# Interazione non verbale: l'attenzione e lo sguardo Tecnologie di Eye tracking

Corso di Interazione uomo-macchina II

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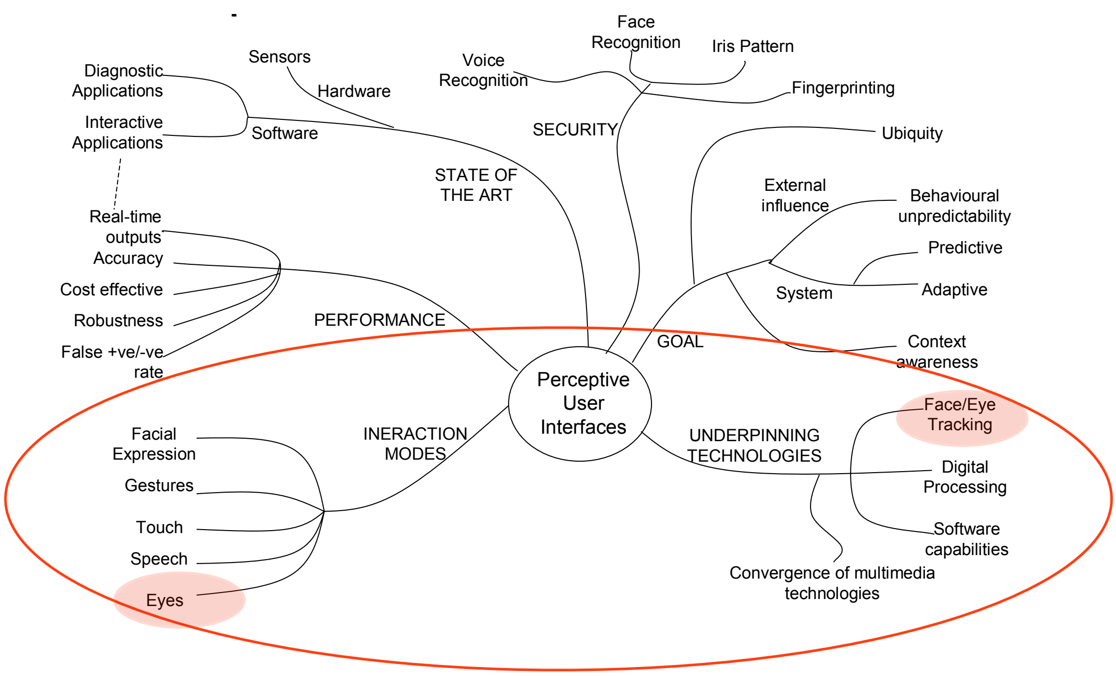
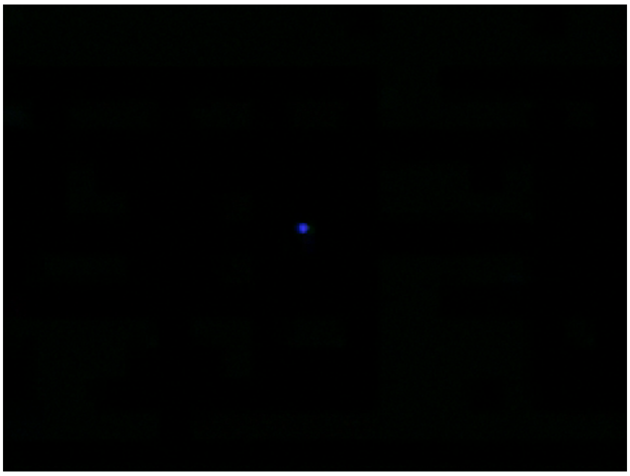
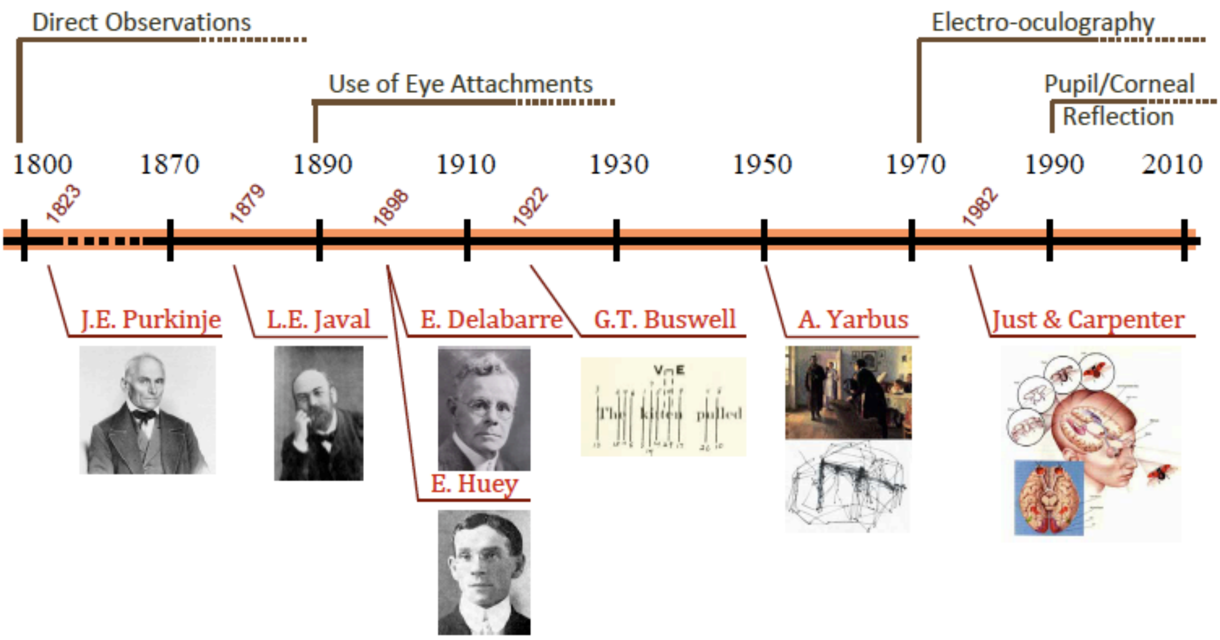
# Perceptual UI



# Eye tracking



# Eye-tracking over time

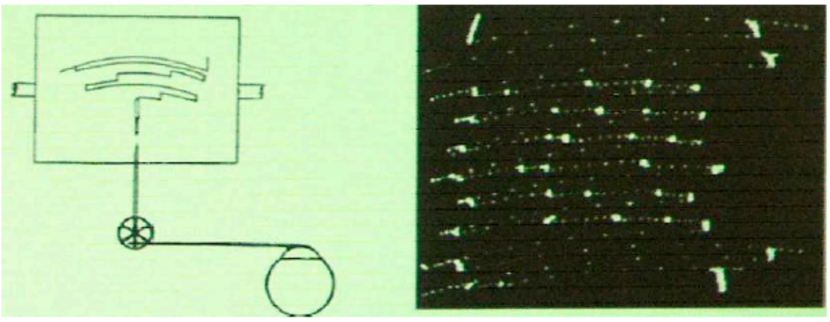


# Eye-tracking over time

- 1878: Javal – Using direct observation Javal, a french physiologist, coins the term "saccade" to describe jerky movements of eyes during reading.

- 1897: Delabarre – Attached a lever to a plaster of paris "cup" placed on cornea.

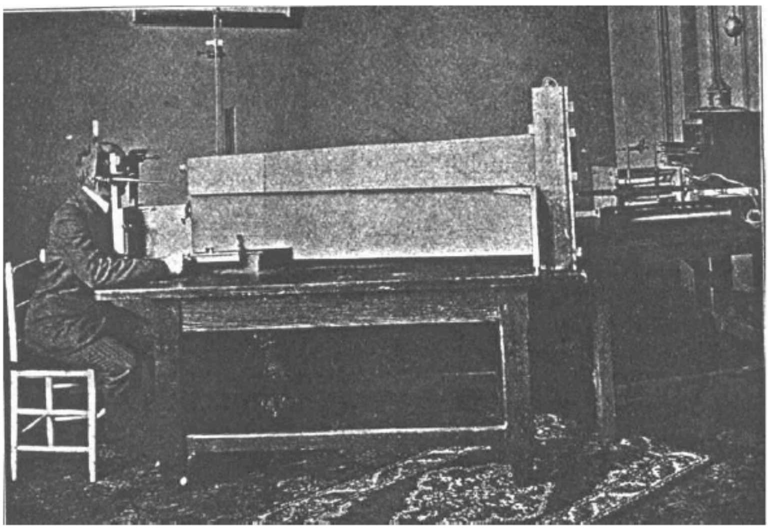
- 1898: Edmund Burke Huey – Refined the technique and recorded movements during reading on "smoke paper" on rotating drum.



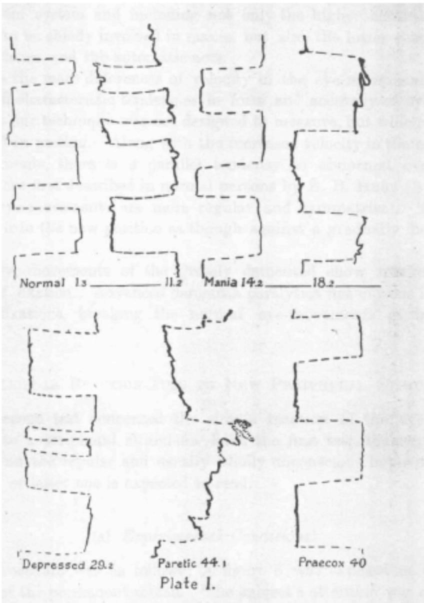
# Eye-tracking over time

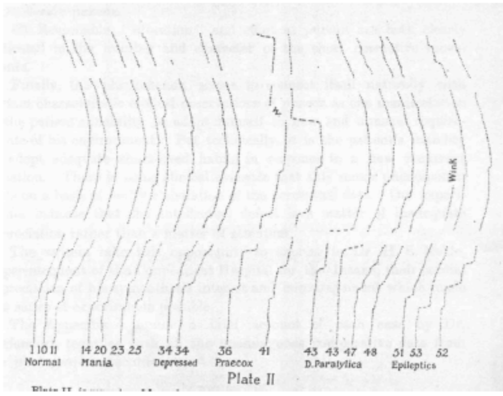
1901: Dodge – creates his Photochronograph which works on corneal reflection.

Uses 100Hz tuning fork to achieve impressive temporal resolution!



# Eye-tracking over time



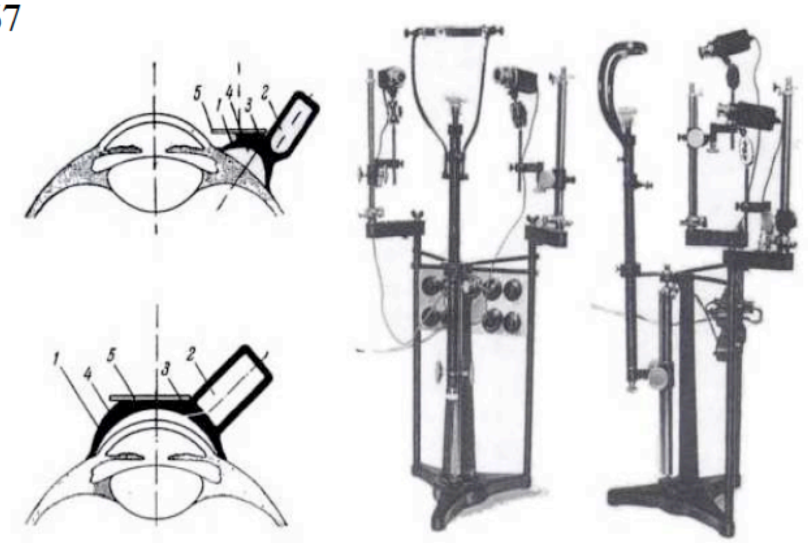




# Eye-tracking over time


1937: Buswell develops Dodge's technology further, and includes head tracking!

## Eye-tracking over time

Yarbus, 1967



Camera based system – using mirrors and illumination
(and some nasty looking suction cups placed on eye…)

## Eye Tracking

- The most common form of eye tracking today is the desktop corneal reflection eye tracker


Image courtesy http://www.polhemus.com

# Wearable Eye Trackers

- Reports gaze coordinates within a scene from an onboard camera
- Camera must be stationary relative to the head
- Deixis towards objects requires object recognition

ASL Model H6 wearable eye tracker

Image Courtesy http://www.a-s-l.com

# Some terms

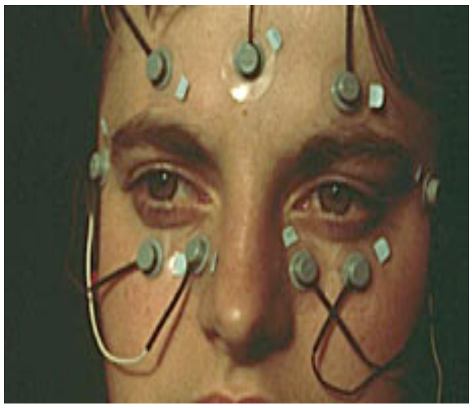
- Accuracy
  - The expected difference in degrees of visual angle between true eye position and mean computed eye position during a fixation.
  - Because of the vision system and physiology of eye the accuracy is usually 0.5-1$^{\circ}$
- Precision
  - Reproducability / Repeatability - the degree to which the repeated measurement of a set of true valuesproduces the same or similar set of measured valuesregardless of the accuracy of these values. (Variance)
- Spatial Resolution
  - The smallest change in eye position that can be measured.
- Temporal Resolution (sampling rate)
  - Number of recorded eye positions per second.

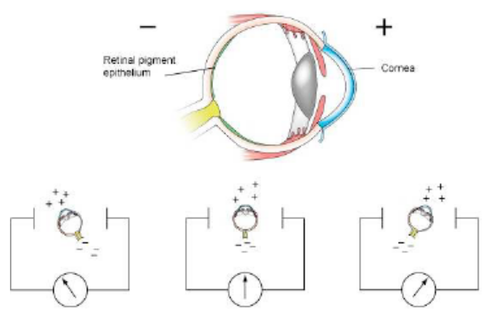
# Eye Tracking Methods

- Rough taxonomy
  - Electronic methods
  - Mechanical methods
  - Video-based methods
    - Single point
    - Two point

# Electronic methods
# // EOG: Electro Oculography (EOG)

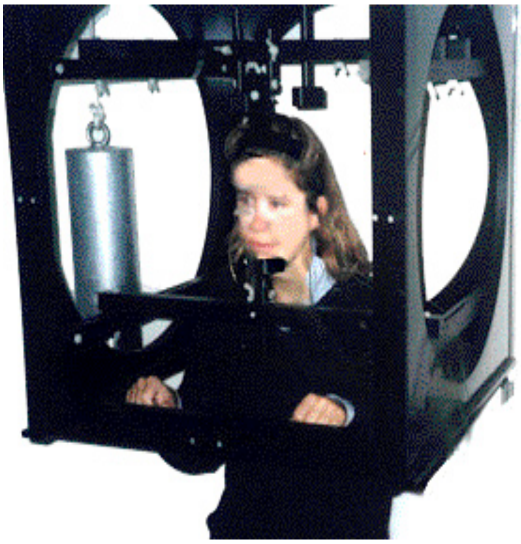
- The most used method is to place skin electrodes around the eyes and measure the potential differences in eye
- Wide range -- poor accuracy
- Better for relative than absolute eye movements
- Mainly used in neurological diagnosis (easy to use in fMRI)





# Mechanical methods
# // Scleral coil

- Based on contact lenses with
  - mirror planes + reflecting IR-light
  - coil + magnetic field
- Very accurate
- Very uncomfortable for users who are not used to wear lenses
  - Usable only for lab studies



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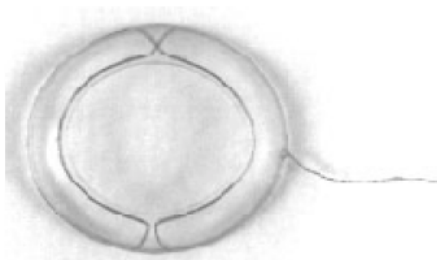
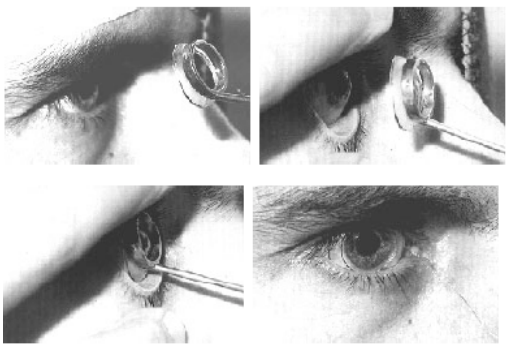
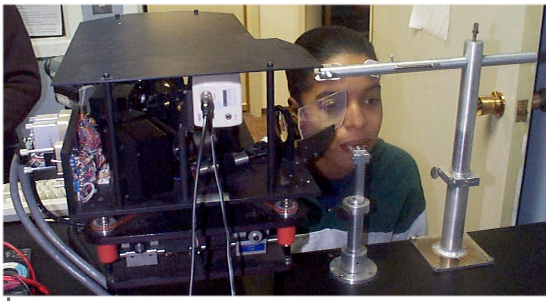
- Very uncomfortable for users who are not used to wear lenses
  - Usable only for lab studies
  - Animal studies





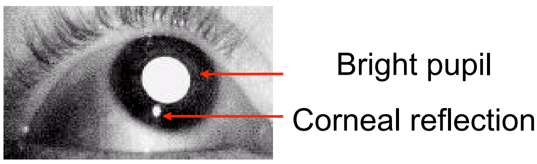
# Single point video-based methods

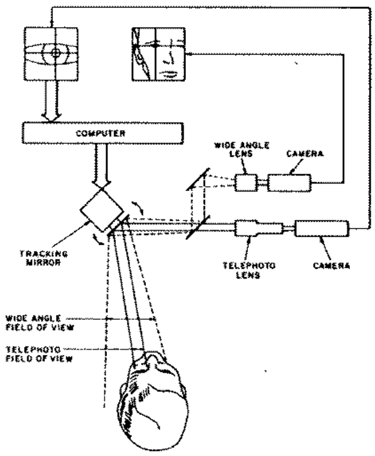
- Tracking ***one*** visible feature of the eyeball, ***e.g.:***
    - limbus (bondary of sclera and iris)
    - pupil
- A video camera observes one of the user's eyes
- Image processing software analyzes the video image and traces the tracked feature
- Based on calibration, the system determines where the user is currently looking
- Head movements not allowed



# Two point video-based method[1]

- The same idea as in the single point method except now two features of eye are tracked – typically
    - corneal reflection
    - pupil
- Uses IR light (invisible to human eye) to
    - produce corneal reflection
    - cause bright or dark pupil, which helps the system to recognize pupil from video image



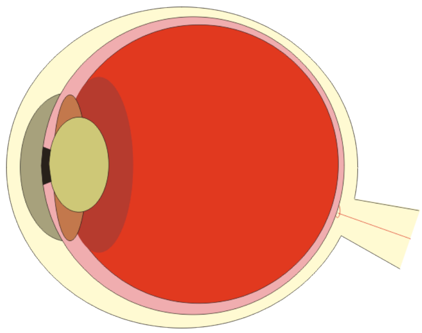



## Two point video-based methods$_2$

- The optics of the system can be mounted on
  - head
  - floor
- If optics are floor mounted, the system is not in contact with the user
- Generally head movements are not restricted and they can be separated from eye movements, but...
  - With floor mounted optics the system has to track the user's head in order to keep the eye in the field of view of camera, which limits the head movements. The performance can be improved with
    - servo controlled tracking mirrors, or
    - a camera taking a wide-angled view of the user's head and by using artificial neural network, the system searches the eye from the image.

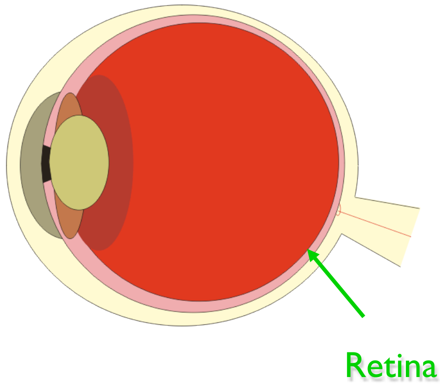
## Two point video-based methods$_2$

To understand how eye tracking works, it is important to have a basic knowledge about the structure of the eye.



The *retina* makes up most of the surface of the back of the eye.

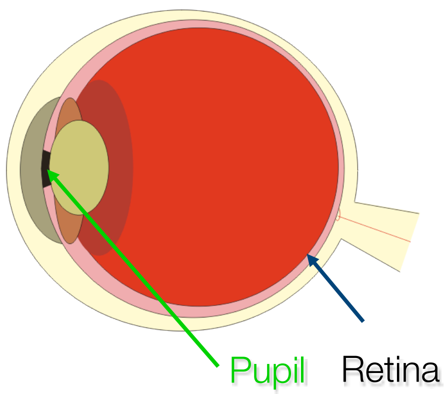
It contains the cells that detect light and send information to the brain through the optic nerve.



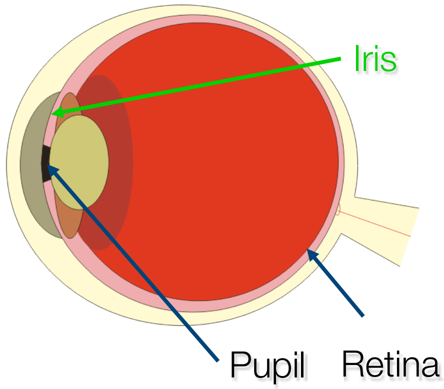

# Basic Eye Biology and Optics

The pupil : an aperture that allows light to enter into the eye.

Normally appears black since, under most perspectives, light does not exit the inside of the eye.



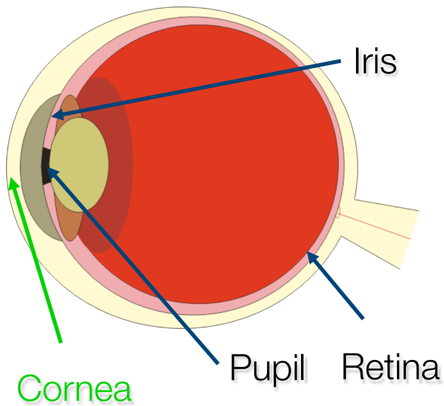
# Basic Eye Biology and Optics




The size of the pupil is related to the iris, which is similar to a shudder that opens and closes.

Is the (normally) coloured part of the eye.

# Basic Eye Biology and Optics

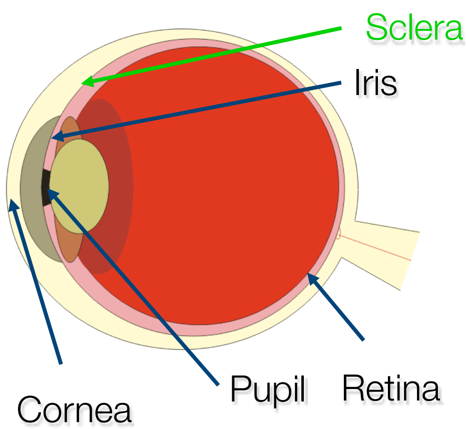



On its way to the pupil, light passes the cornea, which is a thin film-like tissue that covers the eye.

The cornea is mostly transparent. However, significantly, there is some amount of reflection as light passes through it.

# Basic Eye Biology and Optics

The sclera is the white part of the eye.

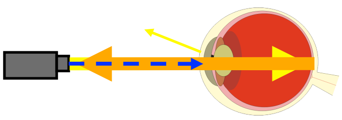





# Basic Eye Biology and Optics

The Illuminators

A beam of near infra-red light is projected from a set of LEDs attached to the camera.



Light  redirected to be coaxial with the imaging direction of the camera by a hot mirror

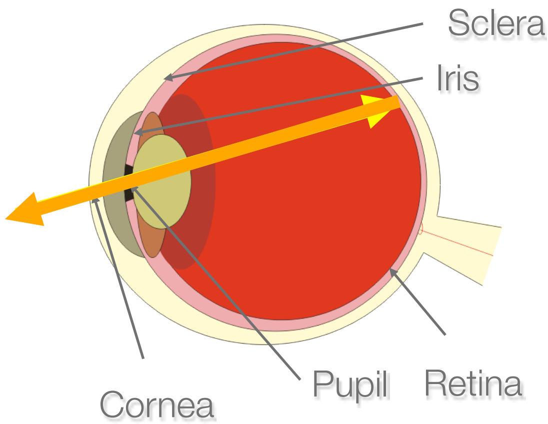
This produces

retro-reflection

corneal reflection

# Basic Eye Biology and Optics

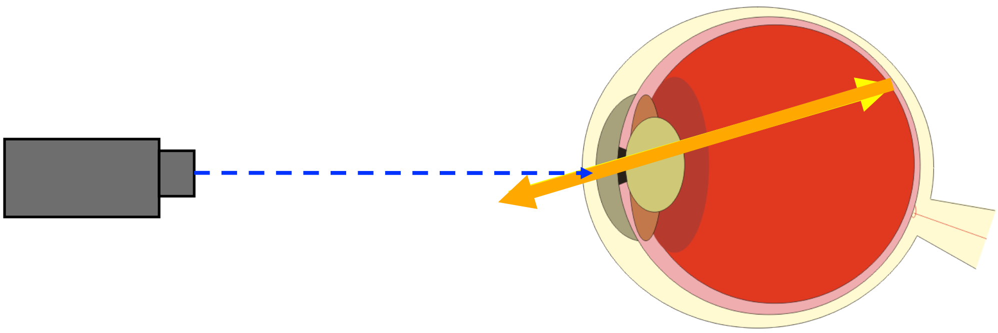
Light crosses the cornea and passes through the pupil until it reaches the back of the eye.



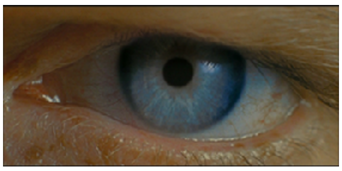

The eye acts as a retroreflector: it reflects a portion of the light back out along the same path that light came in.



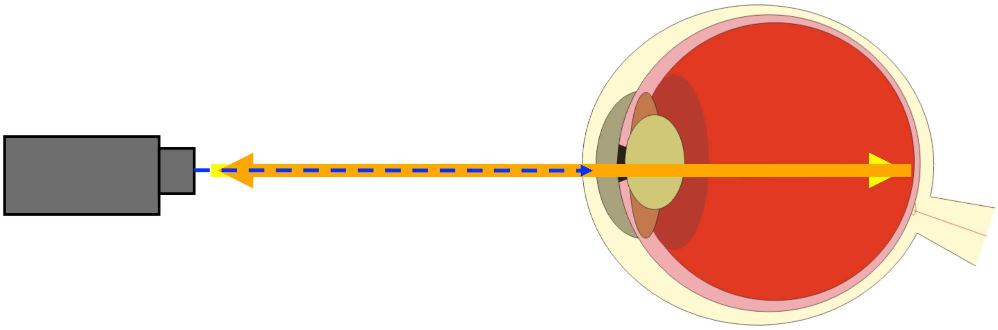
# Basic Eye Biology and Optics



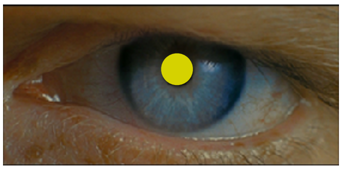
This means that, normally, the pupil looks black since light rarely ever comes from the same point as observation.



# Basic Eye Biology and Optics

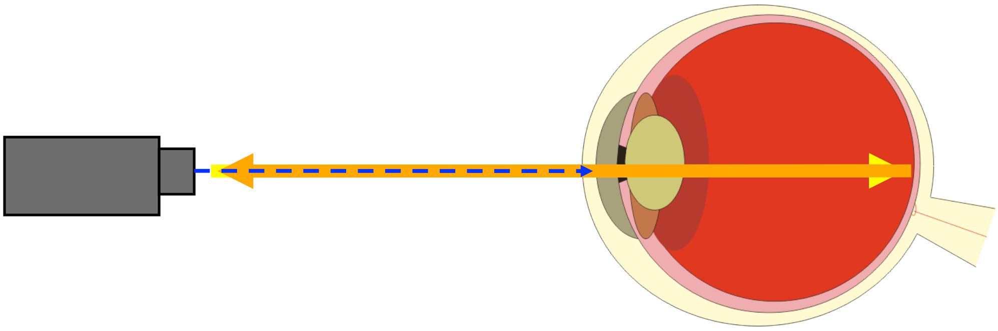


If the light source comes from approximately the same place as observation, the reflected light is observed and the pupil appears bright.



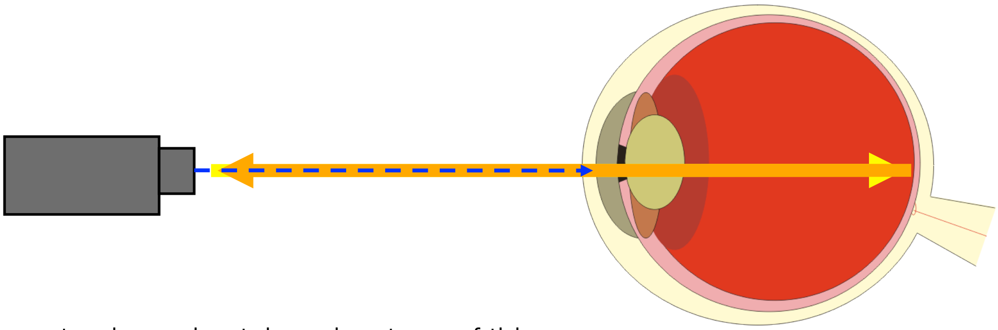


# Basic Eye Biology and Optics



This phenomenon is also what causes redeye in photographs and the bright reflection of animals in headlights.

# Basic Eye Biology and Optics

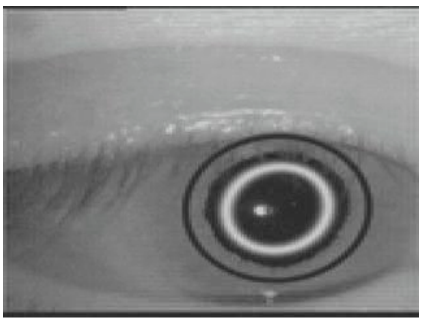


ASL's eye trackers also take advantage of this phenomenon.

Since the pupil appears bright to the camera, the eye tracker can work no matter what the participant's iris color is and can function in low light conditions.



# Basic Eye Biology and Optics



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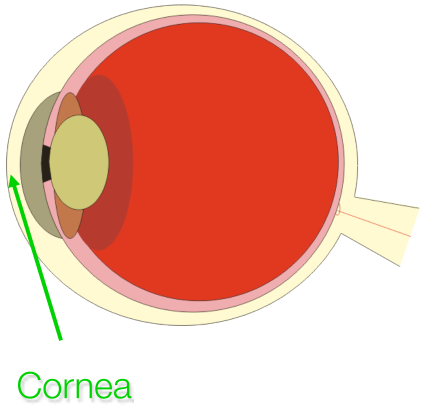
# Basic Eye Biology and Optics

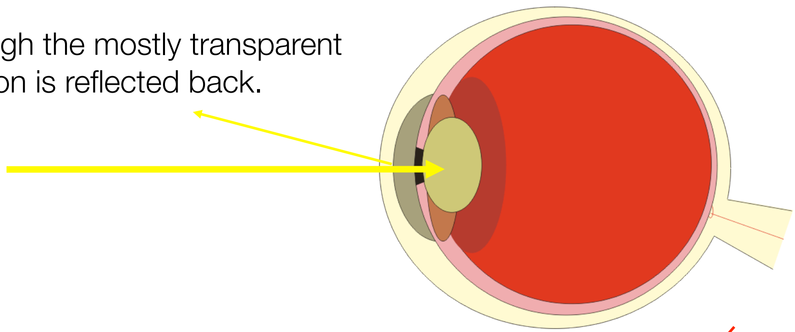


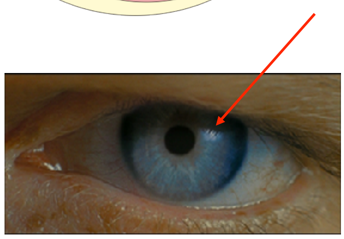

The second important property of the eye for tracking is the slight reflectivity of the cornea.



# Basic Eye Biology and Optics

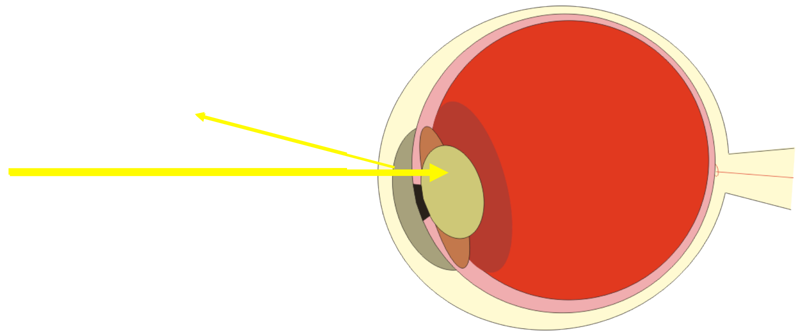
As light passes through the mostly transparent cornea, a small portion is reflected back.





This causes a small reflection to be visible somewhere on the eye.

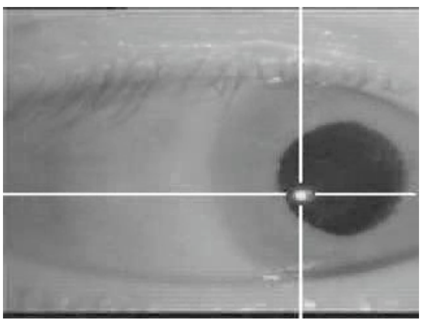
# Basic Eye Biology and Optics



Importantly, the location of this reflection remains the same no matter how the eye turns.

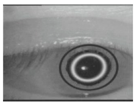


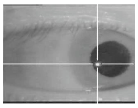
# Basic Eye Biology and Optics



Importantly, the location of this reflection remains the same no matter how the eye turns.

- The Pupil moves and can be used to track the “center” of the eye.



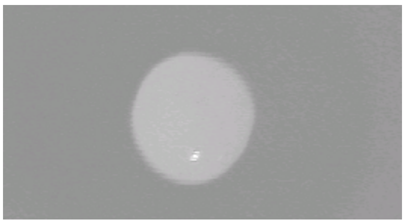


- The Corneal Reflection remains fixed and can be used as an anchor point for the head

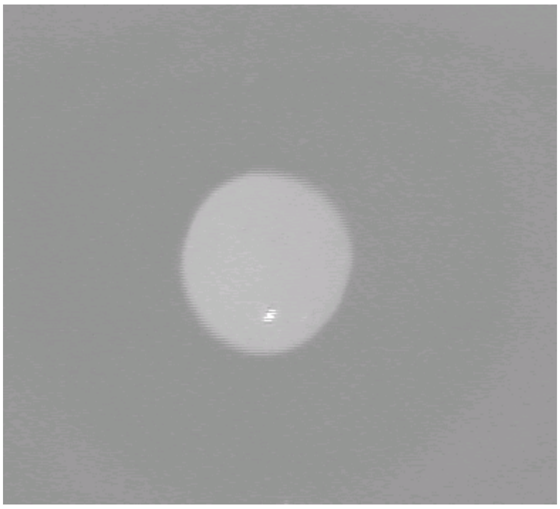
These two properties of the eye can be used to plot the angle of the eye with respect to the head.



This image is what you will see in the Eye Monitor



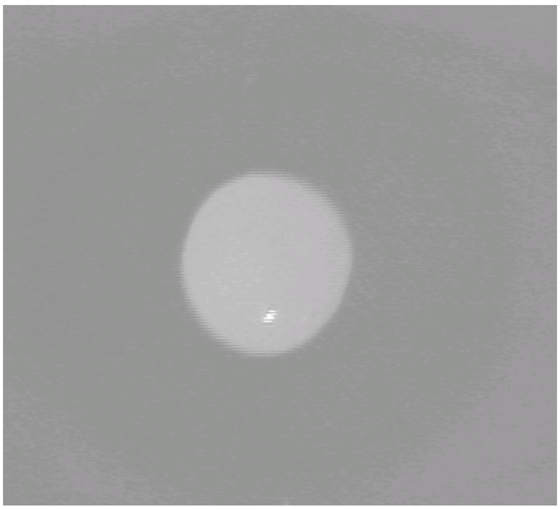
The image is purposefully black and white and low detail because detailed features are not needed and would, in fact, decrease performance.



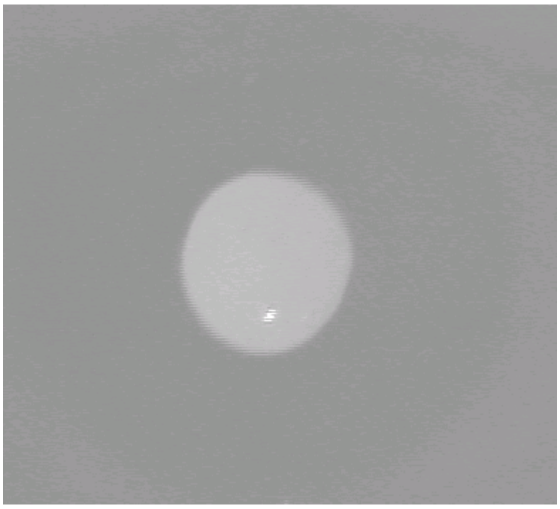
The camera is taking a picture of the eye 60 times a second (approximately every 17 ms).

The system then analyses each picture to find the two features





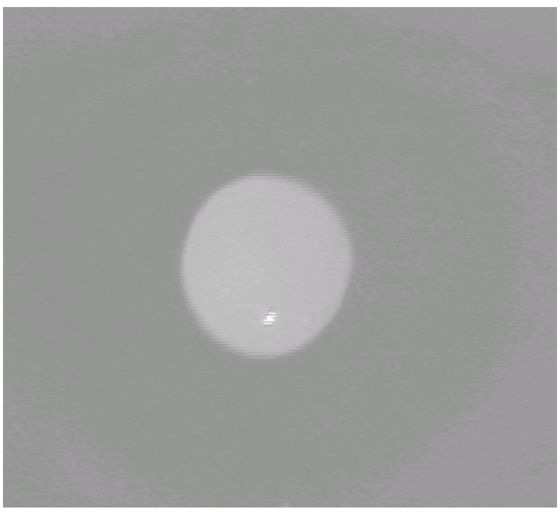
In this process, the computer will look at the luminance or brightness levels of each pixel by sweeping across each row.



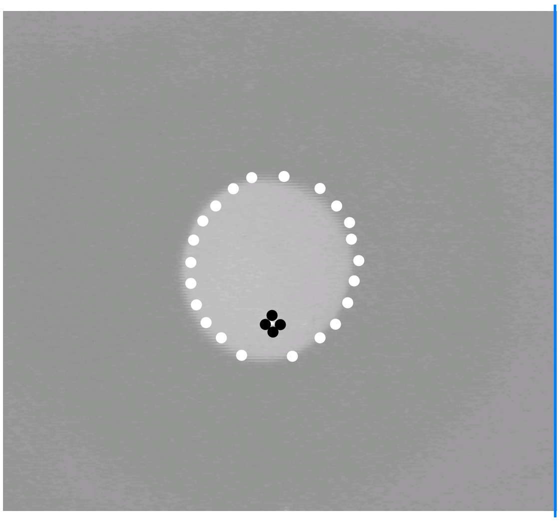
The computer will then look at the luminance or brightness levels of each pixel and compare this value to a pair of thresholds.

If the value exceeds one of these thresholds, that pixel is considered relevant.





It is the change from relevant to not relevant (one side of the threshold to the other) that determines whether a pixel is marked.

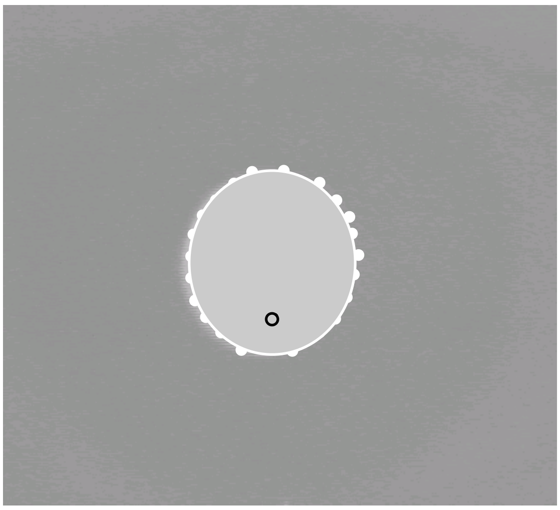


## Brightness Profile

The computer does this for every pixel row in the image.

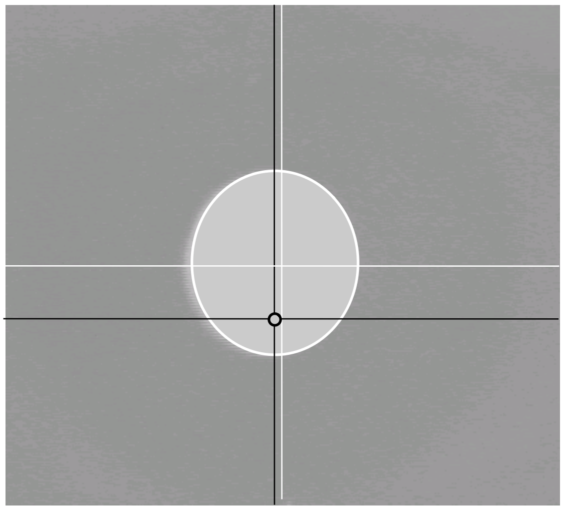
In an ideal image, you would have dots in no other locations than along the actual feature borders.





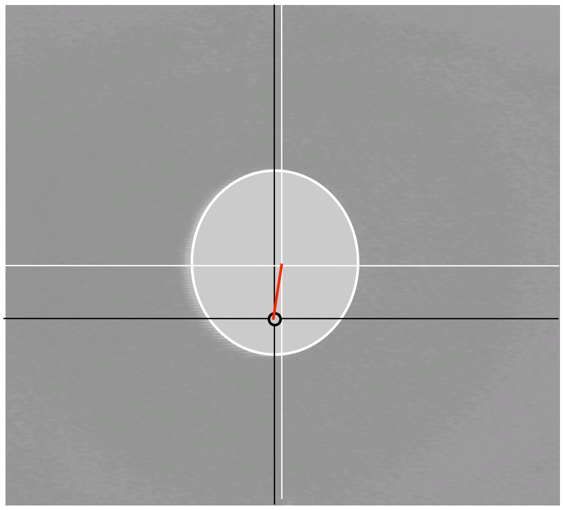
## Brightness Profile

It then draws a best fit ellipse for each of the features



The computer will then draw crosshairs through the centers of these ellipses.





The centers of these crosshairs are the relevant pieces of information for the point of gaze calculations.

The computer compares the vector between these two points.

If it cannot draw this invisible line, it cannot calculate gaze direction.

## Current remote systems

SMI RED

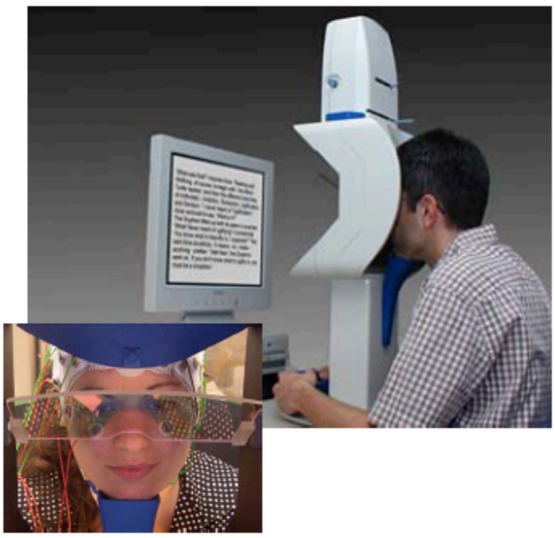
Tobii X120

Tobii T60 XL

Gazepoint (<$500!)

## Current Hi-end systems


SR EyeLink



SMI HiSpeed

## Current mobile systems

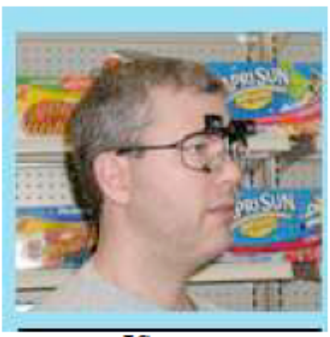

ASL MobileEye


SMI HED

## Current mobile systems

SMI (+ headtracking)

Dikablis



IScan

Tobii

# Specialized systems

3D VR eye tracking

Combined mobile EEG / ET

fMRI compatible systems

# ASL 400

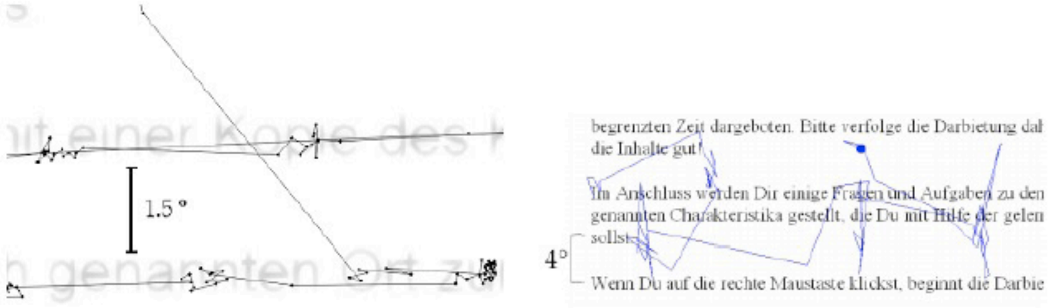
- Main components
  - Floor mounted optics
  - Control unit
  - 2 computers (control & subject)
- Head movements (partially) compensated with tracking mirrors and extended head movement options
- Temporal resolution 50 Hz
- Spatial resolution 0.5$^{O}$
- Tracks only one eye
-



## SMI EyeLink II

- Contains
  - Head mounted optics
  - 2 computers (control & subject)
- Temporal resolution 500 Hz
- Spatial resolution <0.01$^{\circ}$
- Tracks both eyes
- Reasonable analysis software
- WIN API's for Microsoft Visual C++

# Raw data are messy



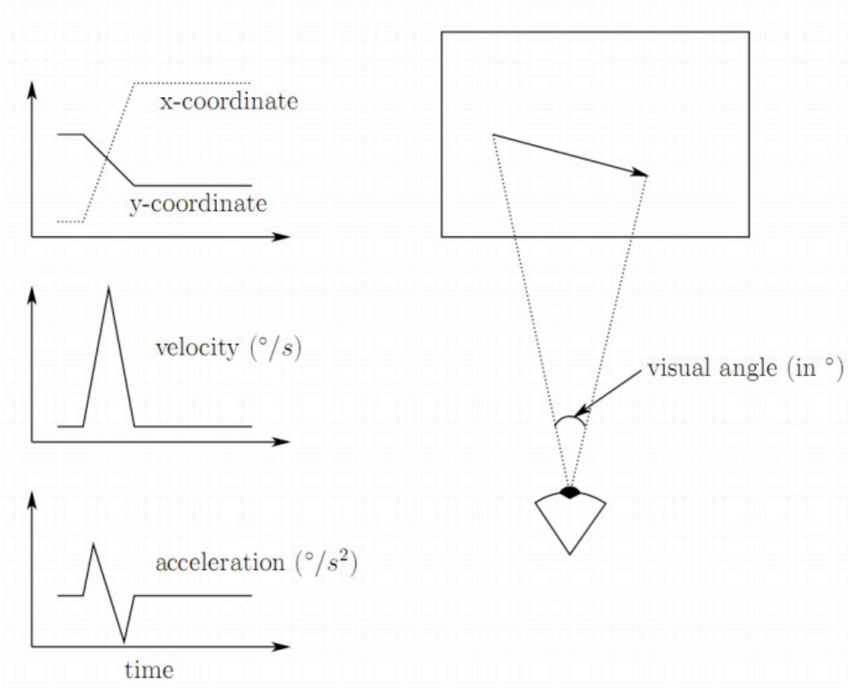

(a) Raw samples at 50 Hz. (b) Raw samples at 50 Hz.


(c) Raw samples at 1250 Hz. SMI HiSpeed 1250.

# Raw data are messy

- Fixations
- Saccades
- Smooth pursuit
- Blinks
- Noise and Artifacts
- Other events (e.g., fixational, nystagmus)

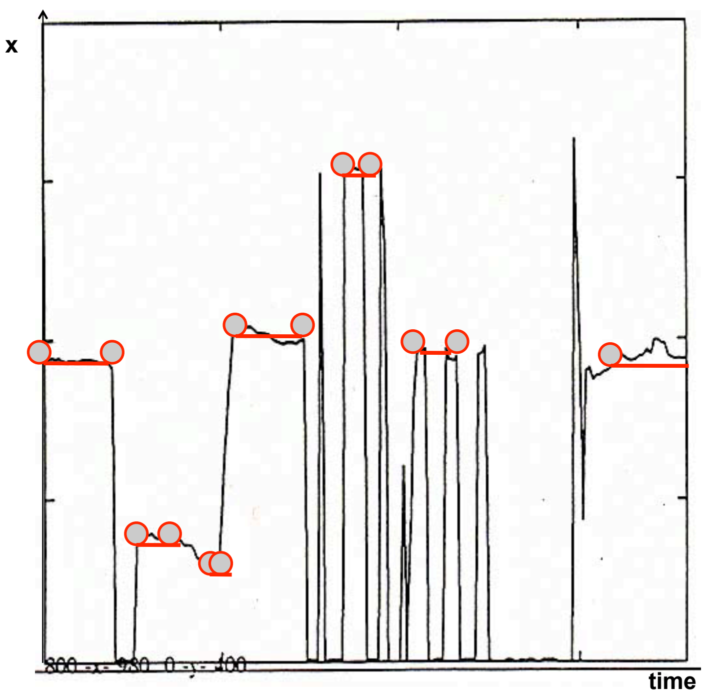
# Raw data are messy




# Filtering the noisy data

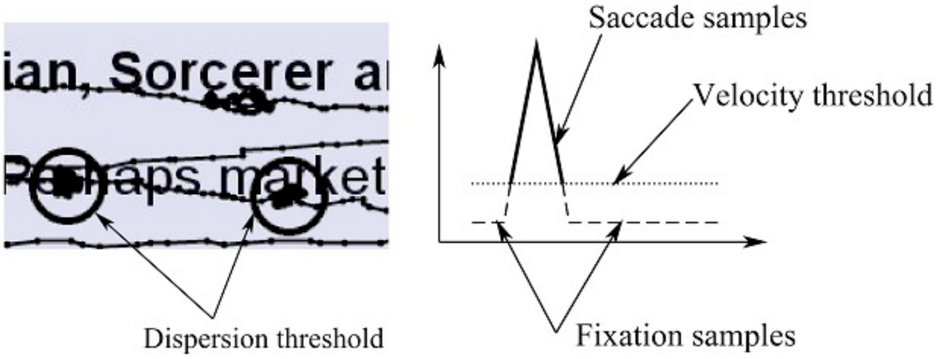
Raw data measured with an eye tracker:

X-coordinates of eye gaze position during ~3 seconds



# Detecting fixations and saccades

- Dispersion algorithms
- Velocity and/or acceleration algorithms




# Fixation identification (real-time)

## A simple algorithm for identifying the fixations in real-time [Siebert00]:

1) Fixation starts when the eye position stays within 0.5° > 100 ms (spatial and temporal thresholds filter the jitter)

2) Fixation continues as long as the position stays within 1°

3) Shorter than 200 ms failure to track the eye does not terminate the fixation

# Visualization of scanpaths

- circles are the fixations (center is the point of gaze during the fixation)
- radius depicts the length of the fixation
- lines are the saccades between fixations


# HCI related issues

- Need to design and study new interaction techniques suitable for exploiting eye input
  - eye is a perceptual device, not evolved into a control organ
  - people are not used to operate things by simply looking at them - if poorly done it could be very annoying
- Noisy data - need to refine in order to get useful dialogue information (fixations, eye events, intentions)
  - accuracy restricted by biological characteristics of the eye

# Google GLASS

- Un approccio complementare (Google) GLASS

http://www.google.com/glass/start/

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(Phys.org) —Advertising models could in the future expand from clicks to pupil dilations. Google's patent for a Gaze Tracking System became public last week. Originally filed in May 2011, the patent presents an idea for wearers of a head mounted device—and in 2013 observers are guessing this may be Google Glass—to have gaze tracked so that the system can pin down exactly what the user is looking at and even the emotional responses via pupil dilation. Information about where the user was gazing when viewing the external scene would be sent over to a server. Then the real work would start. An image recognition algorithm would be executed on the scene images to identify items within the external scenes viewed by the user. A gazing log tracking the identified items viewed by the user would be generated.

Read more at: http://phys.org/news/2013-08-pay-per-gaze-google-patent-ad.html#jCp

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The patent discusses how this would work: "Under a pay per gaze advertising scheme, advertisers are charged based upon whether a user actually viewed their advertisement. Pay per gaze advertising need not be limited to on-line advertisements, but rather can be extended to conventional advertisement media including billboards, magazines, newspapers, and other forms of conventional print media." The system would involve "determining which, if any, of the identified items within the external scenes viewed by the user are advertisements; and charging advertisers associated with the advertisements based at least in part on a per gaze basis."

Read more at: http://phys.org/news/2013-08-pay-per-gaze-google-patent-ad.html#jCp