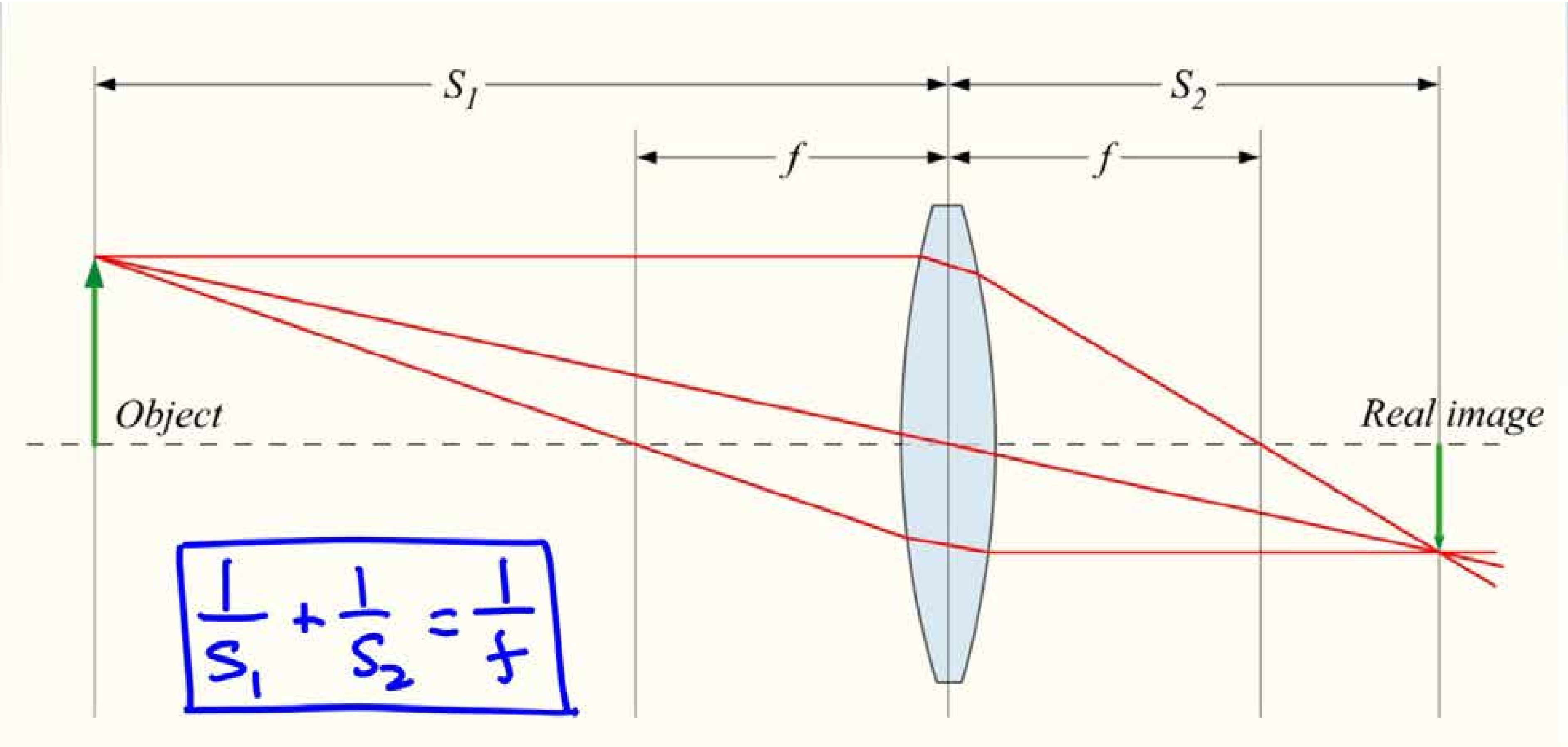
Human Vision: Physiology

CS 498: Virtual Reality

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

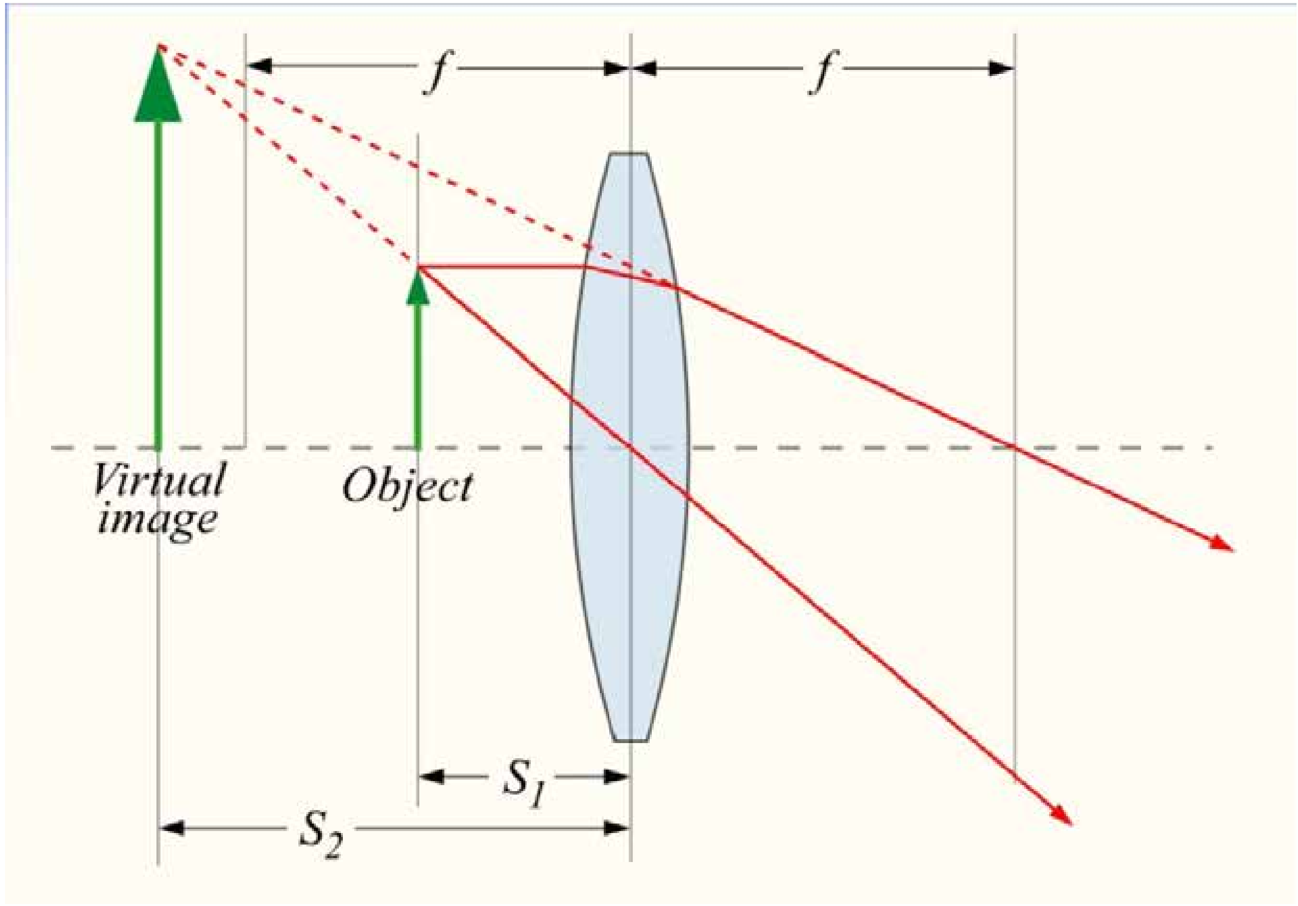
Eric Shaffer

Imaging Properties of a Lens



Object is at distance > f, its “real image” is in focus at distance s_2.

Beyond Review: Magnification



Object is at distance < f,
its “real image” is not in focus.

The “virtual image” is formed at behind the lens...we see this enlarged image through the lens...

“Virtual image” is not a real image...that wording just di·op·ter

/dīˈäptər/

noun

a unit of refractive power that is equal to the reciprocal of the focal length (in meters) of a given lens.

Diopter measures how much the lens bends light
Magnification measure by what factor the size of the image is increased

These quantities are related…

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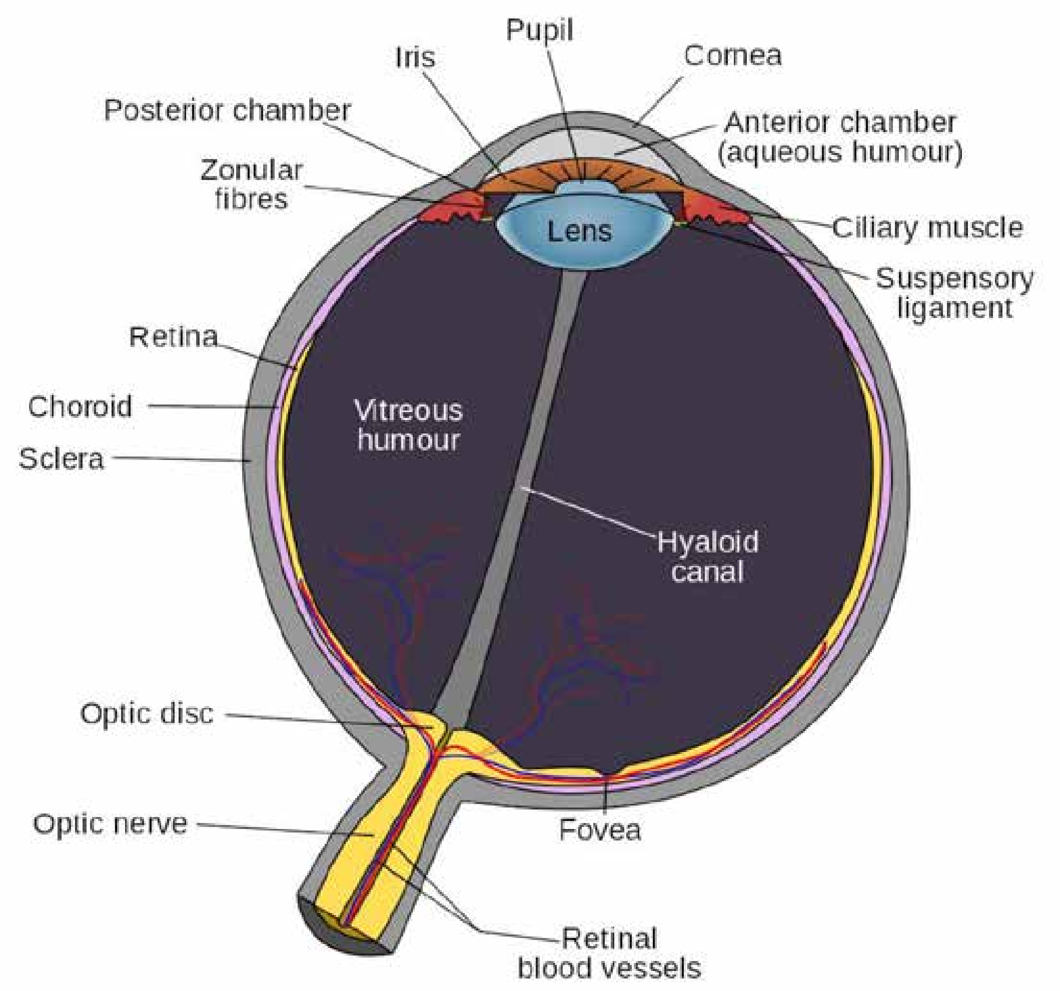
It's usually approximated as –

Diopter is measured in meters! Well…m^{-1}

Structure of the Human Eye



Key Physical Components

bends light…like a lens

liquid..bends light

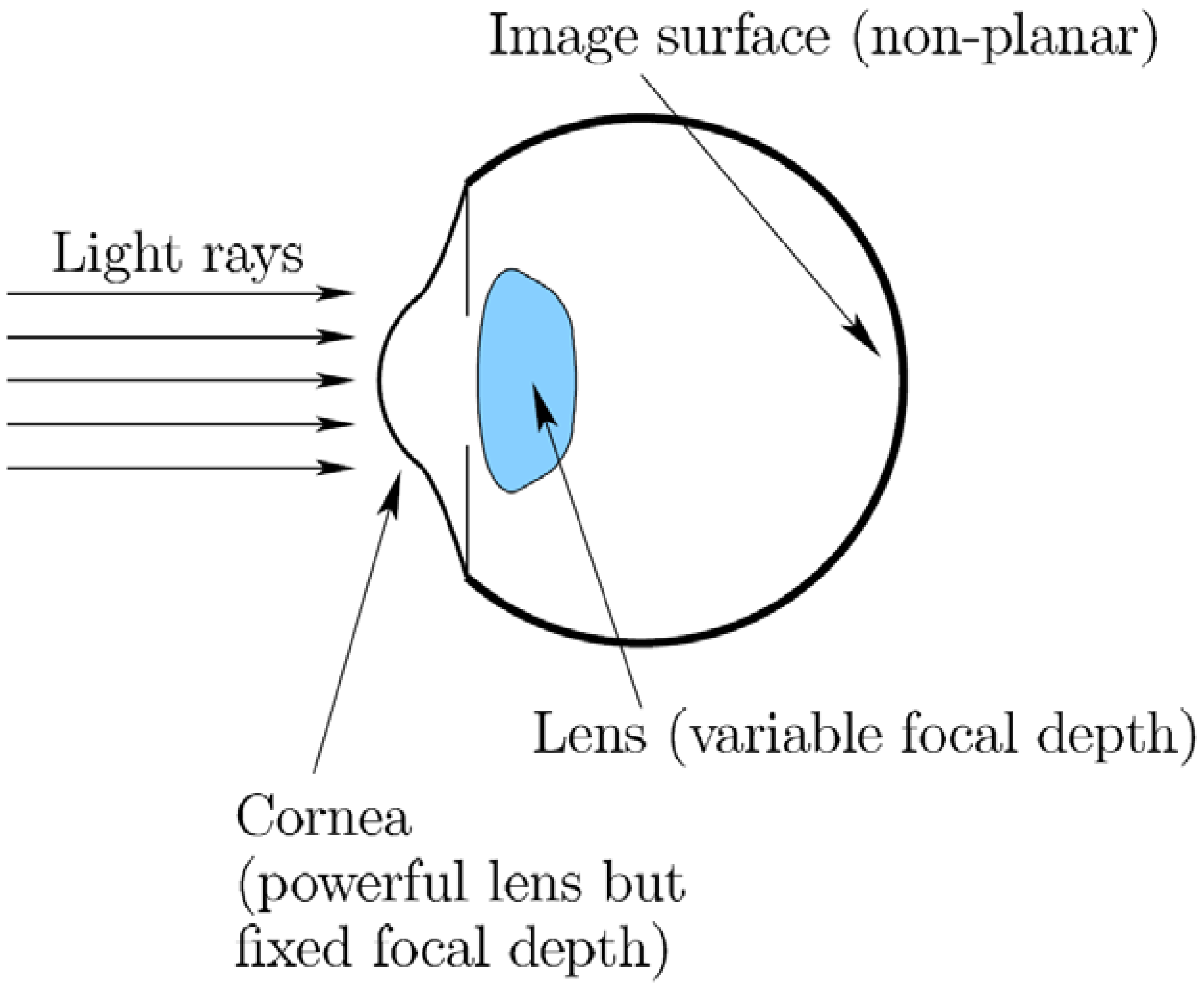
can change the diopter of eye
…uses ciliary muscle to change shape

liquid..bends light

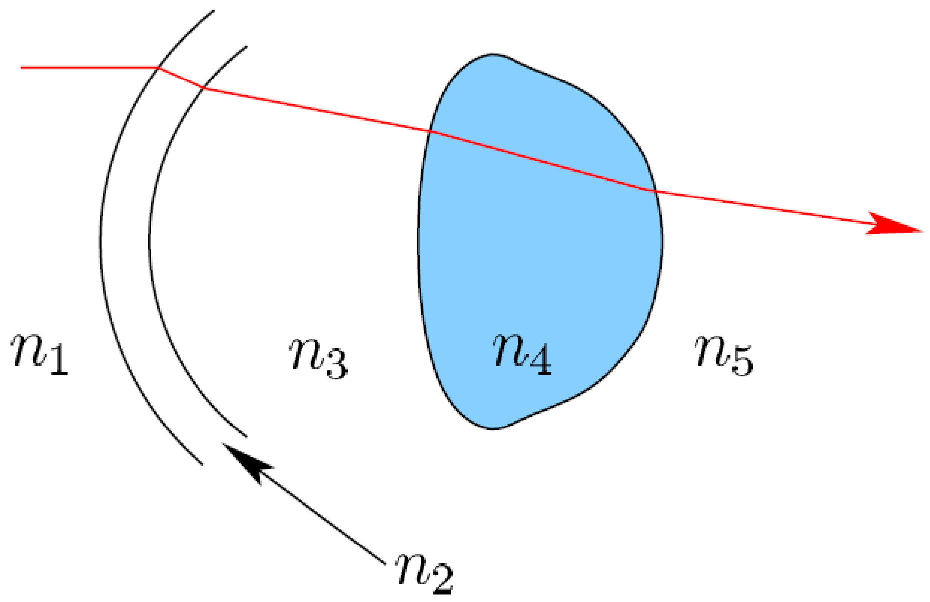
sensory array of cells

greatest concentration of receptors

Structure of the Human Eye



Optical Power of the Human Eye



1. $n_1 = 1.009$ (air)
2. $n_2 = 1.376$ (cornea)
3. $n_3 = 1.336$ (aqueous fluid)
4. $n_4 = 1.413$ (lens)
5. $n_5 = 1.337$ (vitreous fluid)

Figure 4.25: A ray of light travels through five media before hitting the retina. The indices of refraction are indicated. Considering Snell's law, the greatest bending occurs due to the transition from air to the cornea. Note that once the ray enters the eye, it passes through only liquid or solid materials.

Structure of the Human Eye

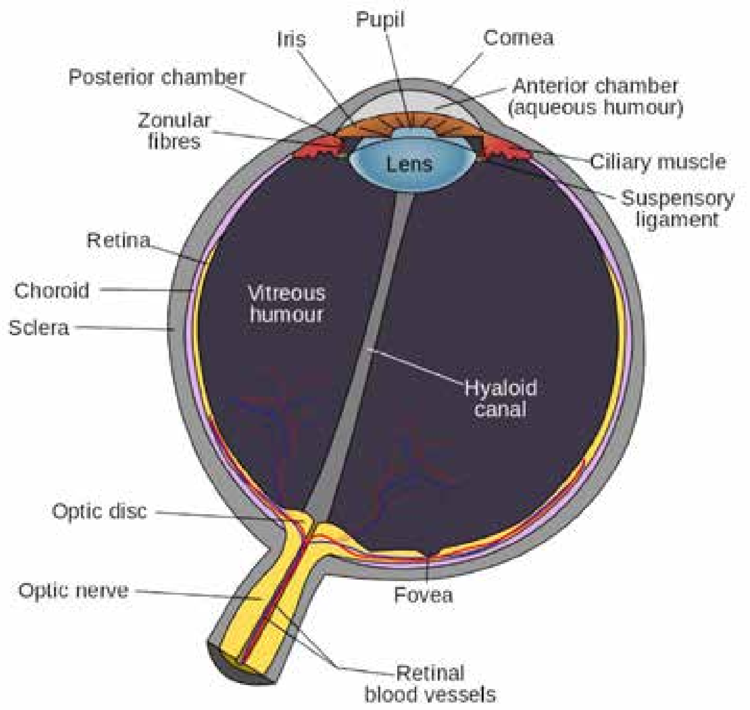
The diopter of the human eye is about 58.

Eye lens is not spherical.

Retina (and retinal image) is not planar.

Ciliary muscle has the ability

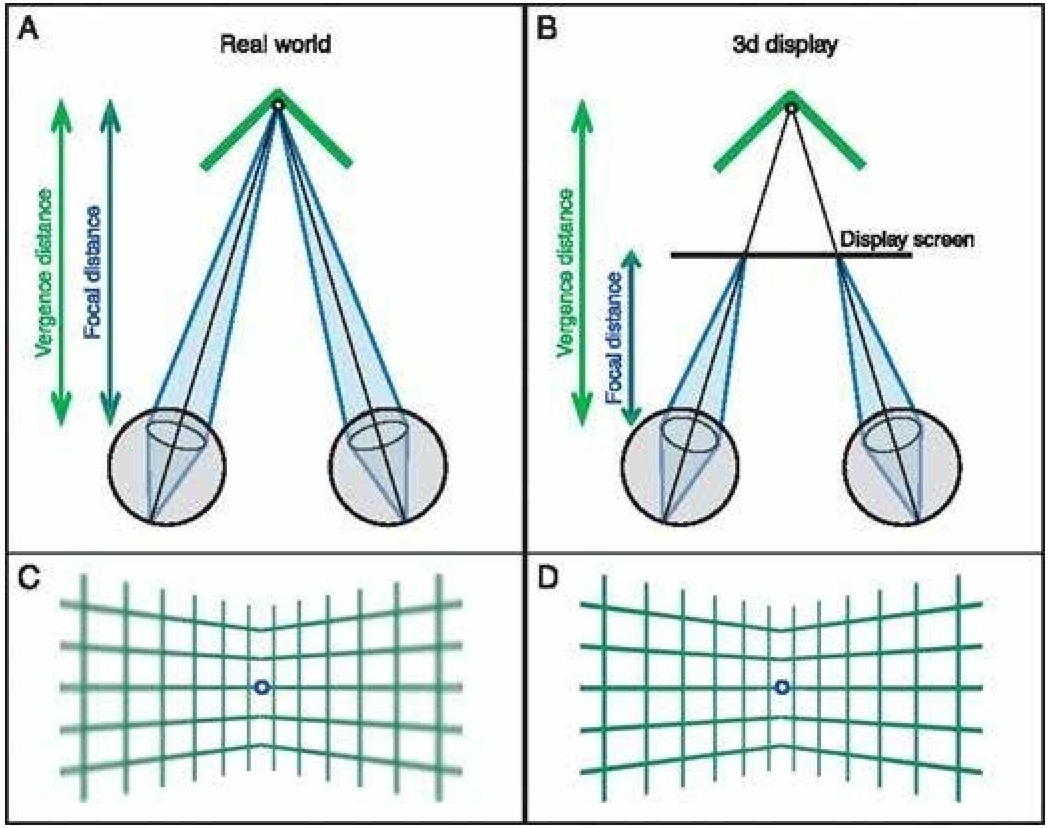
Optic nerve forms a blind spot in the human eye.



Assume the person has no vision defect.

Vergence-Accommodation Conflict

Eyes are accommodating to the screen distance
Eyes converge to some other depth in virtual scene

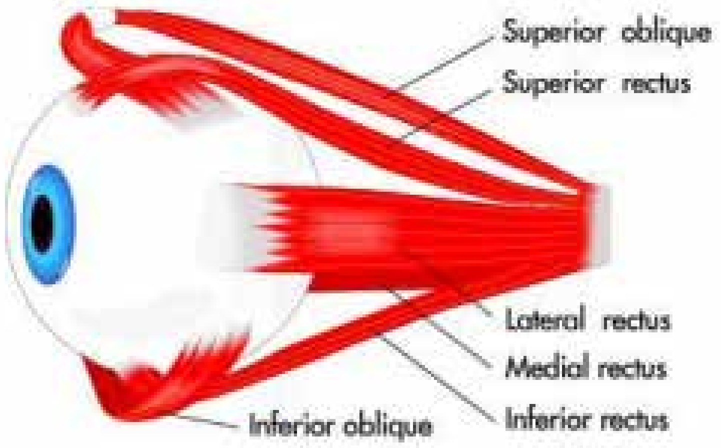


Can cause fatigue and headaches

Still an area of current research

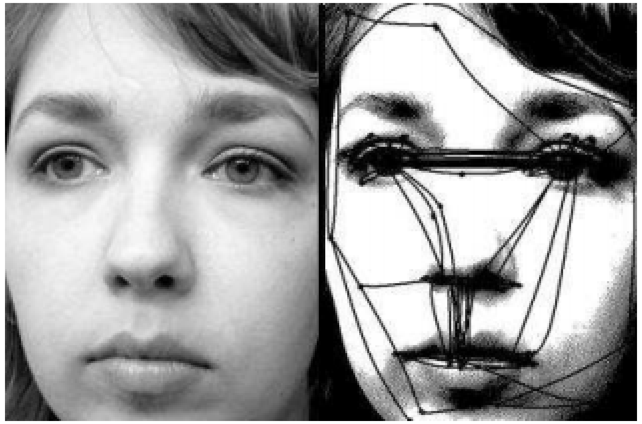
Eye Movements

- When viewing an object, eyes move and scan over it
  - Experimentally shown that suppression of motion results in no visual perception
- Six types of eye movements
  - Saccades
  - Smooth pursuit
  - Vestibulo-ocular reflex
  - Optokinetic reflex
  - Vergence
  - Micosaccades



Saccades

- Rapid movement
  - 45 ms
  - Rotation covers 900 degrees per second
- Quickly relocates fovea to important features in scene
- Can be consciously controlled



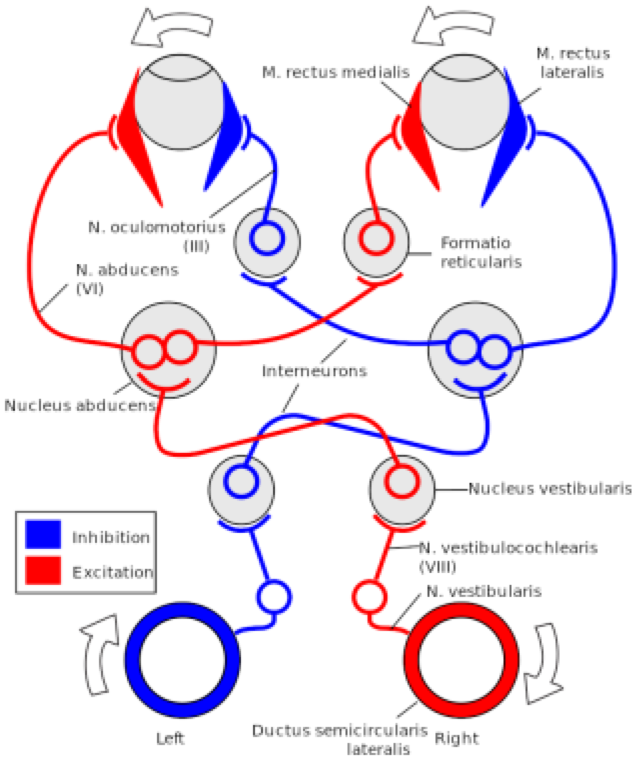
Vestibulo-Occular Reflex

Involuntary movement of the eye to counter head movement

Provides image stabilization

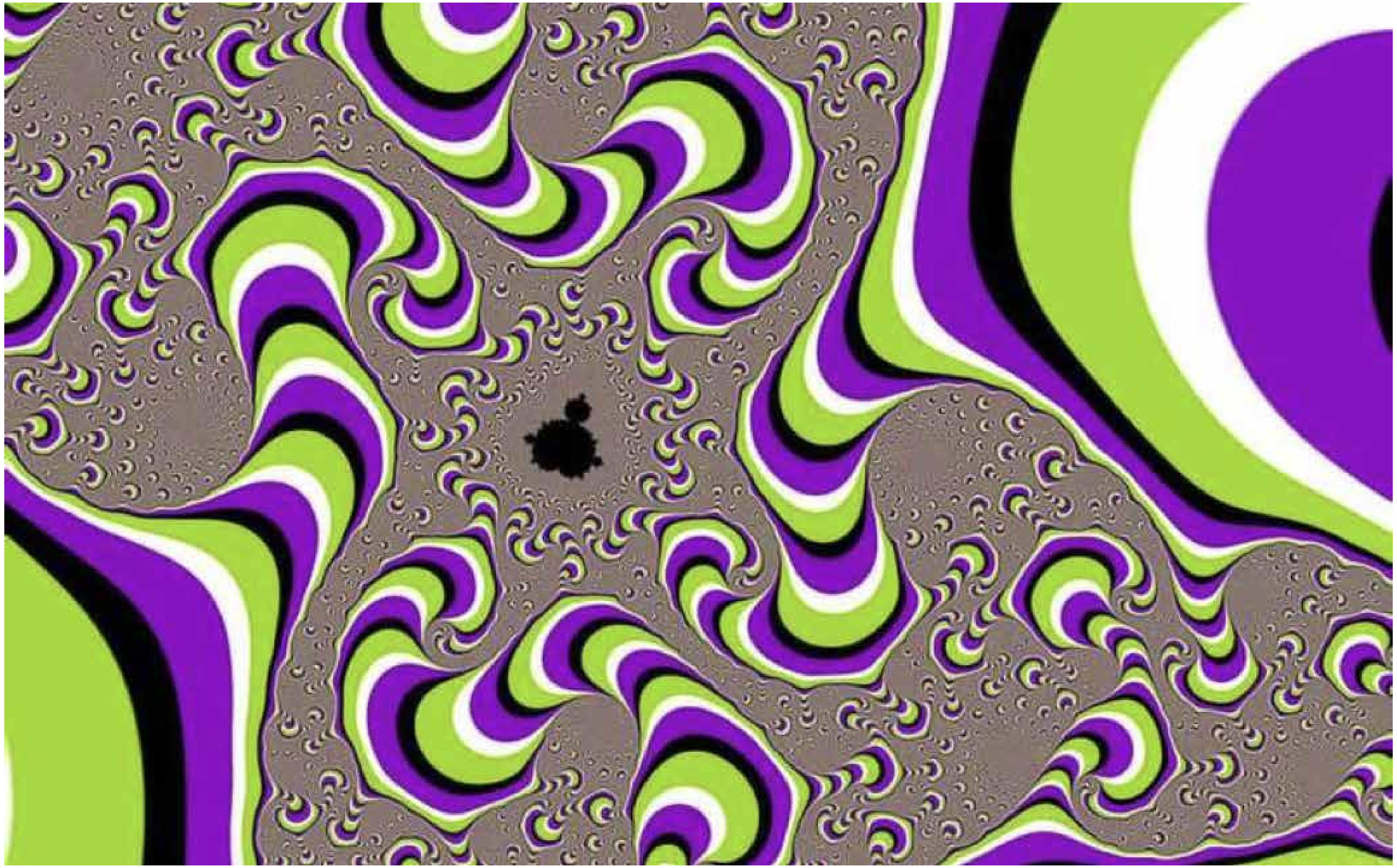
"Hold your finger at a comfortable distance in front of your face and fixate on it. Next, yaw your head back and forth (like you are nodding "no"), turning about 20 or 30 degrees to the left and right sides each time. You may notice that your eyes are effortlessly rotating to counteract the rotation of your head so that your finger remains in view. The eye motion is involuntary. If you do not believe it, then try to avoid rotating your eyes while paying attention to your finger and rotating your head."

- LaValle



Other Motions

- Smooth Pursuit
  - Slow rotation to track a target feature like a person walking by
  - Reduces motion blur on retina (blur due to slow photoreceptors)
- Optokinetic
  - Rapid an involuntary feature tracking on fast-moving object
- Vergence
  - Inward or outward rotation to focus
- Microsaccades
  - Involuntary rotations of less than 1 degree…erratic paths…not well understood



Optical Illusion of the Day:

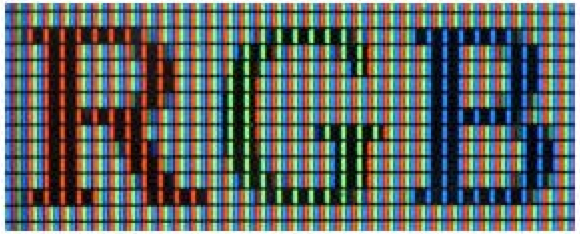
The fractal appears to move unless you fixate on single point.

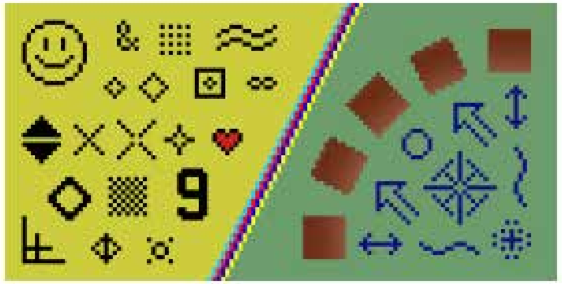
Implications for VR: Display Requirements

Key Questions
- Spatial Resolution: What pixel density is needed?
- Intensity Resolution: What range and resolution of brightness is needed?
- Temporal Resolution: How fast do they pixels need to change value?

Pixel Density

In 2010, Steve Jobs of Apple claimed 326 pixels per linear inch yields a
Meaning individual pixels are not discernible at a normal viewing distance





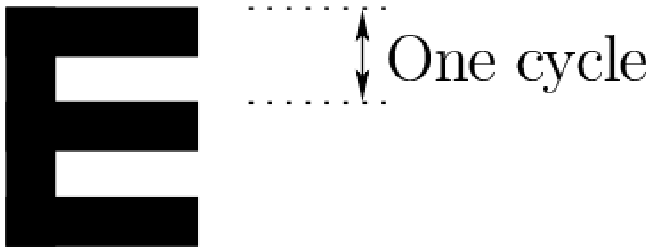
Aliasing

Screen Door Effect

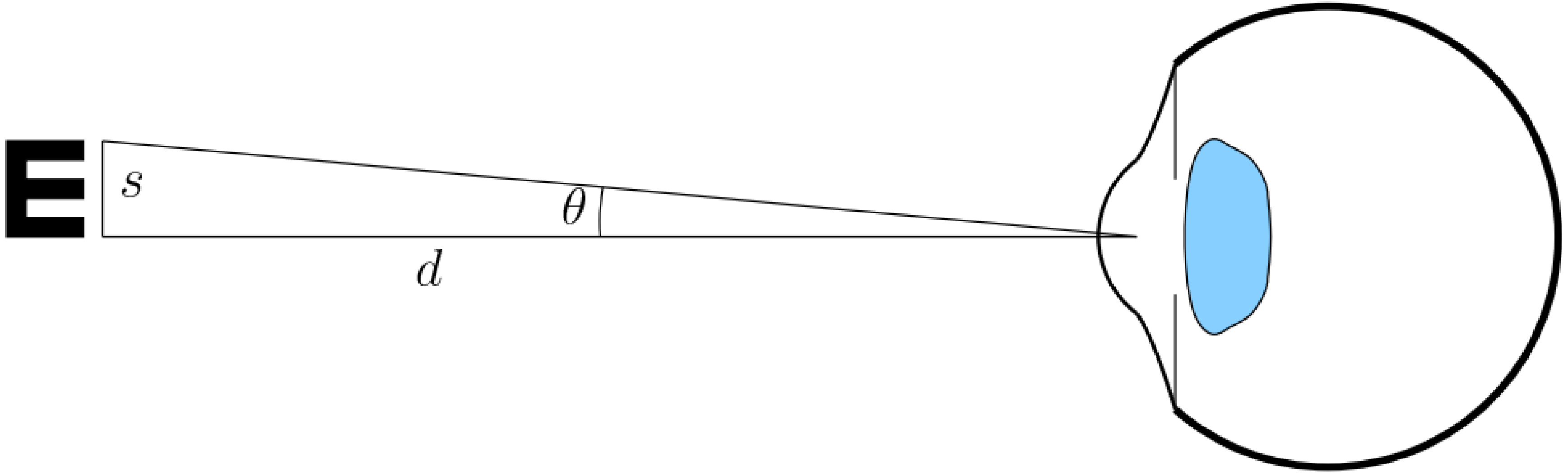
Cycles per Degree

number of stripes that can be seen as separate along a viewing arc of 1 degree
20/20 line on eye chart, letter size is 30 cycles per degree viewed from 20 feet

We can compute appropriate size s using



Eye chart letter

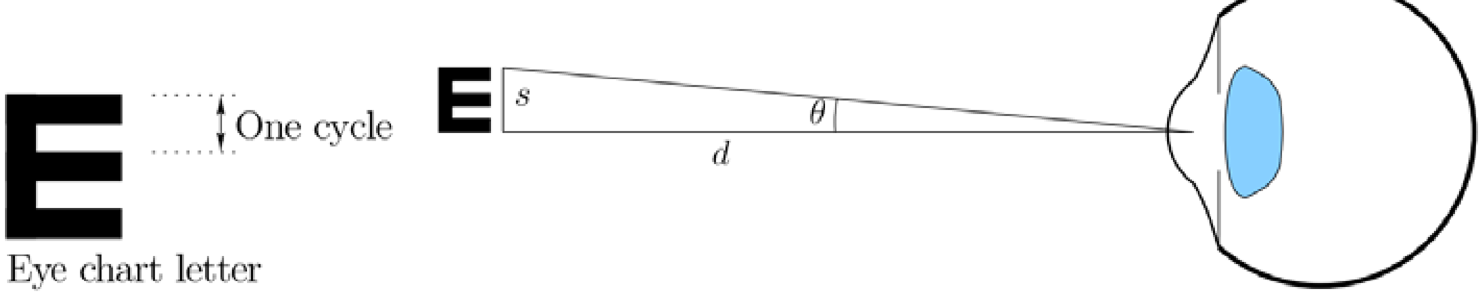


Cycles per Degree and the Retina display

Person with 20/20 vision viewing screen that is 20 feet (6.096m) away

To generate 30 cycles per degree, it must have at least 60 pixels per degree.
The size would be s = 20   tan 1 = 0.349ft, which is equivalent to 4.189in.
So 60/4.189 = 14.32 PPI would be sufficient.

Suppose that a smartphone screen is placed 12 inches from the user’s eye.
s = 12 tan 1   = 0.209in. This requires that the
Screen should have at least 60/0.209 = 286.4 PPI.
This is satisfied by the 326 PPI originally claimed by Apple.



Cycles per Degree for VR

Young people (gamers?!) often have higher visual acuity…up to 77 or more cycles per degree…would need around 4500 PPI

There are lenses…screen is very close…let's say 1.5in

So, $s = 1 \ \tan 1 \quad = 0.0261$in

Display must have at least 2291.6 PPI to achieve 30 cycles per degree

More complicated in practice (e.g. intensity can affect acuity, etc.)

HTC Vive Pro is 615 PPI
Some 2018 R&D demos of screens close to 2000PPI

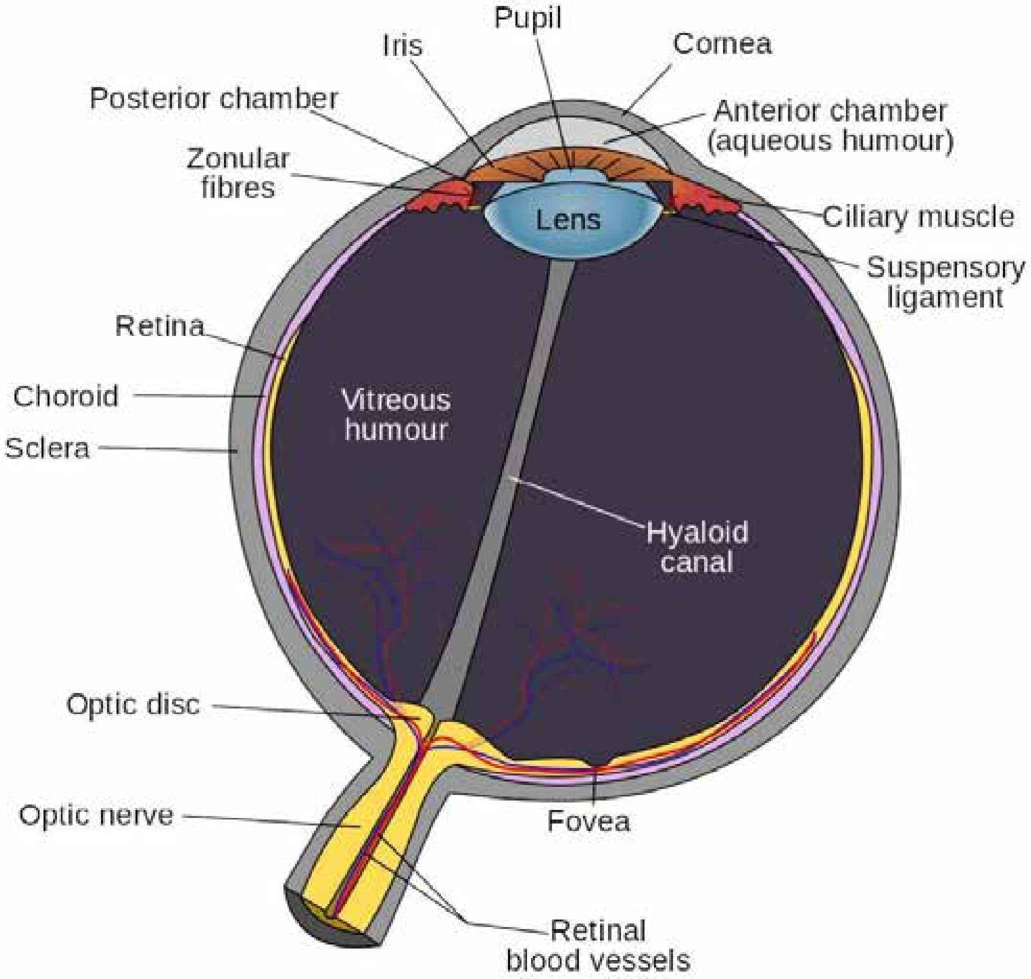
What about Field of View?

- Maximum human field of view is around 270 degrees
  - How does a human achieve that FOV without head movement?
- Cannot just bring a flat screen closer
  - Lens distortion at periphery
  - Also, super-close lenses would require VR subjects to remove their eyelashes….
- Curved screen may help, but lens problem not yet solved…..

Foveated Rendering

What do you think this means?

Hint: We’re always looking for ways to optimize…to do the job with the least resources possible



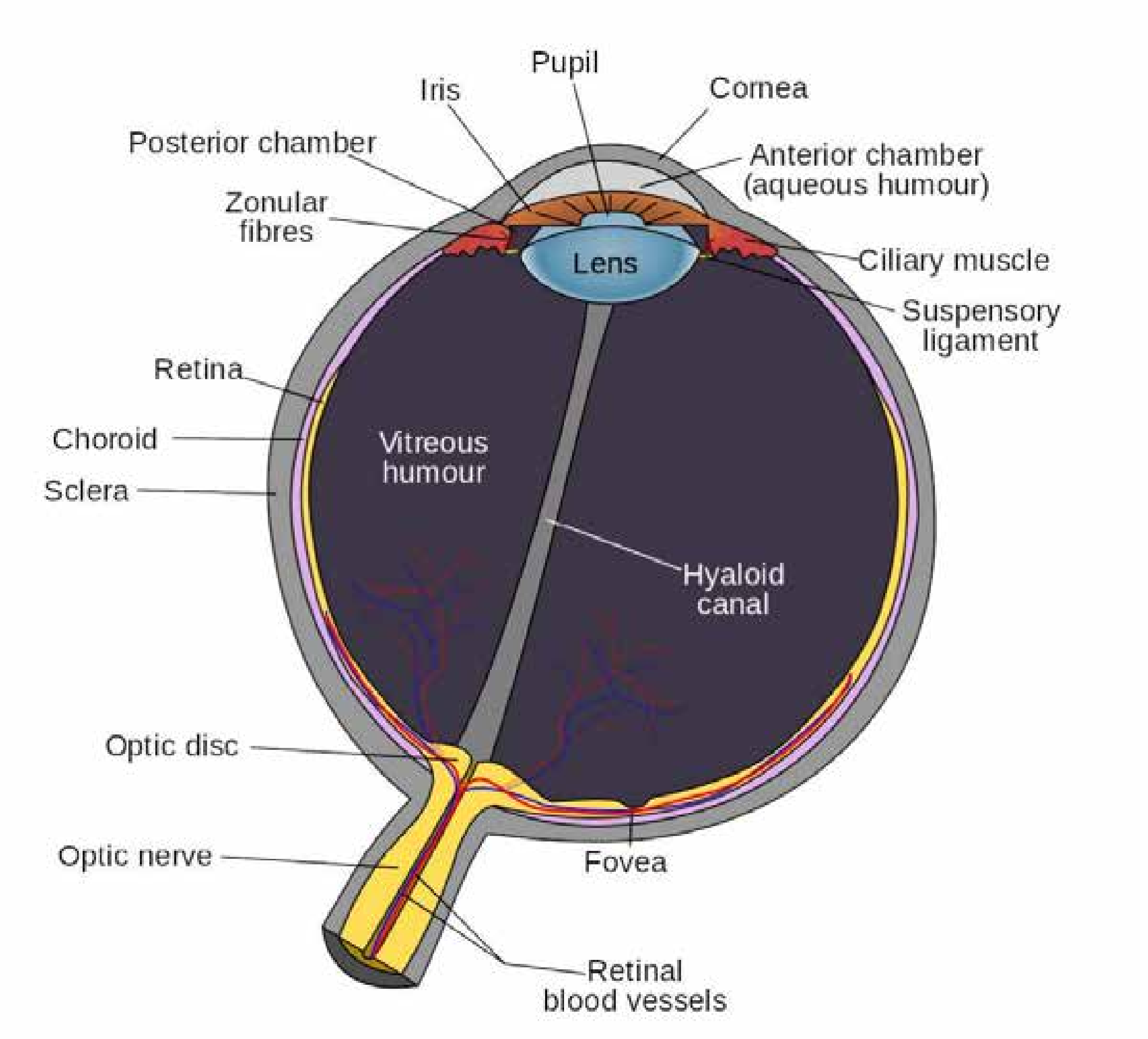
Foveated Rendering

If we could track the eye
Keep a movable display lined up with fovea   fewer pixels needed

Has been done in practice...sort of

Fixed display
Lower resolution on periphery

Works but not well enough



Foveated Rendering

VOR Gain

What does VOR mean?

VOR Gain is a ratio
compares the eye rotation rate (numerator)
to counter the rotation and translation rate of the head (denominator)

Head motion has 6 DOF….so VOR Gain has six components

For head pitch and yaw, the VOR gain is close to 1.0.
For example, if you yaw your head to the left at 10 per second,
then the eye yaws at 10 per second in the opposite direction.

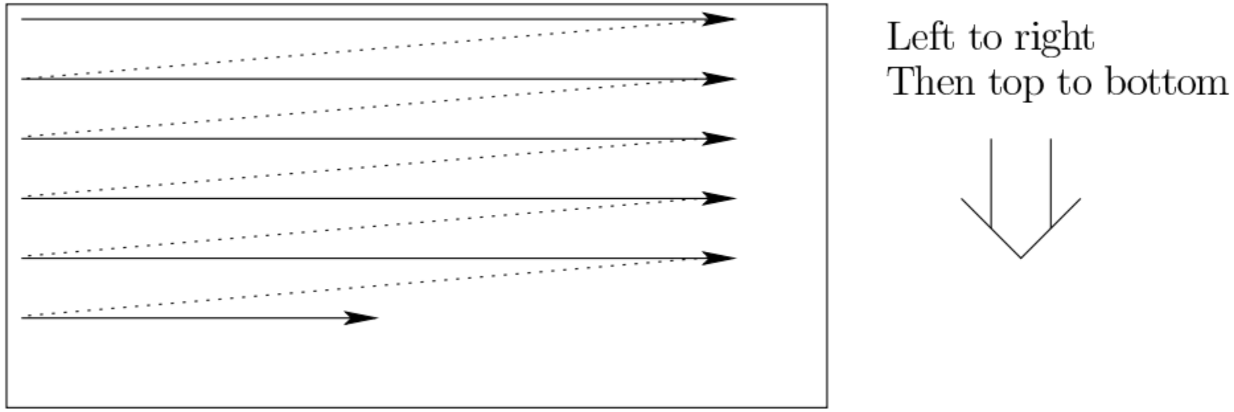
The VOR roll gain is very small because the eyes have a tiny roll range

The VOR translational gain depends on the distance to the features

VOR Gain Adaptation

- Brain will adapt VOR to different optics
  - Happens to people with glasses
- Also happens with bad VR displays
  - Increases happiness with VR experience
  - Requires readjustment outside VR

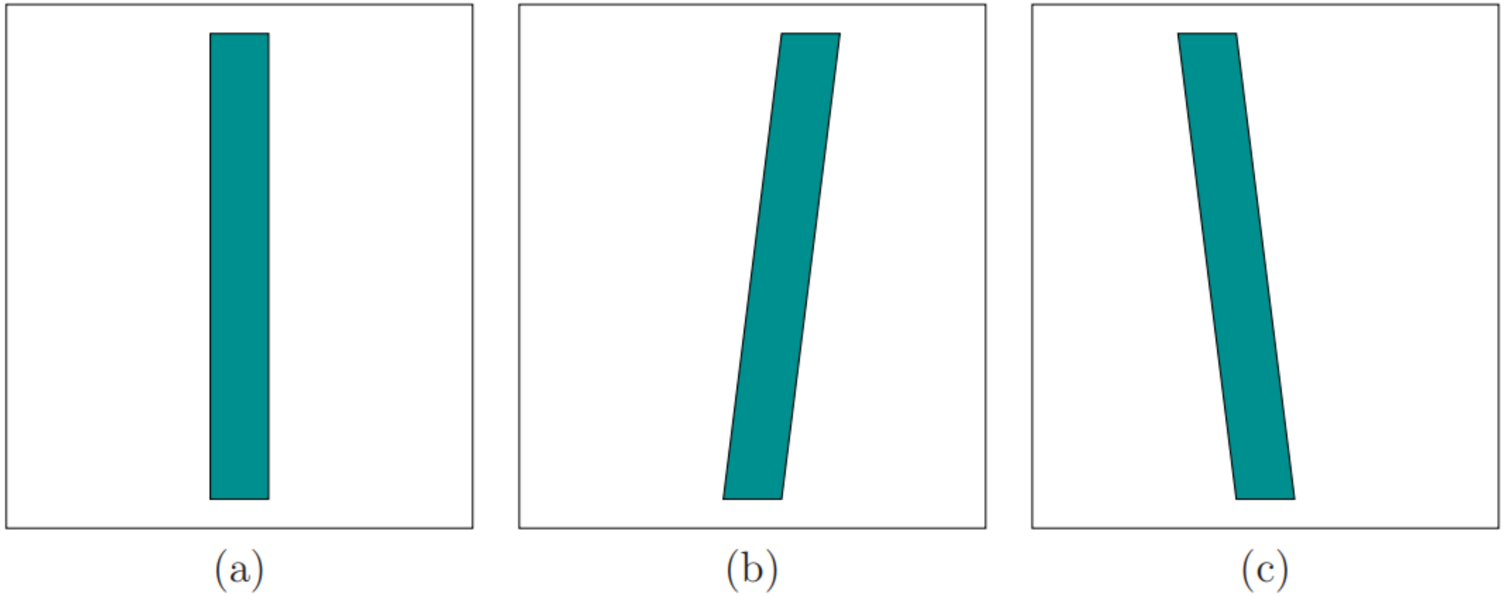
Display Scanout



CRTs used an electron beam to energize phospors on the screen…possible that your grandparents have a particle accelerator in their basement…

Most displays still work in the way as old TV sets and CRT monitors
Updating pixels line-by-line.
For 60 FPS (frames per second) display, could take up to 16.67ms

Artifacts due to Display Scanout



How could this be fixed in rendering?

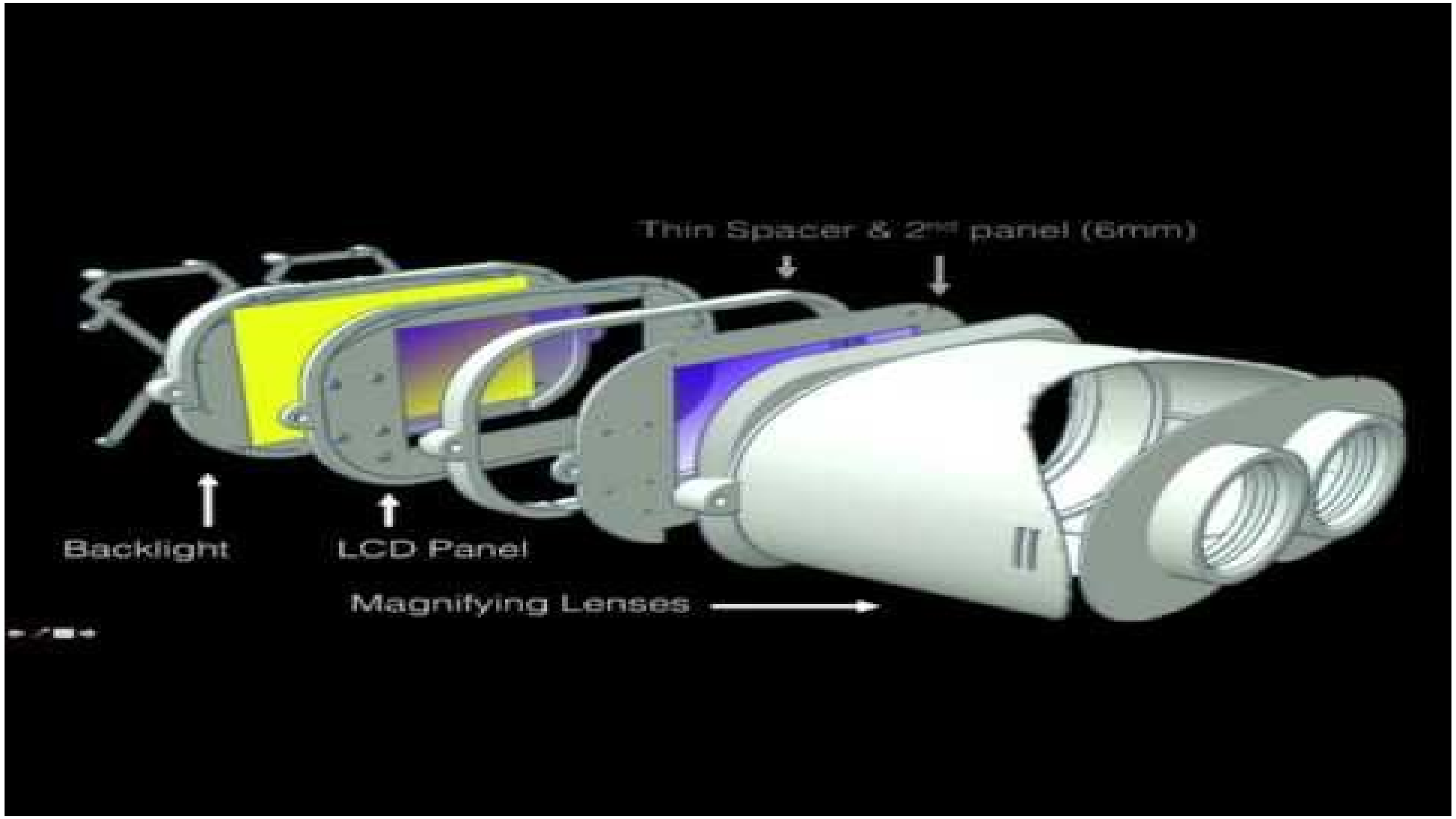
(a) Normally slow recharge rate of our photoreceptors don’t see scanout

But if the head or object moves in the virtual world
(b) smooth pursuit as rectangle moves right
(c) stationary rectangle with right head rotation and VOR compensation
Also might see motion blur….

Retinal Image Slip

- We are only beginning to understand vision issues with VR
- Retinal Image Slip
  - In the real world, head/eye motion causes small sliding of image on retina
  - Evidence shows that this slip is different in VR than in real world
  - In VR, we see increased microsaccades
  - Which means….?

Addressing Vergence Accommodation Mismatch



Work is from 2015....difficult problem...