Mojo Lens -
AR Contact Lenses for Real People

Mike Wiemer – CTO

Renaldi Winoto – VP ASIC & HW

PC

Internet

Mobile

?

“I’m excited about AR. My view is it’s the next big thing, and it will pervade our entire lives.”

- Tim Cook, January 2020


In Progress


mojo

Why Smart Contact Lenses?

150M+ Choose Contact Lenses Worldwide

Confidently You

- Feel like yourself; no frames obstructing face
- Look younger
- Fashion freedom (sunglasses)
- Always on and ready

Face Friendly

- Lightweight
- Avoids fogging/sweating
- No frames rubbing on nose and ears, falling off
- Works with other equipment

Unique Capabilities

- AR content wherever you look
- Unlimited Field of View
- “See” with your eyes closed
- Best location for highly accurate health sensors

Low Vision

Contrast

Edges

Zoom

For use
DURING
the activity

Sports & Athletics

Current Status

mojo

Mojo Lens

Past — Present — Future

2017

FIRST LIGHT

Craft build
Single LED
Wireless power

2017

STATIC IMAGE

Static projector

2018

DYNAMIC CONTENT

microLED display
Wireless data

2019

WEARABLE LENS

Semi-automated build
Oxygenation
Custom-fit

2021

FEATURE COMPLETE

Hi-res microLED display
Fast wireless data
Computer vision
Battery power
Eye tracking

202-

FIRST PRODUCT

Prescription
Cosmetics

2021 Lens Integration: In-Progress

Recent Pulse-Build for Toxicology Testing

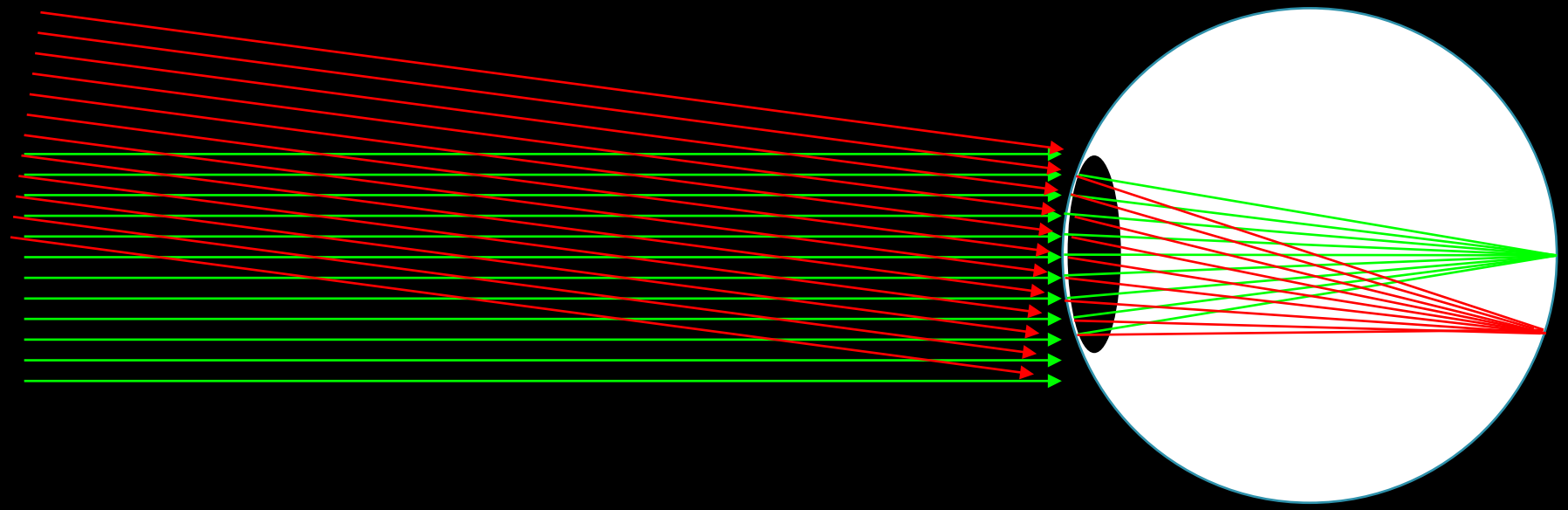
How does an AR Contact Lens work?

The Display

Review: Simplified Model of How We See

Peripheral Point

Gaze Point



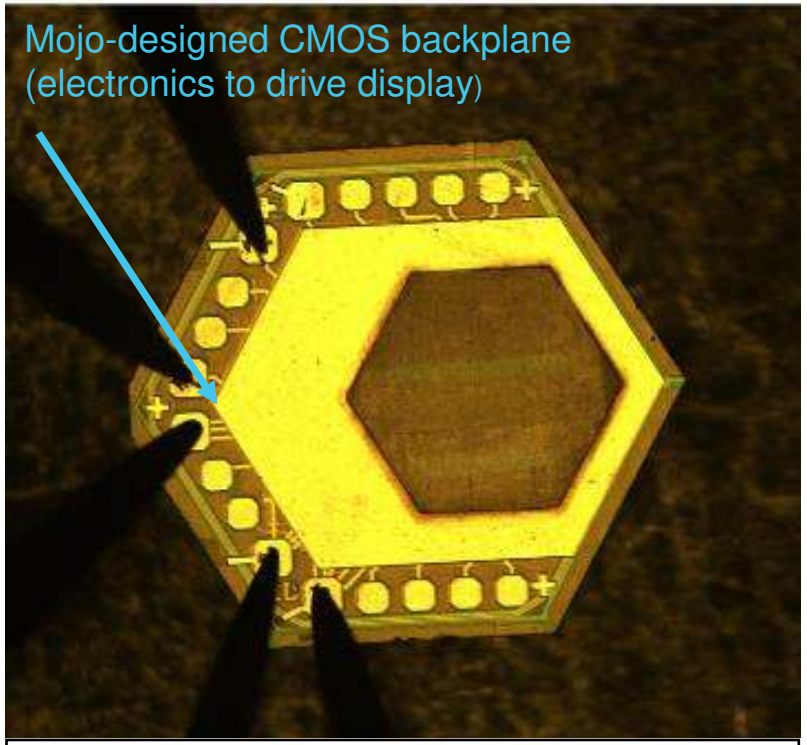
Larger pupil means brighter image

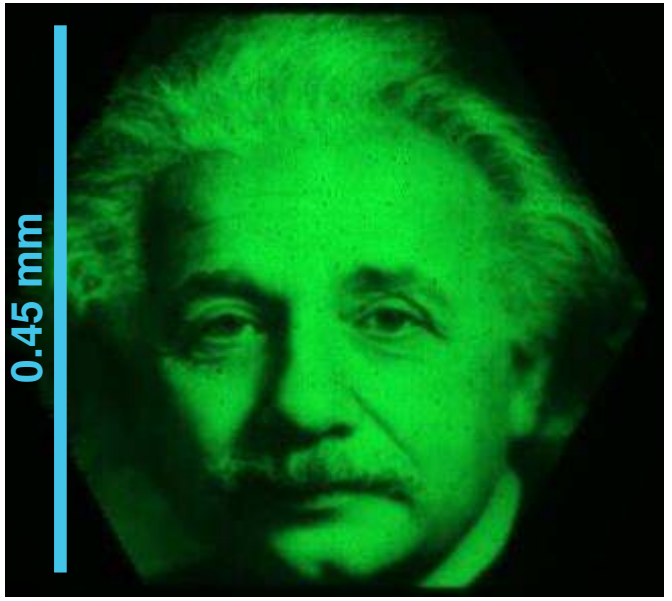
How Does an AR Contact Lens Work?

Start with the world’s tiniest display…

World's Densest Active Microdisplay

Pixel pitch = 1.87µm
14,000 pixels per inch





Example microdisplay images viewed directly through a microscope

Impossibly Small

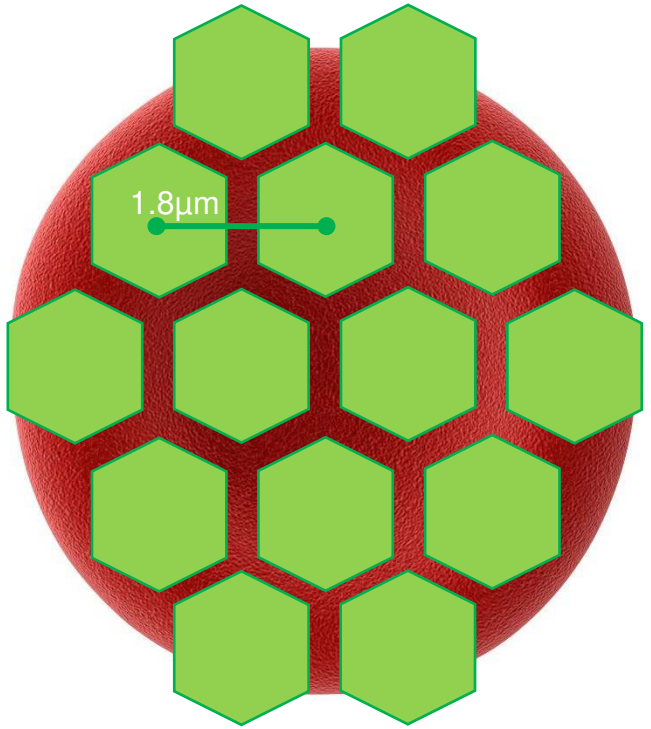
Ladybug
(~10mm)

Pencil Eraser
(~5mm)

Mojo Display
(~0.45mm)

Pixel Pitch Smaller than Cells

Red Blood Cell
(~7µm)



Mojo Pixel Pitch
(1.8µm)

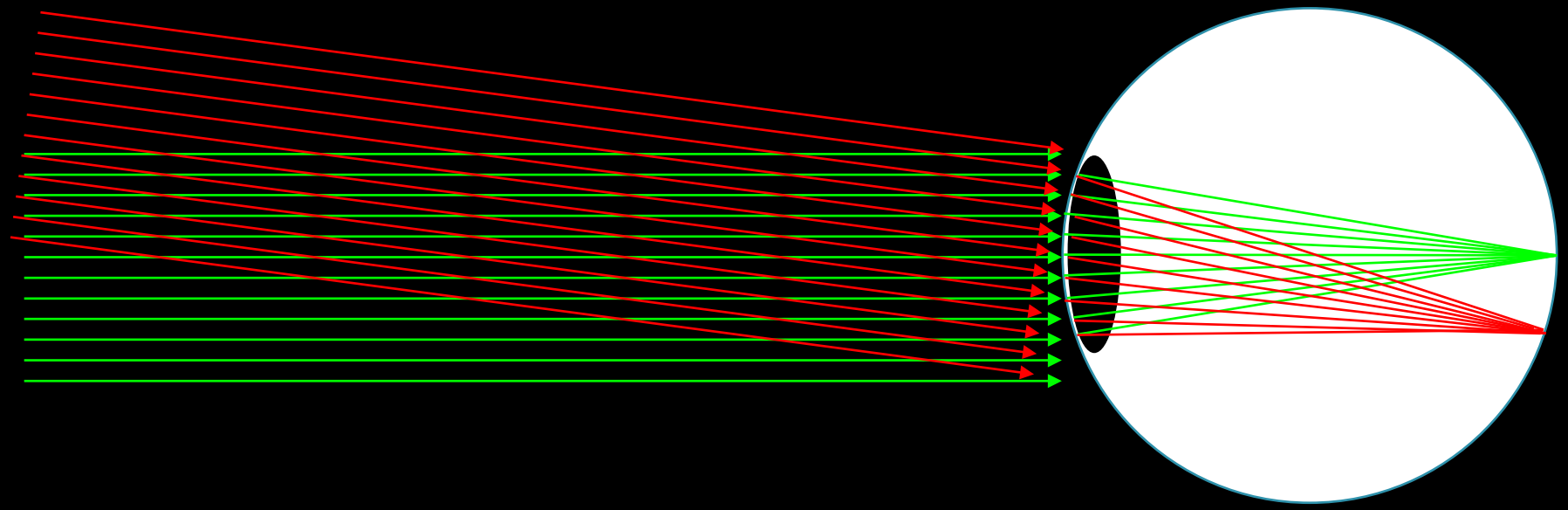
How Does an AR Contact Lens Work?

Next, we need a place to put it …

Where Can We Put the Mojo 14K PPI Display?

Peripheral Point

Gaze Point



Criteria:

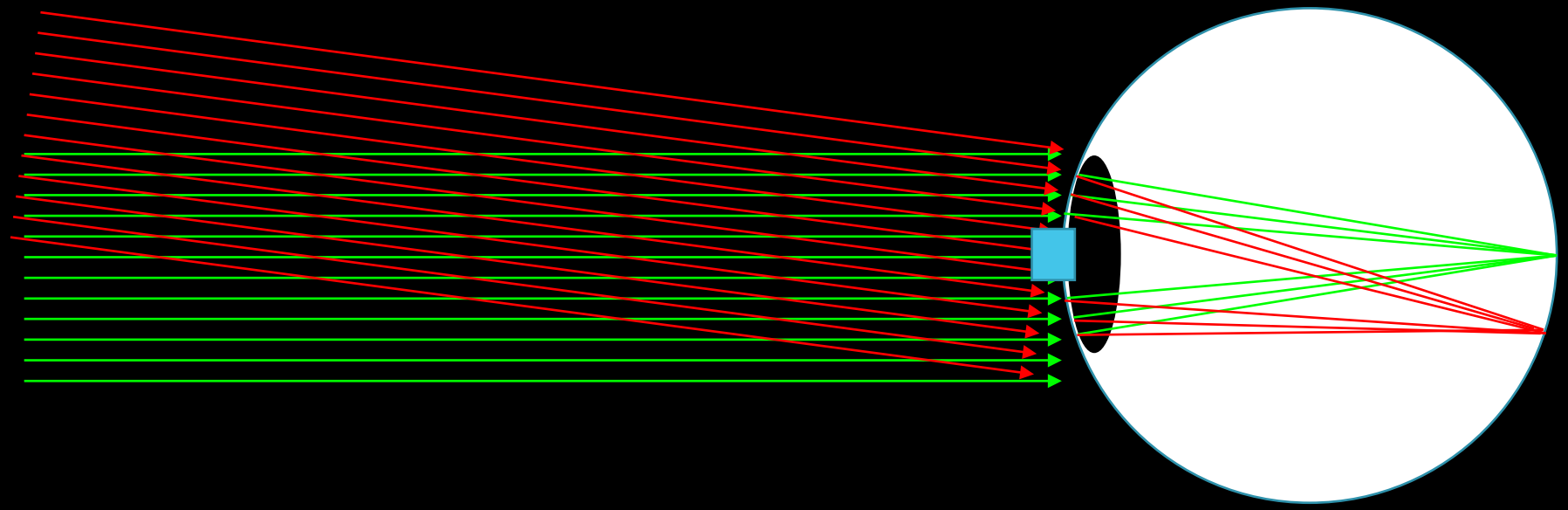
- Light from display must pass through pupil
- Display must be invisible, must not create blind spot
- Display must have no impact on visual acuity

Put the Display Right in Front of the Pupil!

An obscuration much smaller than the pupil is INVISIBLE when placed right in front of the pupil

Peripheral Point

Gaze Point



Criteria:

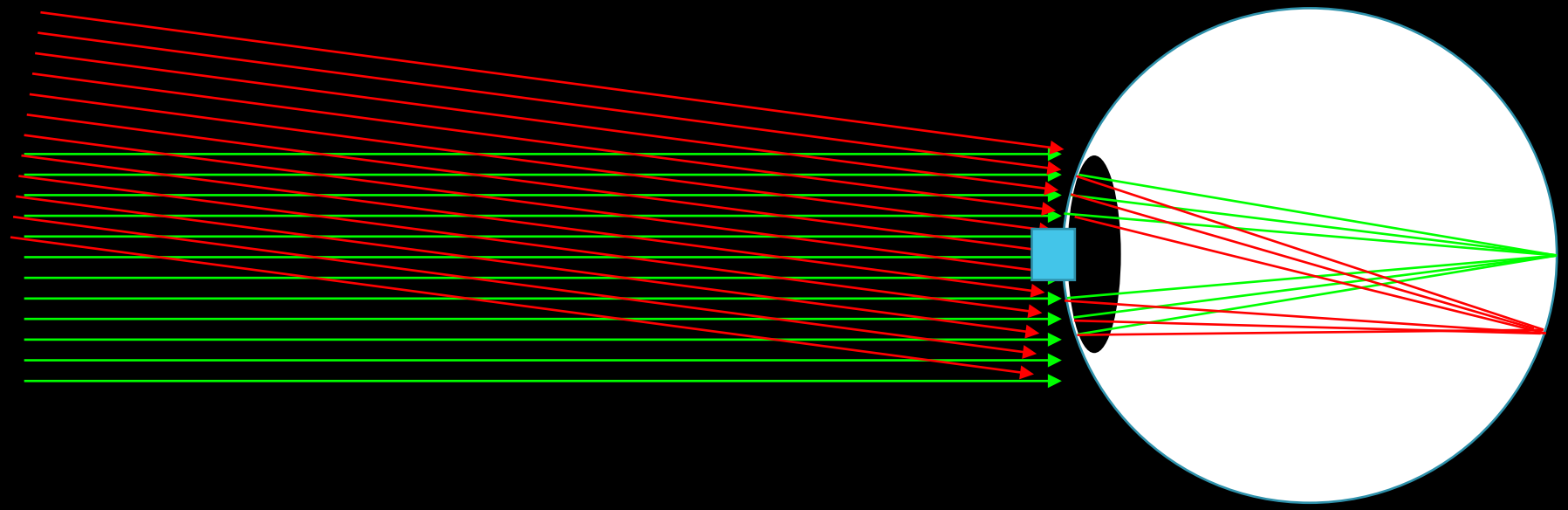
- Light from display must pass through pupil
- Display must be invisible, must not create blind spot
- Display must have no impact on visual acuity

Put the Display Right in Front of the Pupil!

An obscuration much smaller than the pupil is INVISIBLE when placed right in front of the pupil

Peripheral Point

Gaze Point



Criteria:

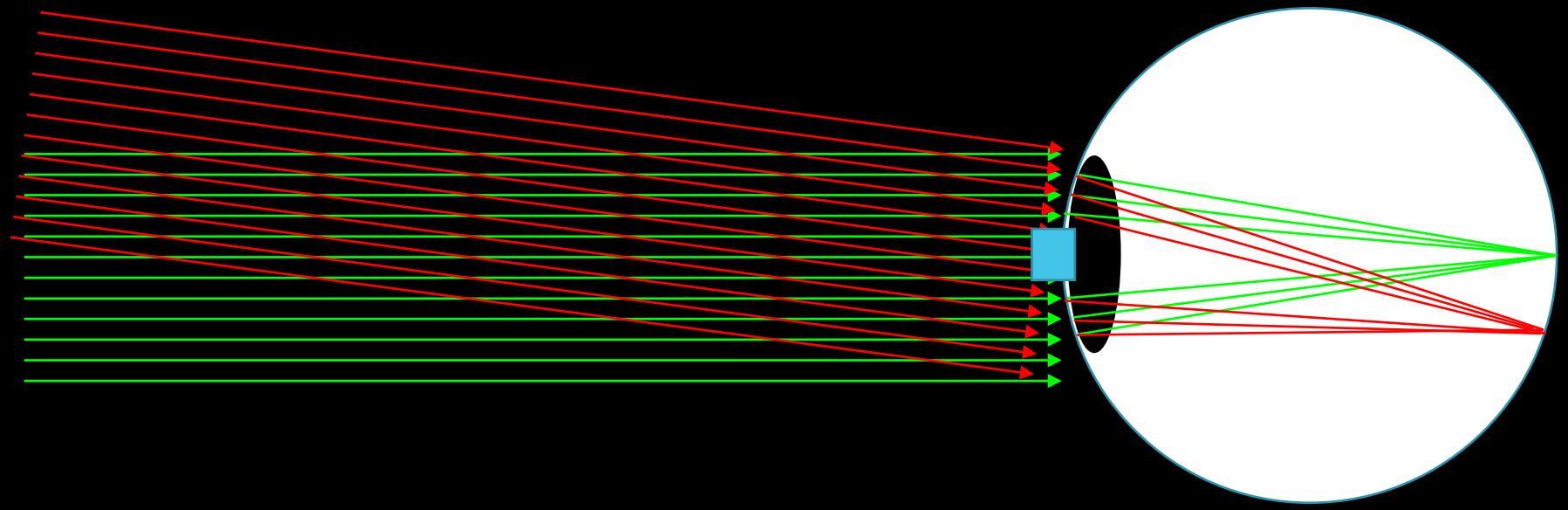
- Light from display must pass through pupil
- Display must be invisible, must not create blind spot
- Display must have no impact on visual acuity

Put the Display Right in Front of the Pupil!

An obscuration much smaller than the pupil is INVISIBLE when placed right in front of the pupil

Peripheral Point

Gaze Point



Criteria:

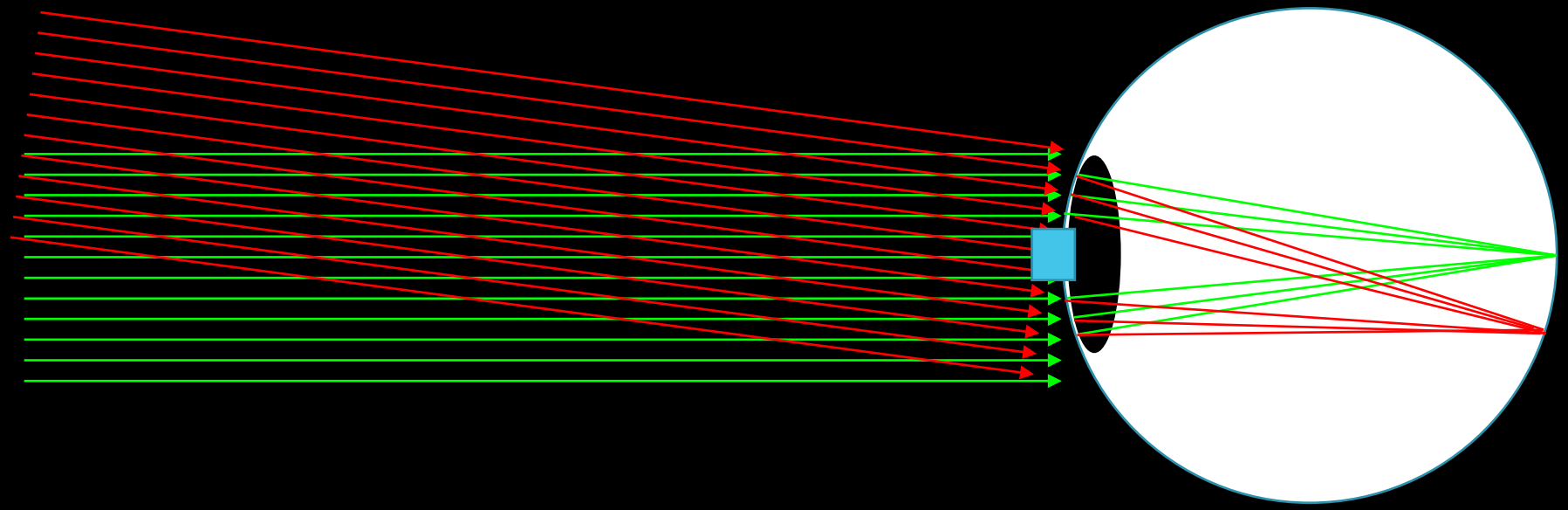
- ✔ Light from display must pass through pupil
  - Display must be invisible, must not create blind spot
  - Display must have no impact on visual acuity

Put the Display Right in Front of the Pupil!

An obscuration much smaller than the pupil is INVISIBLE when placed right in front of the pupil

Peripheral Point

Gaze Point



Criteria:

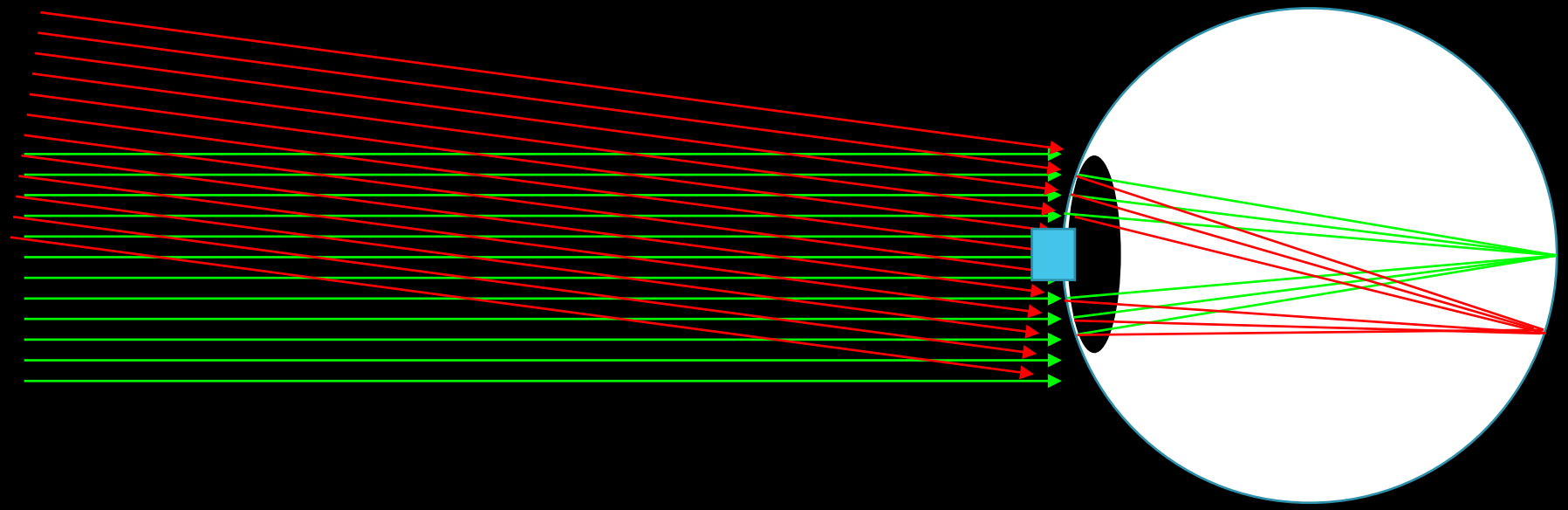
- ✔ Light from display must pass through pupil
- ✔ Display must be invisible, must not create blind spot
  - Display must have no impact on visual acuity

Put the Display Right in Front of the Pupil!

An obscuration much smaller than the pupil is INVISIBLE when placed right in front of the pupil

Peripheral Point

Gaze Point



Criteria:

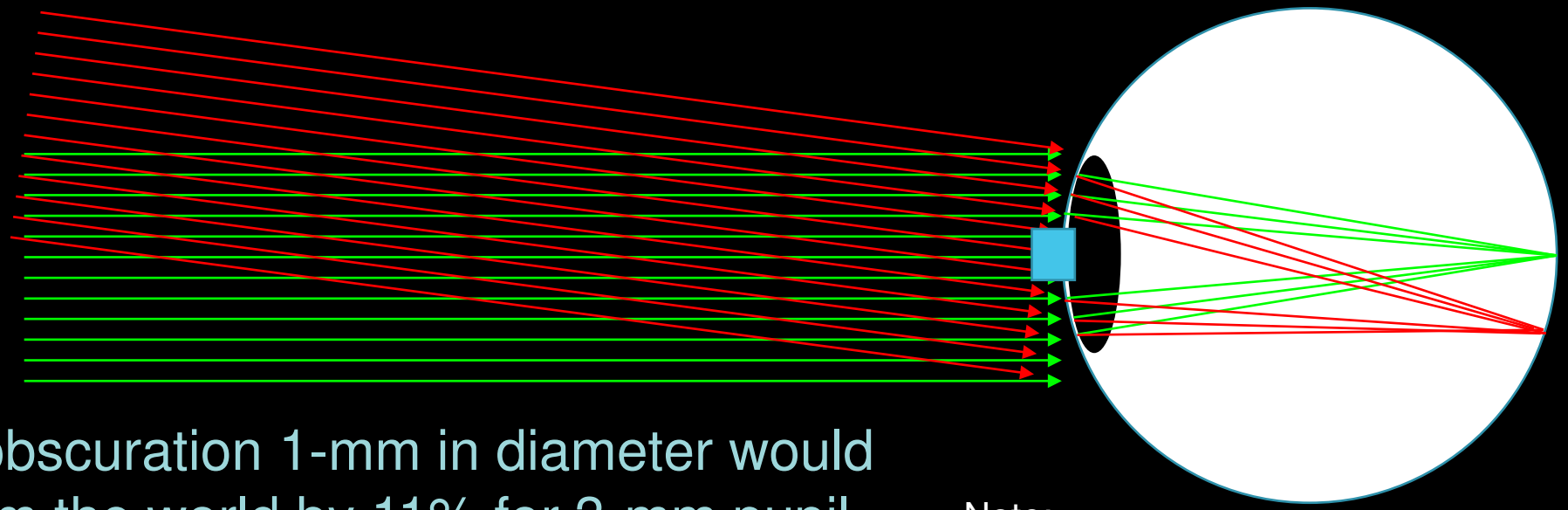
- ✔ Light from display must pass through pupil
- ✔ Display must be invisible, must not create blind spot
- ✔ Display must have no impact on visual acuity

Put the Display Right in Front of the Pupil!

Has same effect as slightly reducing the pupil diameter

Peripheral Point

Gaze Point



Example: An obscuration 1-mm in diameter would
- Dim the world by 11% for 3-mm pupil
- Dim the world by 6% for a 4-mm pupil
- Dim the world by 4% for a 5-mm pupil

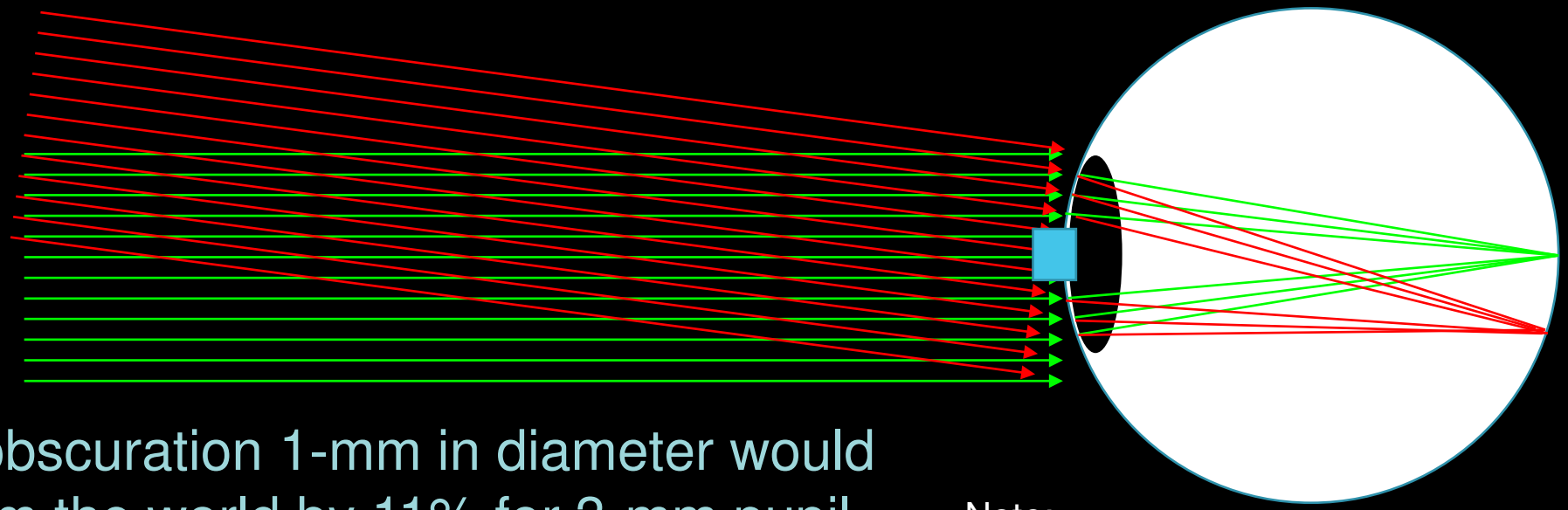
Note:
Typical Pupil Range is 2mm – 8mm
8mm in the dark
2mm outdoors on a very bright day

Put the Display Right in Front of the Pupil!

Has same effect as slightly reducing the pupil diameter

Peripheral Point

Gaze Point



Example: An obscuration 1-mm in diameter would
- Dim the world by 11% for 3-mm pupil
- Dim the world by 6% for a 4-mm pupil
- Dim the world by 4% for a 5-mm pupil

Compare to clear, uncoated glasses, which dim the world by 8%

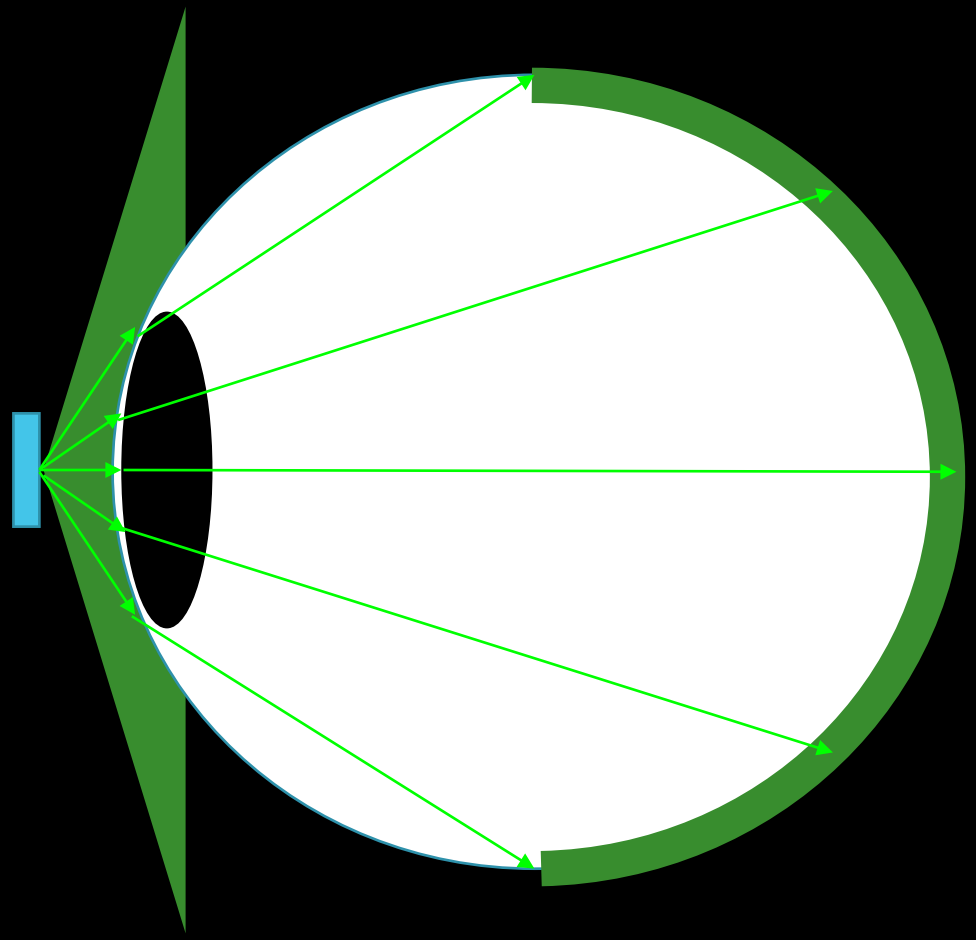
Note:
Typical Pupil Range is 2mm – 8mm
8mm in the dark
2mm outdoors on a very bright day

How Does an AR Contact Lens Work?

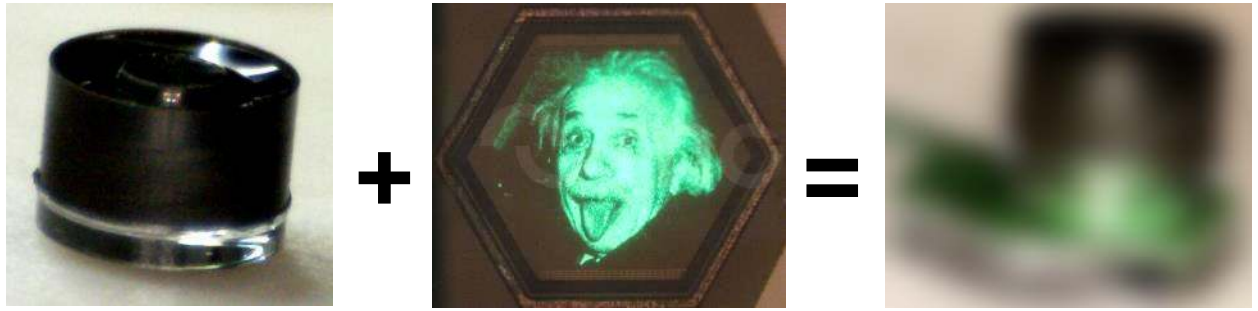
Do we need any optics with the display?

Do we need any optics with the display?

Yes!
A display held close to the eye will not form an image.



“Femtoprojector” (Optic + Display)



Reflective Projection Optic | Display | Femtoprojector

Tiny assembly:

- Fits in a contact lens, right in front of the pupil
- Projects a clear, sharp, digital image on the retina
- Doesn’t impact the users natural view of the world

How Does an AR Contact Lens Work?

Now that we can project an image on the retina,
how do we fool the brain into thinking it is REAL?

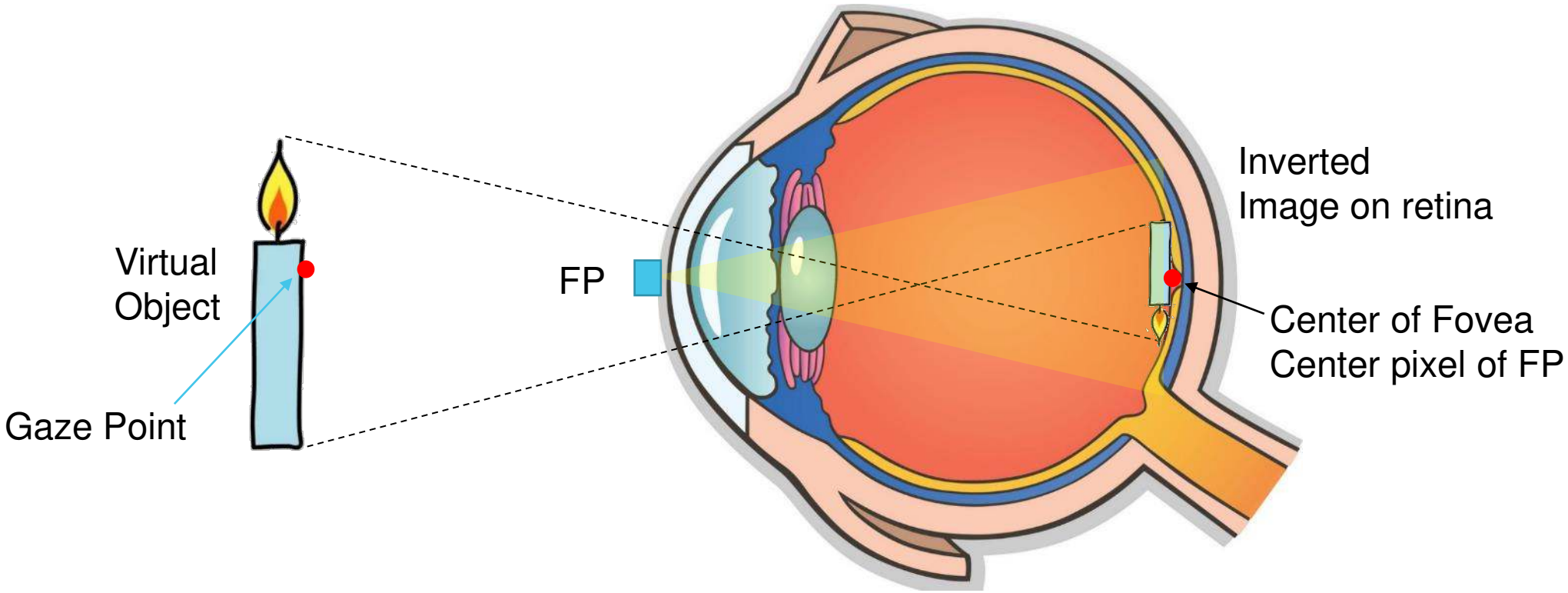
Eye Tracking

How Does an AR Contact Lens Work?

Do we REALLY need eye-tracking?

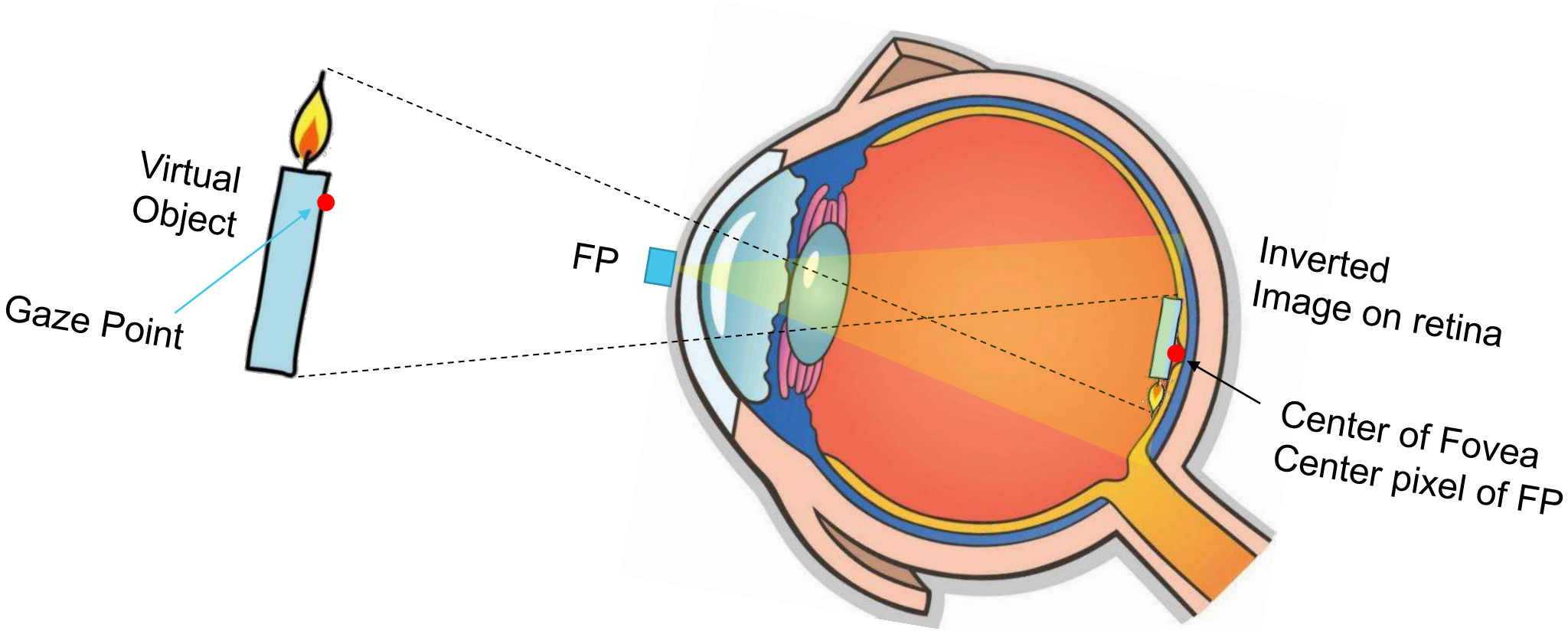
What would happen if we just display a static image with the Femtoprojector?

The Maddening Static Display



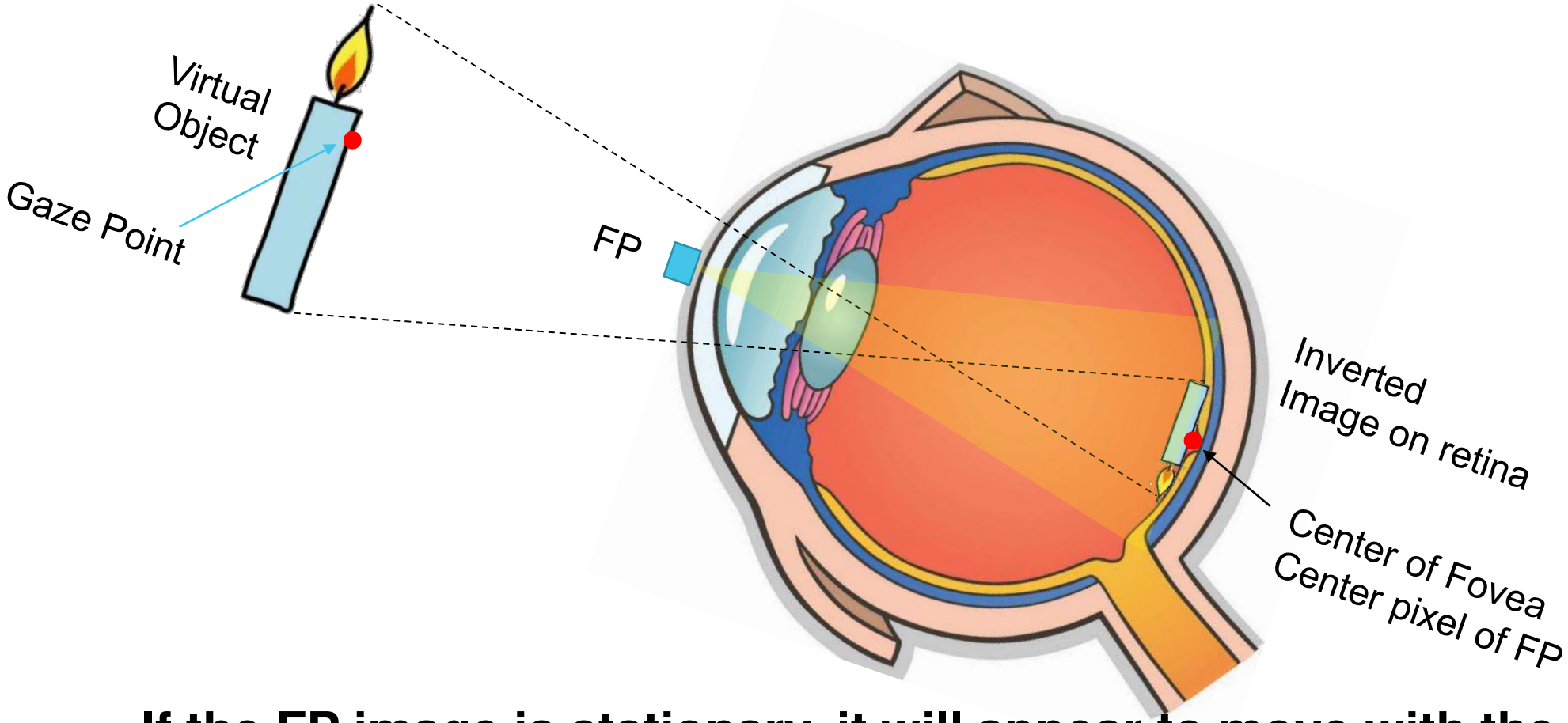
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



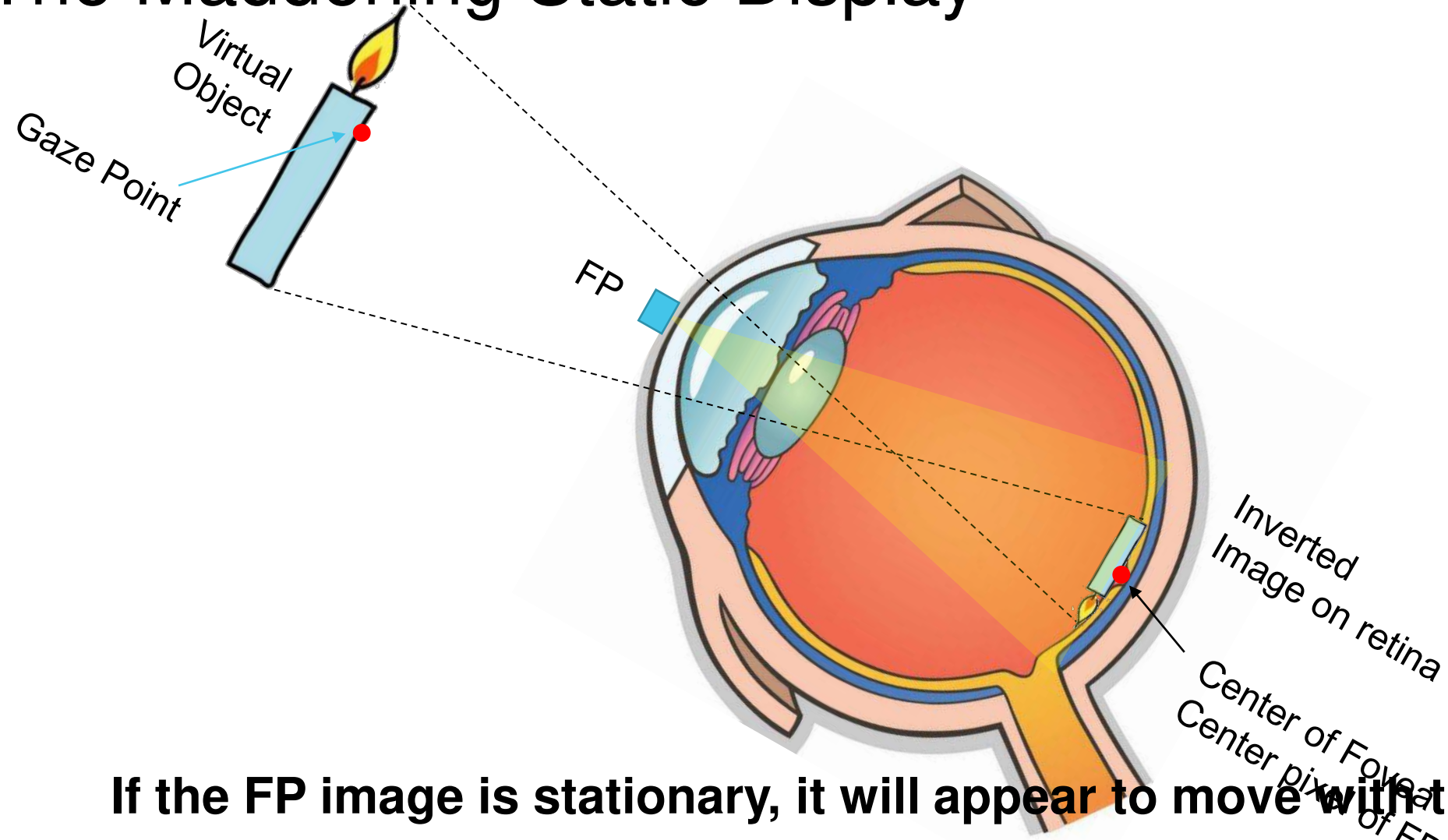
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



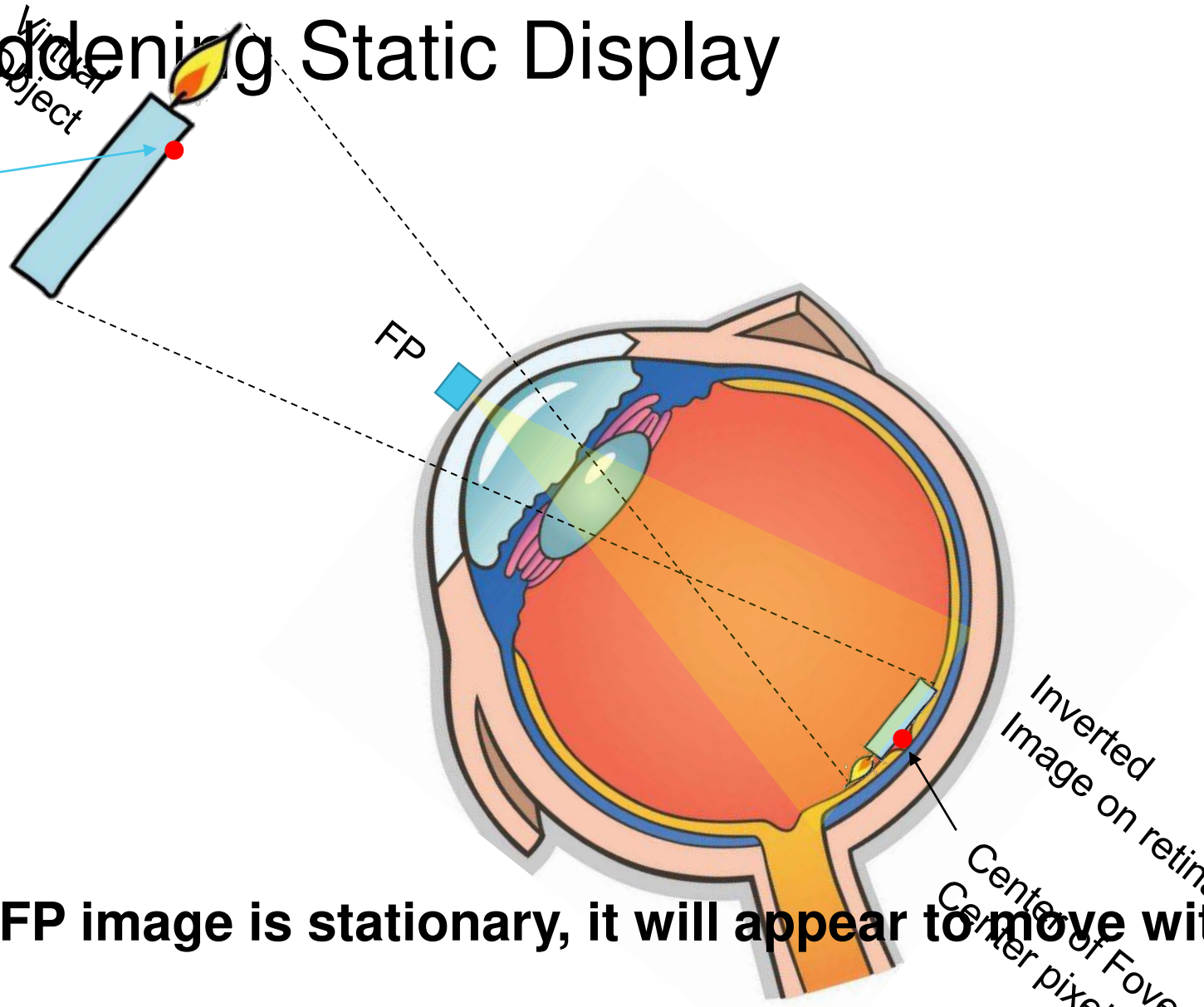
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



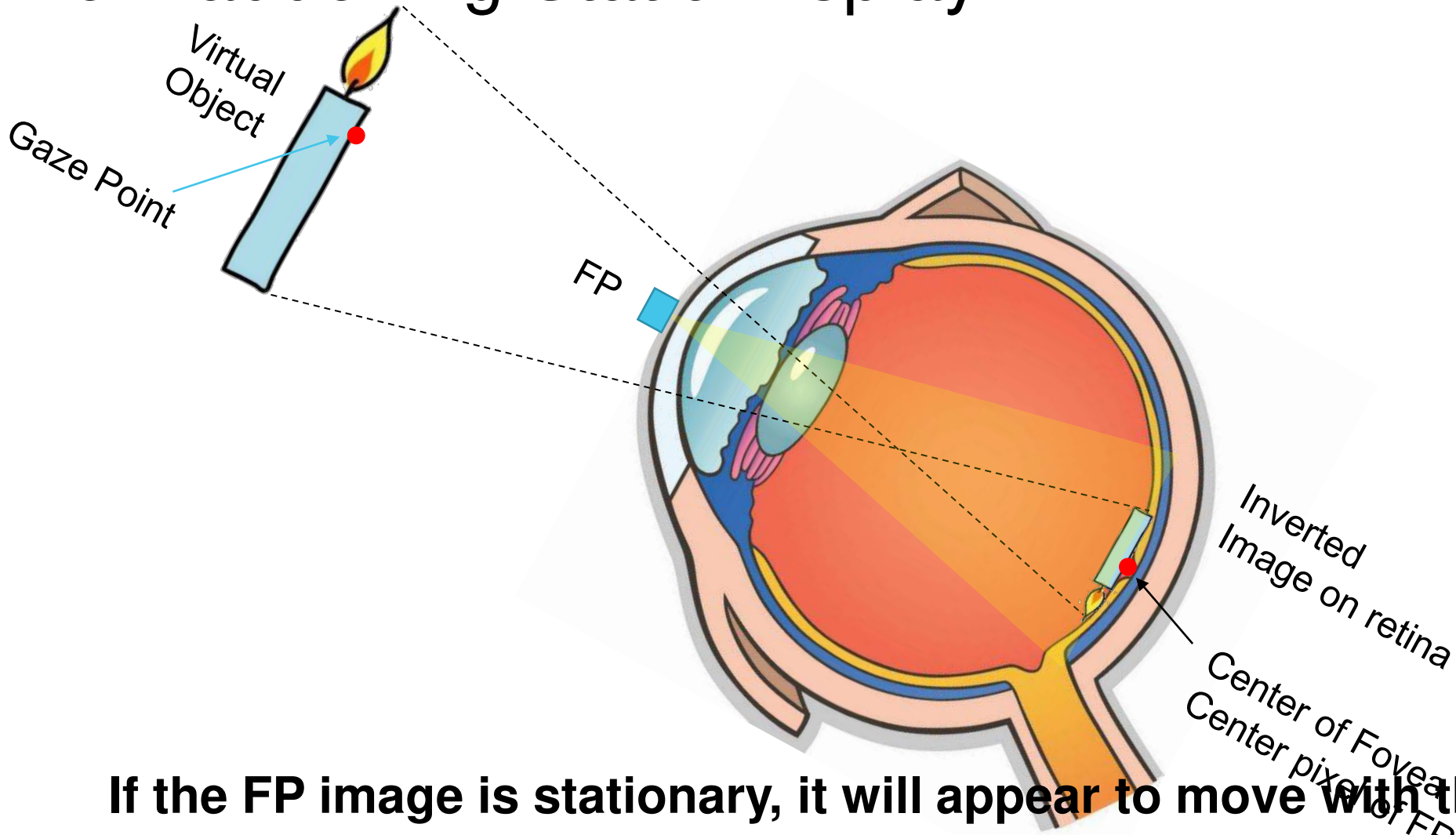
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



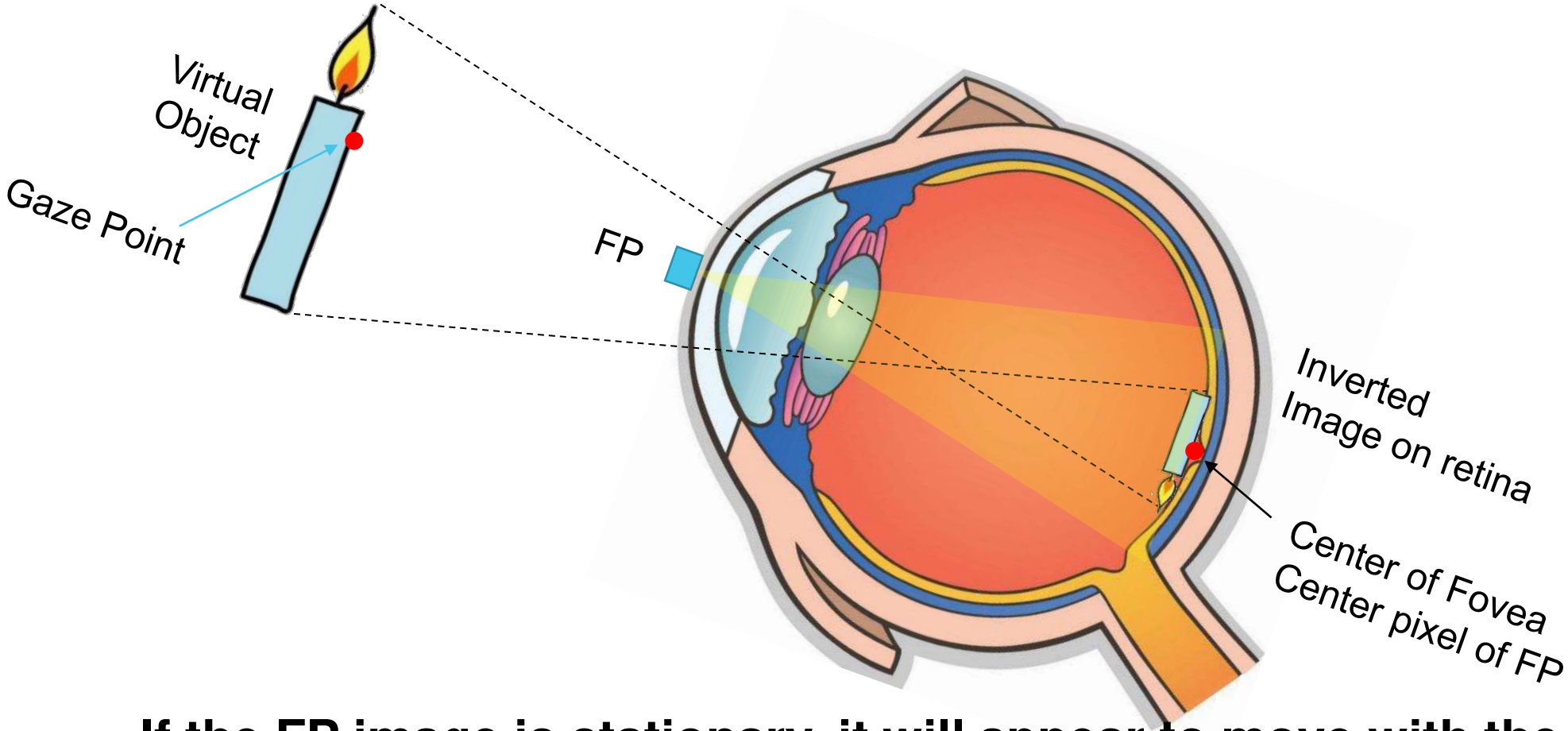
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



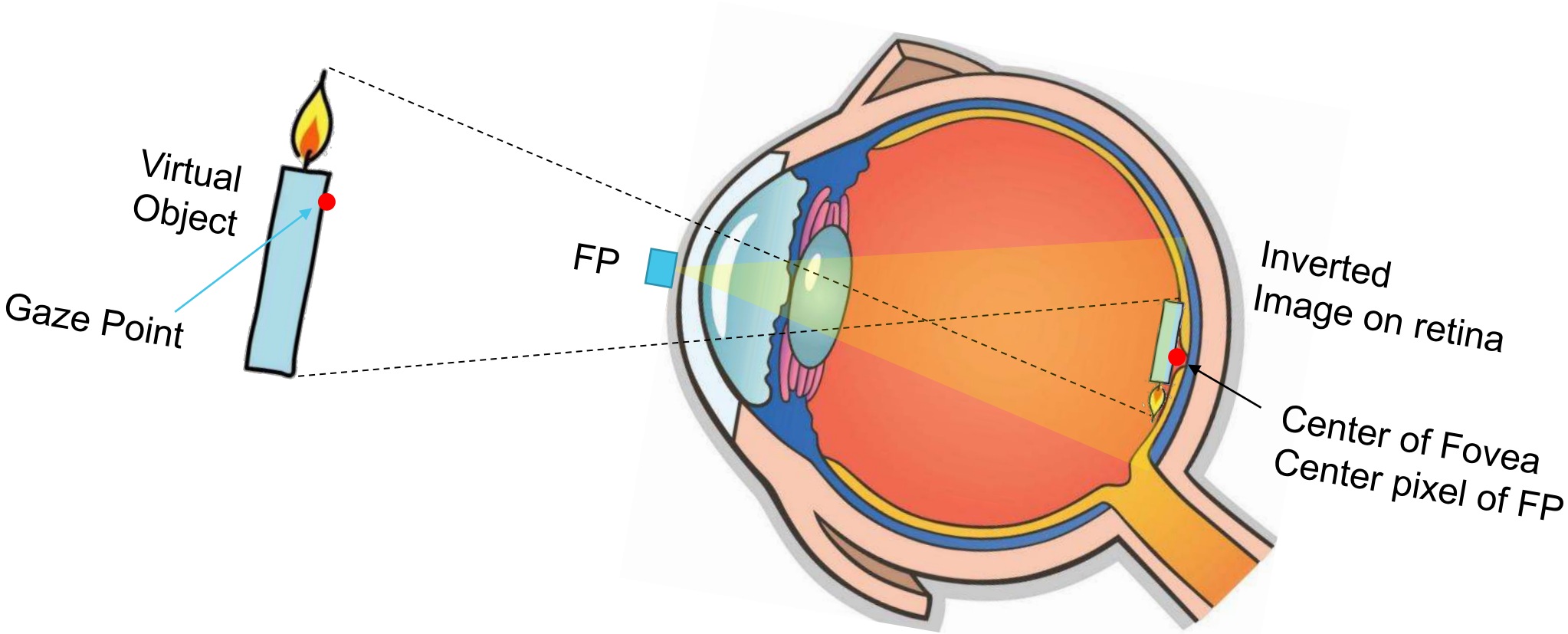
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



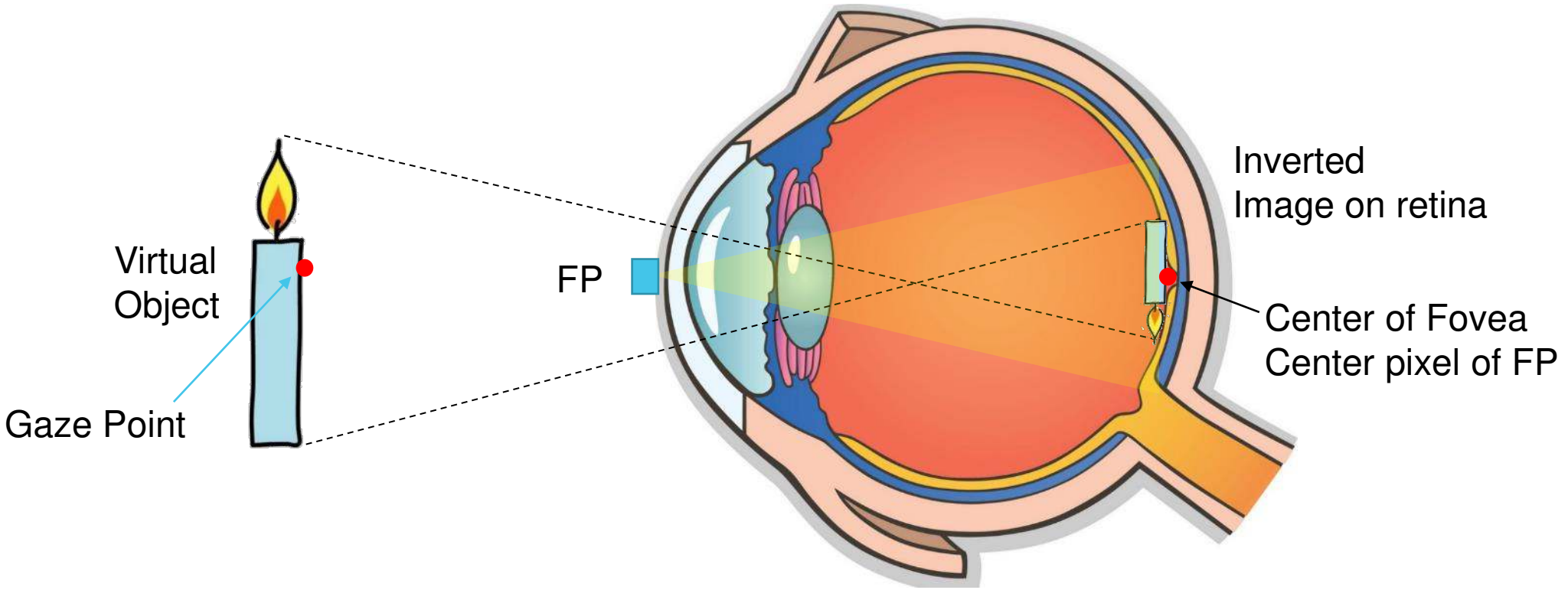
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



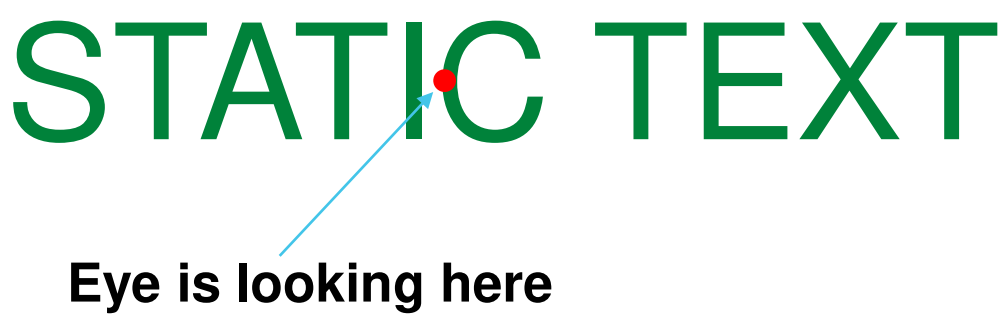
If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



If the FP image is stationary, it will appear to move with the eye.

The Maddening Static Display



Static Text is Displayed. The eye is fixated at the center.

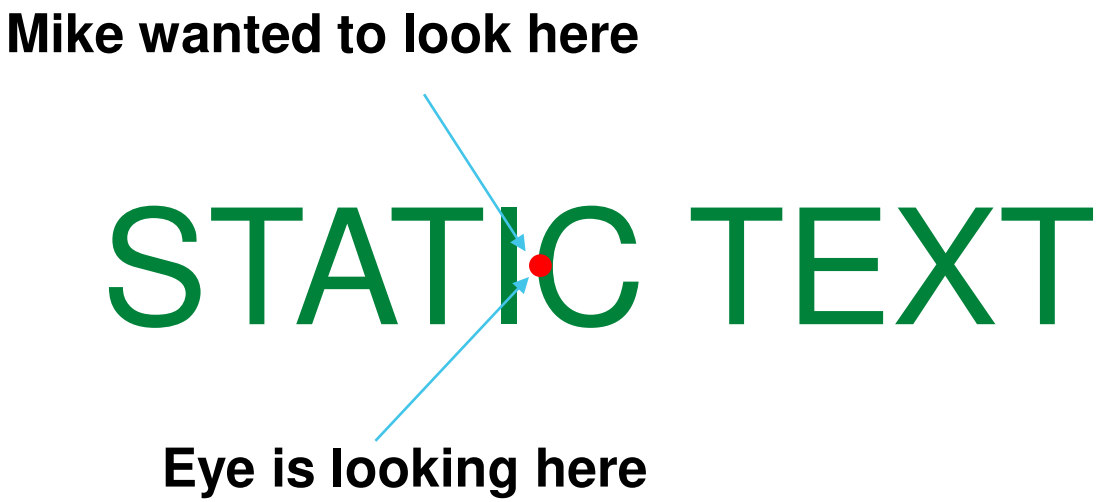
The Maddening Static Display

Mike wants to look here

Eye is looking here

The Brain tells the eye to jump to the “S”

The Maddening Static Display



The eye moved, but the “S” is no closer to the fovea.

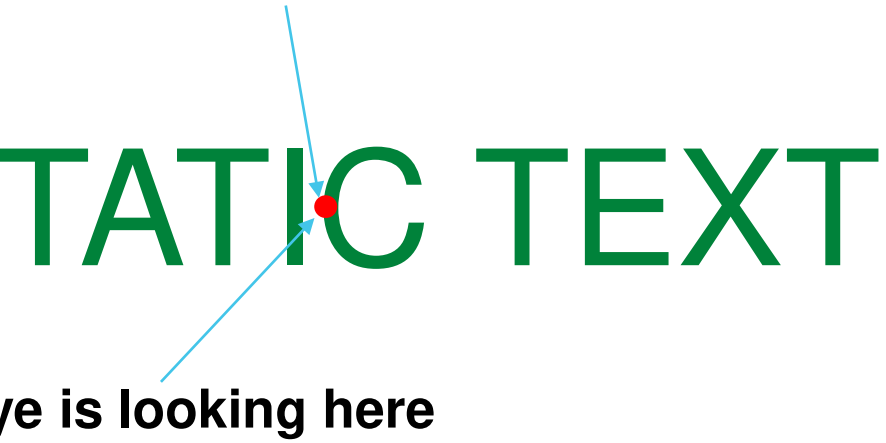
The Maddening Static Display

Mike now wants to look here!!

The eye moved, but the “S” is no closer to the fovea.

The Maddening Static Display

Mike now wants to look here!!



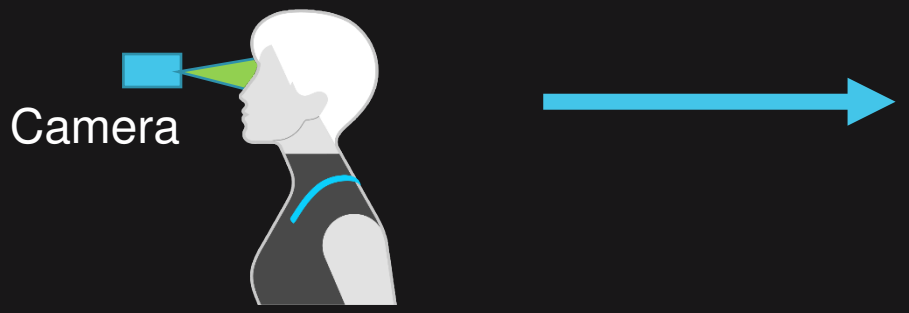
ye is looking here

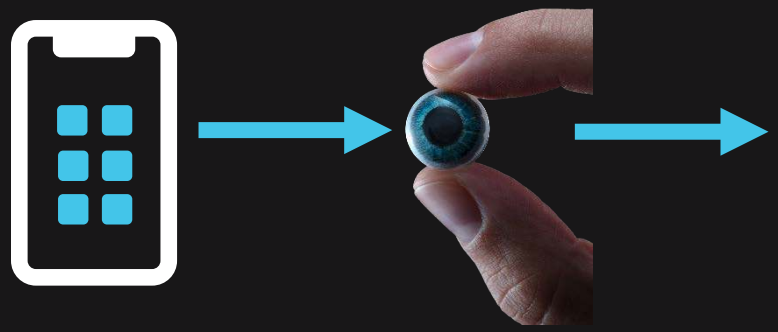
OUCH!! My eyes are at their limit!!

How Does an AR Contact Lens Work?

Eye-tracking must be a fundamental part of any contact lens display system.

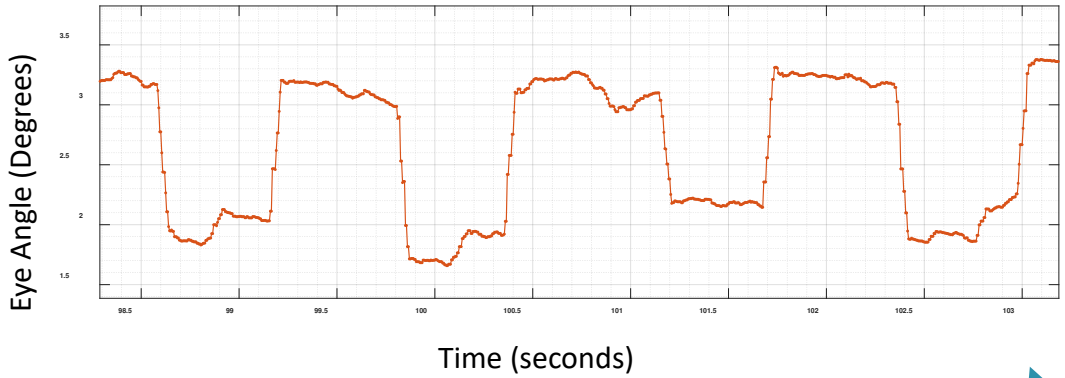
World’s Best Eye Tracker?





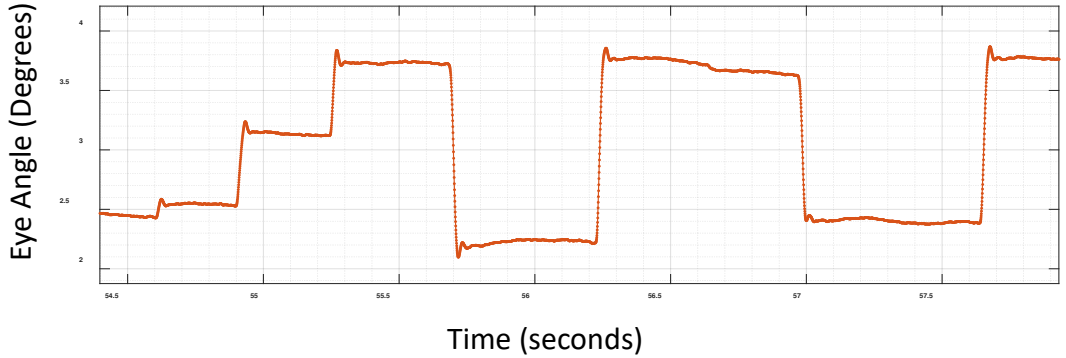
Mobile Phone
Motion Sensors

Inside a
Contact Lens



Commercial Video Tracker – noisy

Mojo Lens Tracking – rock solid



The Chips Behind Mojo Lens

mojo

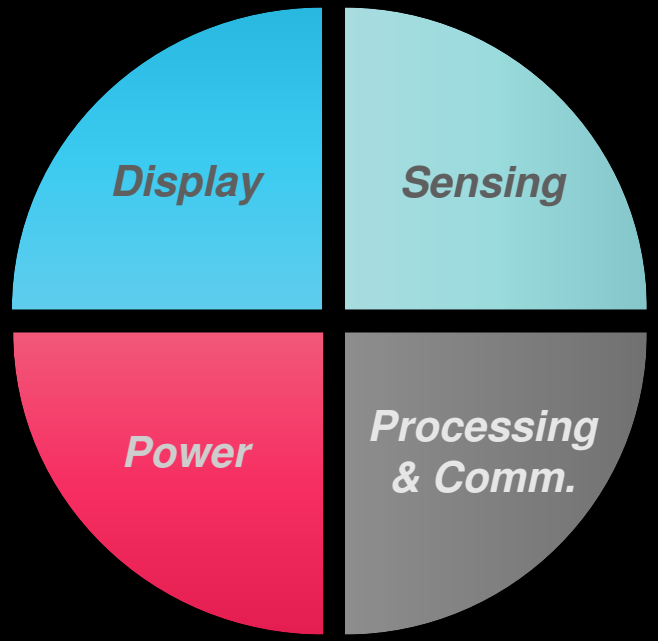
What does an AR contact lens do?

Display

- CMOS backplane + GaN LED
- Ultra-low power consumption, optimized for sparse content

Power

- Provide power, charging
- Ensure safety



Sense

- Eye-tracking sensors
- ULP Imager
- Provide context awareness

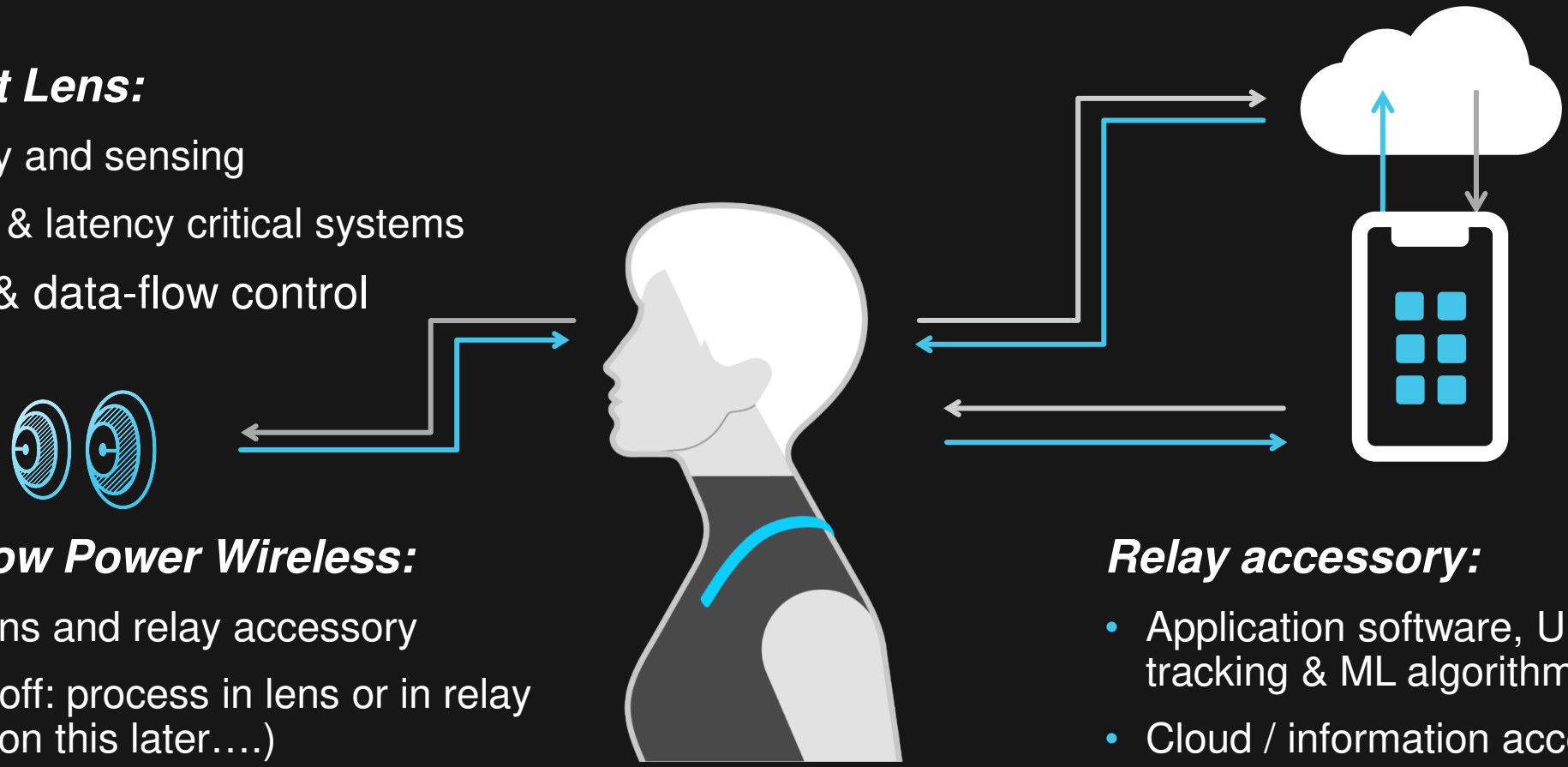
Processing & Communication

- Interpret sensor data
- Lens control & UI
- Cloud / information access

Mojo Lens – System Partition

Contact Lens:

- Display and sensing
- Safety & latency critical systems
- Lens & data-flow control



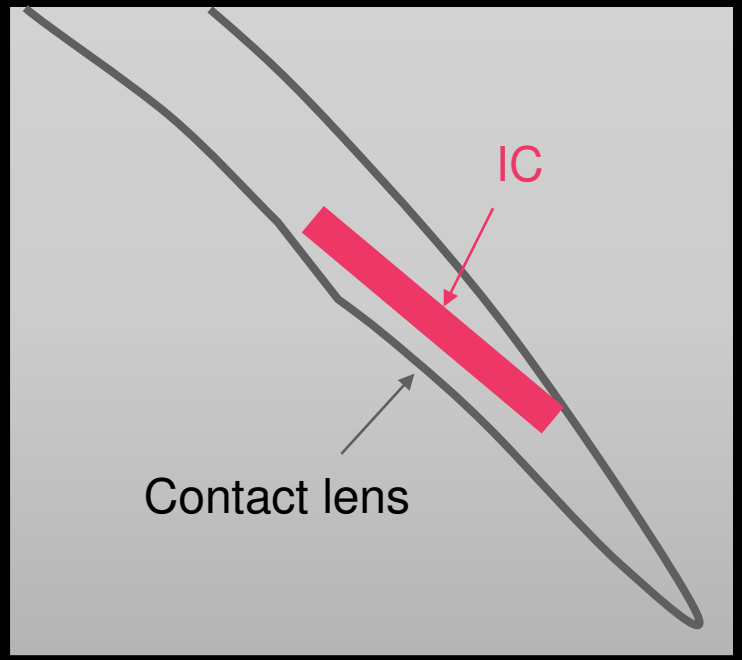
Ultra-Low Power Wireless:

- Link lens and relay accessory
- Trade-off: process in lens or in relay (more on this later….)

Relay accessory:

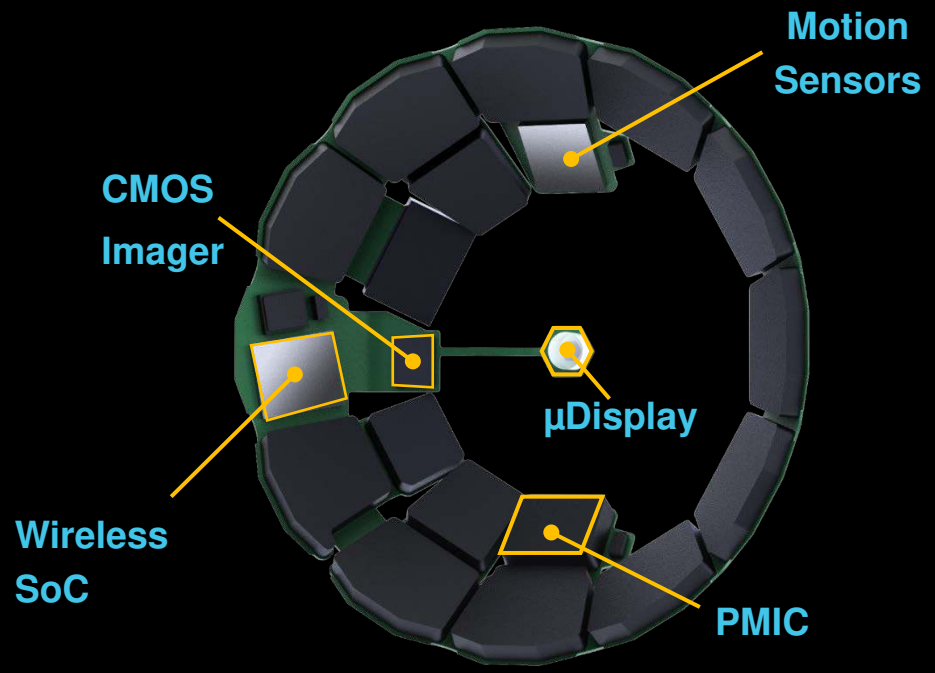
- Application software, UI stack, tracking & ML algorithms
- Cloud / information access

How to put chips in a contact lens?

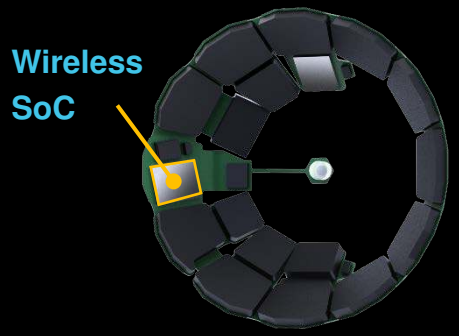


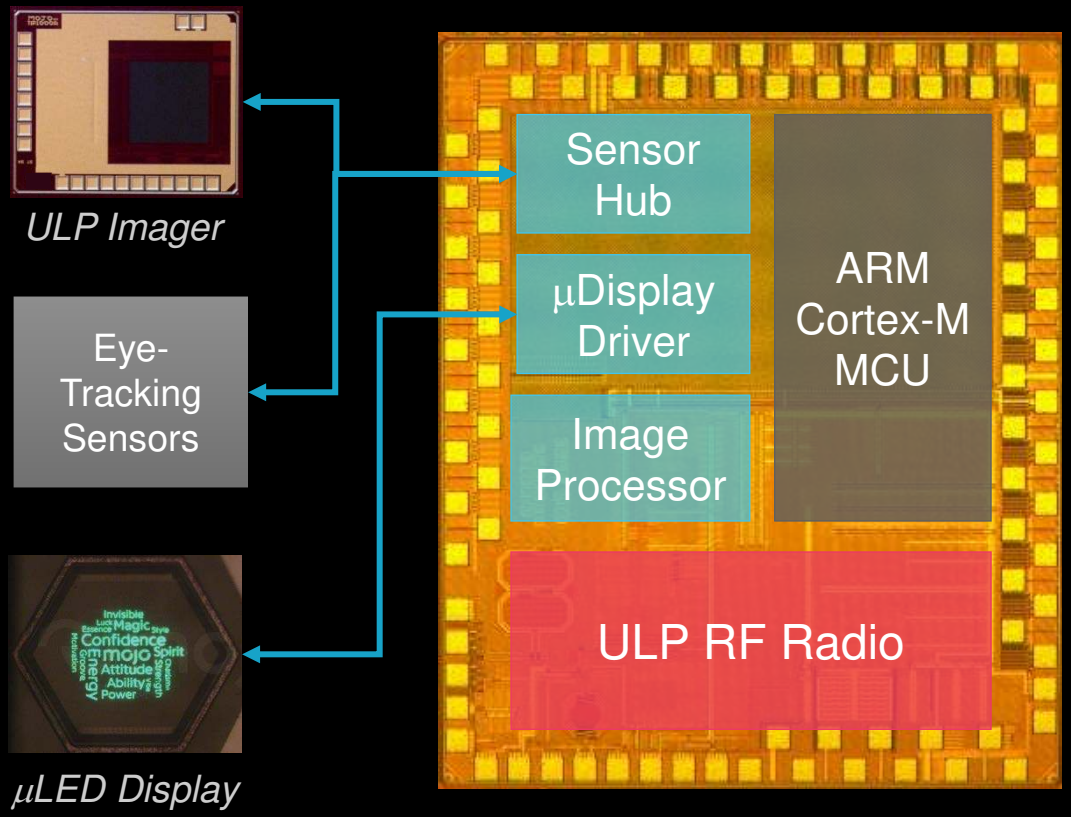
- Contact lens is a 3-D curved surface
- How do we fit rectangular-shaped chips?

- Multiple *small* chips are better than one *large* chip
- Flex PCB as a connectivity substrate



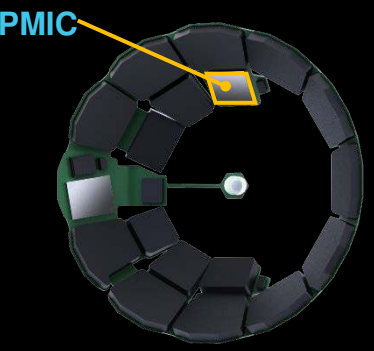
Ultra-Low Power Wireless SoC

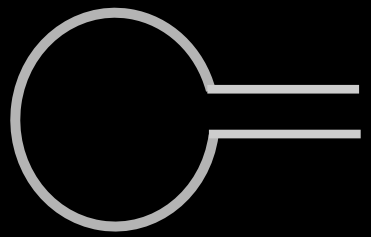


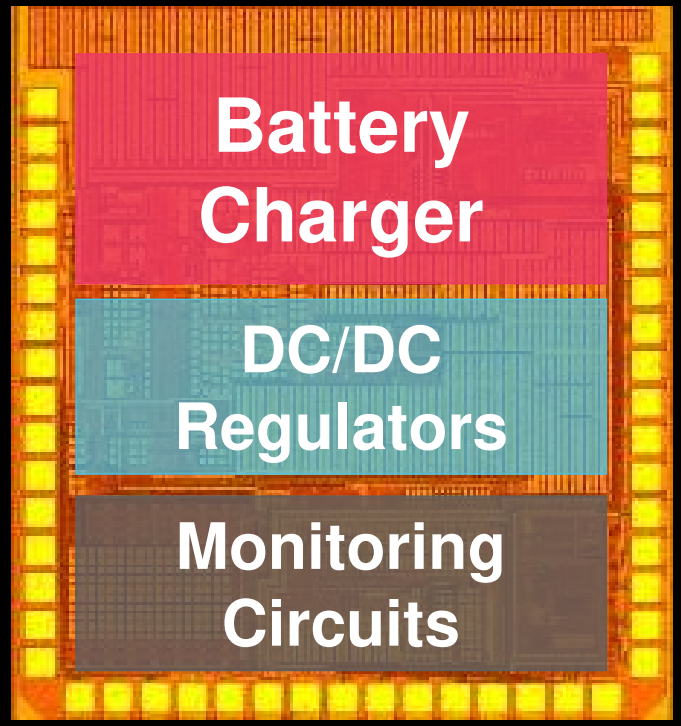


- Contains the state machine that controls the lens
- Data in and out of the lens is routed through this SoC
- Image processor for vision enhancements

Power Management IC for a Smart Contact Lens

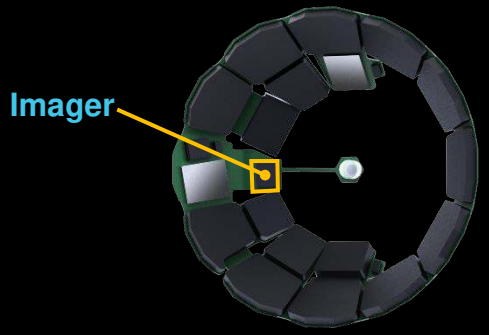


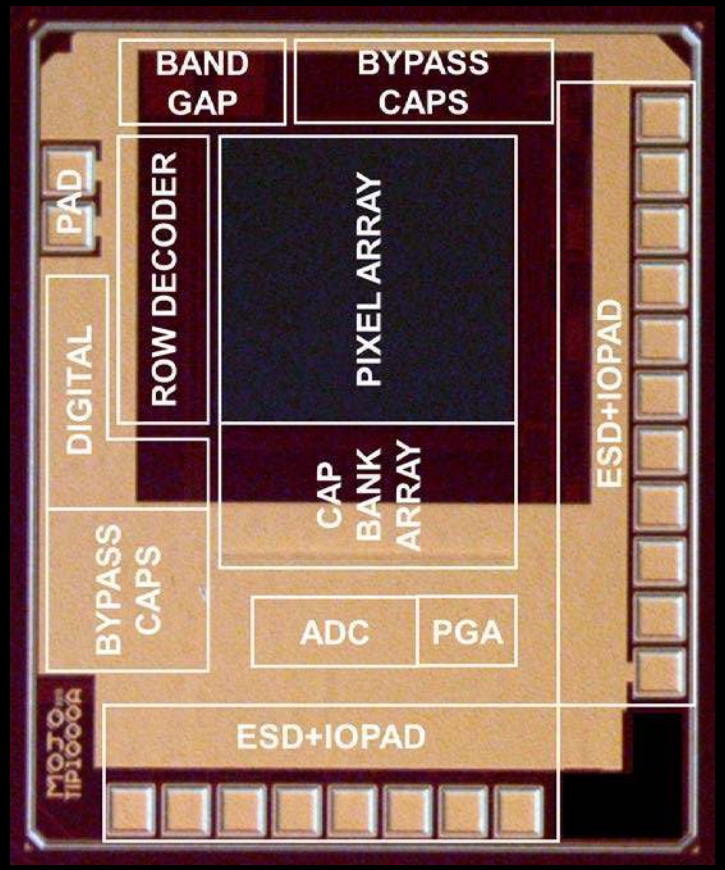




- Batteries are charged wirelessly overnight…
- PMIC generates needed voltage rails and continuously monitors parameters to ensure safety

ULP CMOS Imager





- Small form factor, ultra-low power, back-side CMOS image sensor
- 256x256, 44FPS at **61µWatt**
  - 21 pJ/frame/pixel
  - Up to 88FPS at lower grayscale depth
  - 2x, 4x and 8x subsampling & binning modes to optimize power/data-rate
- 1mm x 1.3mm die area

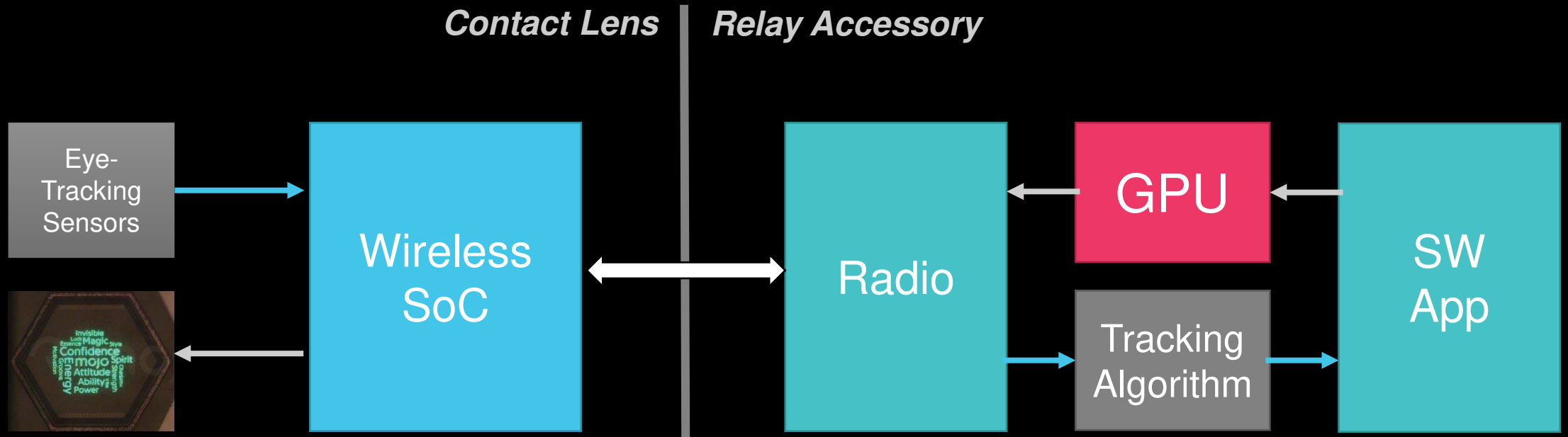
ref: R. Singh, ISSCC 2021

Putting it Together….

Application Examples:

- Eye-tracking → Render Loop
- Low vision image enhancements

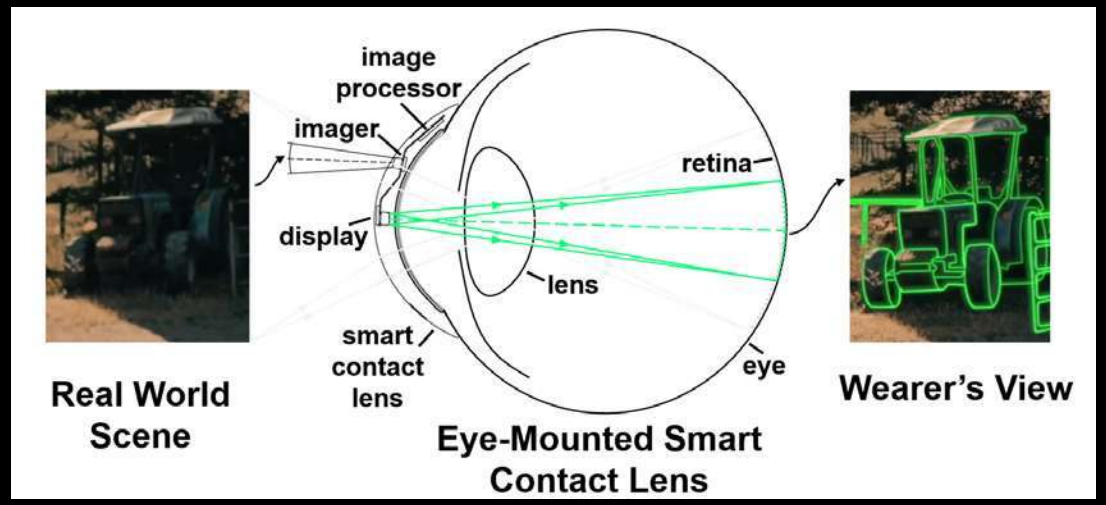
Eye-Tracking → Render Loop

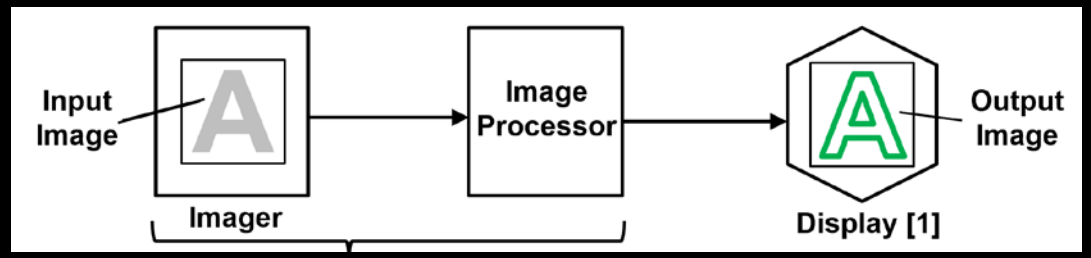


- Collect sensor data
- Display image

- Interpret sensor data, adjust output image
- User interaction & application stack

On-Lens Image Processing for Low Vision





- All processing done in lens:
  - Minimize latency
  - Cheaper to process locally in lens than transmitting to relay
- Programmable enhancement mode:
  - Contrast adjustment
  - Edge detection
  - Edge detection + contrast adjustment

ref ISSCC 2021


mojo
Eyes Up