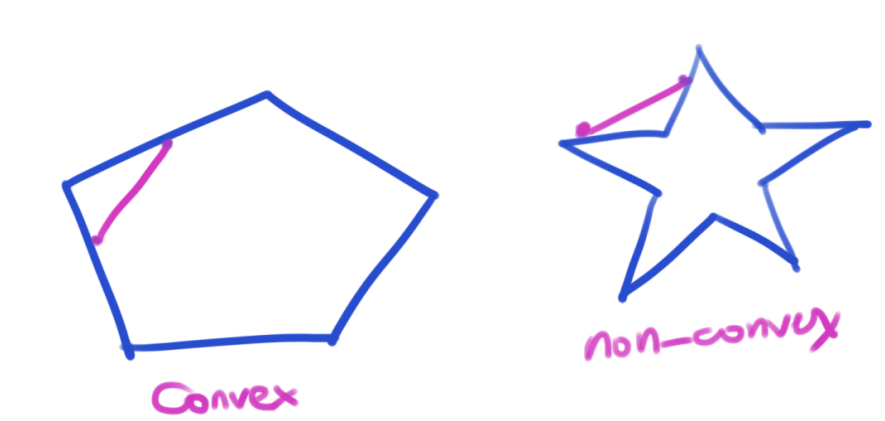

dot product of each edge against
the normal N is not 0
non-planar
N = (D-A) x (B-A)
B
C
D
A
N = (D-A) x (B-A)
dot product of each edge
against normal N is 0
B
planar
C
A
D

Question 10

Devise a test to check whether a polygon on the x-y plane is convex.

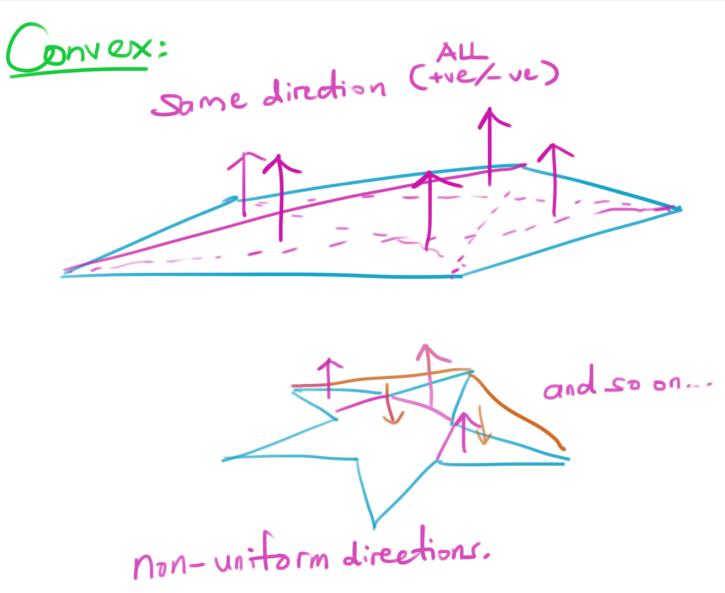
What is a convex polygon

Convex polygon is a polygon that is identical to its **convex hull**.



If you choose any two points on the boundary of a convex polygon and draw a line between, the line should be entirely contained within the polygon.

Method from Tutorial answer



Iterating through $i = 0$ to $n - 1$ where there are n vertices, find each

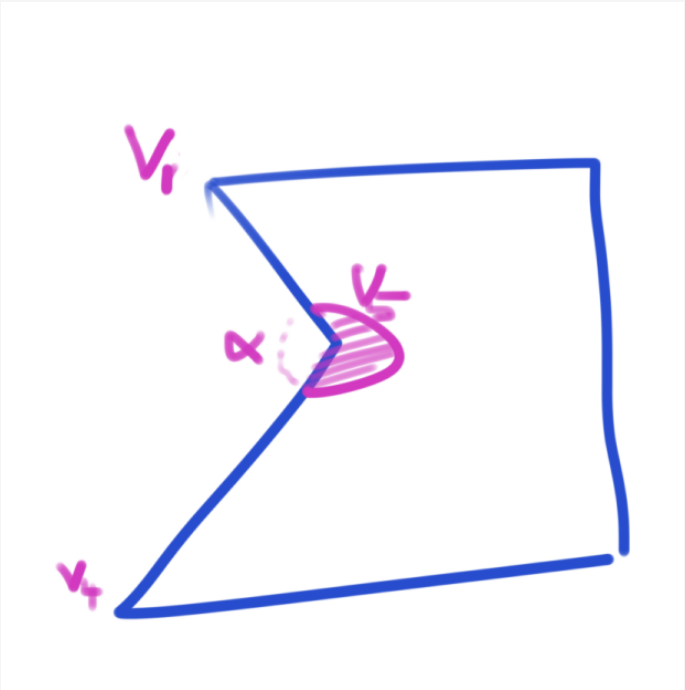
$$n_i = \|(v_{i-1} - v_i) \times (v_{i+1} - v_i)\|$$

if **at least one n_i is not identical to the rest**, then polygon is non-convex.

Note: I'm omitting that you have to take the $x \mod n$ of each of the v_x here for conciseness.

What about inner angles?

One property of convex polygons: all interior angles $< 180°$



Checking this is tricky as the dot product of the vectors $v_4 - v_5$ and $v_1 - v_5$ gives you $\cos \alpha$, not the cosine of the interior angle $2\pi - \alpha$. One way would be to compute the cross product, which we would have done so using the other method anyway.

Thanks! Get the slides here.

https://trxe.github.io/cs3241-notes