

# Eye Tracking Technologies and Applications

**Marco Porta**

**Computer Vision & Multimedia Lab**

(<https://vision.unipv.it/>)

Dipartimento di Ingegneria Industriale e dell'Informazione

**Università di Pavia (Italy)**

E-mail: [marco.porta@unipv.it](mailto:marco.porta@unipv.it)

Web: <https://vision.unipv.it/people/porta/>

## Eye Tracking basics

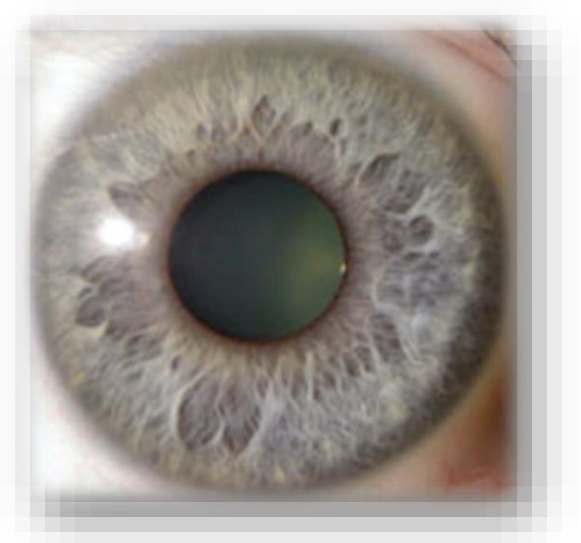
# What is Eye Tracking?

Eye movements occur as almost instantaneous **saccades** followed by **fixations**

- saccades → very fast ( $< 100$  ms)
- fixations → 100 - 600 ms

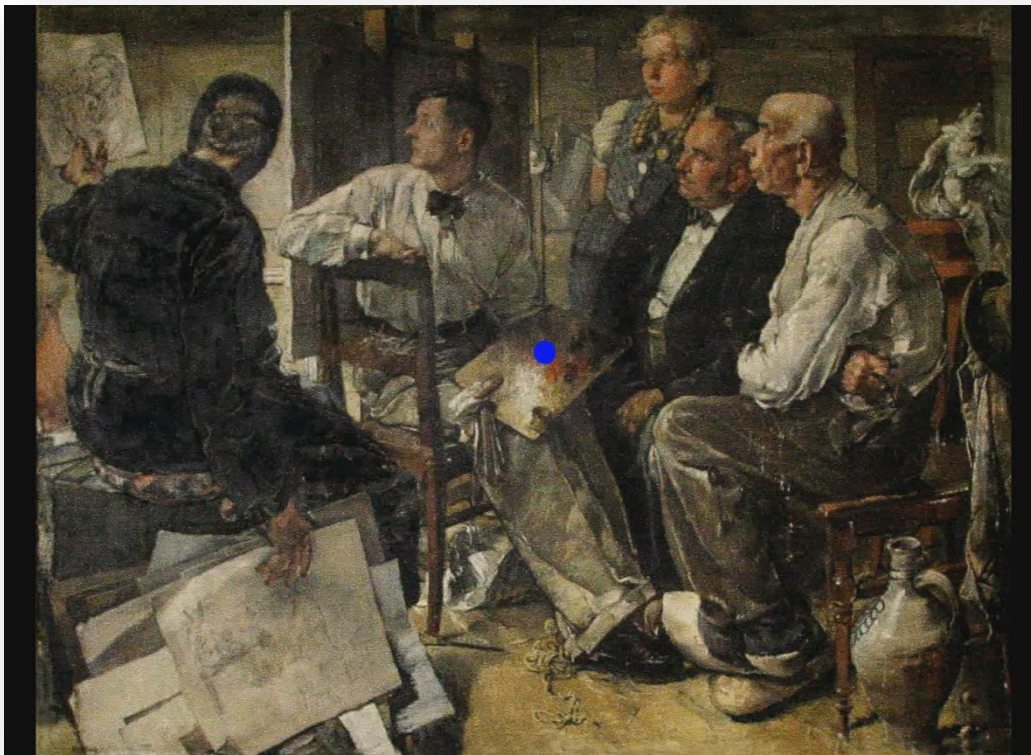
An **eye tracker** is a device able to follow the user's eyes, to detect where the gaze is directed

it measures how infrared light is reflected by the cornea and by the retina through the pupil



## Eye Tracking basics

# Where are you looking at?



Circles



fixations

size proportional to  
fixation time

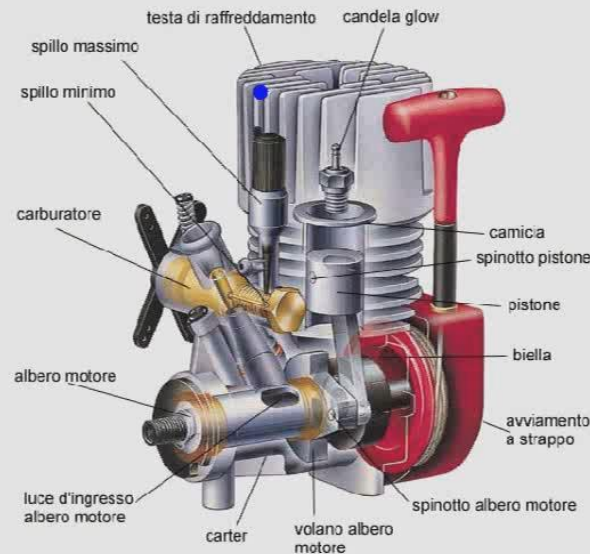
## Eye Tracking basics

# Where are you looking at?

### Componenti dei motori

In commercio esiste una vasta gamma di motori, i quali si differenziano per alcune caratteristiche come ad esempio la cilindrata.

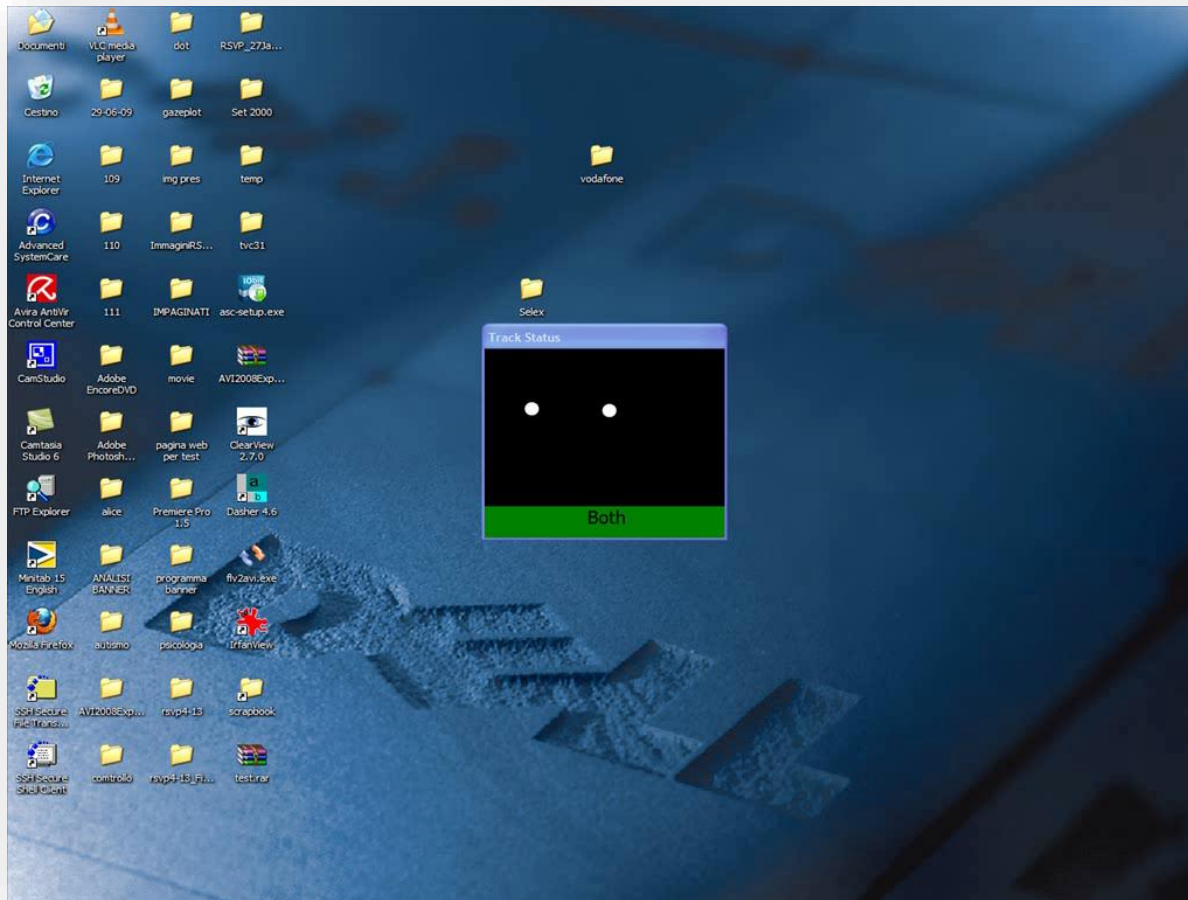
I motori diesel e benzina hanno gli stessi componenti essenziali. La camera di combustione è costituita da un cilindro, solitamente fisso e chiuso a un'estremità, in cui si muove un pistone (o stantuffo) ad accoppiamento preciso. Il moto alterno del pistone determina una variazione di volume della camera, tra la testa del pistone stesso e l'estremità chiusa del cilindro. La faccia esterna del pistone è collegata all'albero a gomiti tramite una biella, che costituisce il meccanismo di trasmissione e di trasformazione del moto alterno in moto rotatorio. Nei motori policilindrici l'albero a gomiti presenta una parte a sbalzo - detta bottone della manovella - per ogni biella, in modo che la potenza dei singoli cilindri venga applicata all'albero a gomiti nel punto più adatto durante la rotazione. Gli alberi a gomiti sono dotati di pesanti volani e contrappesi che, grazie alla loro inerzia, riducono al minimo le irregolarità nel movimento dell'albero.





## Eye Tracking basics

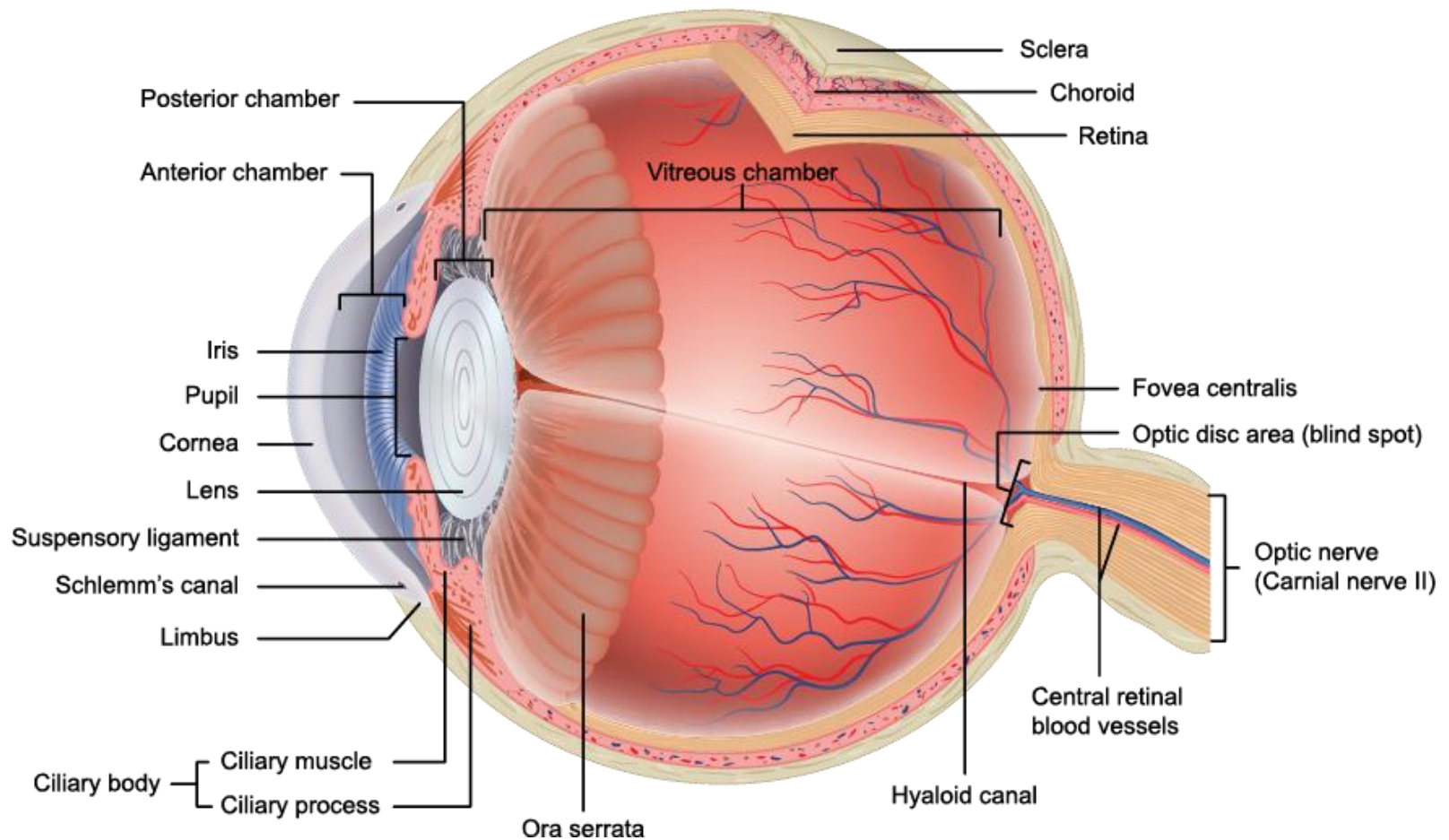
# Where are you looking at?





## Eye Tracking basics

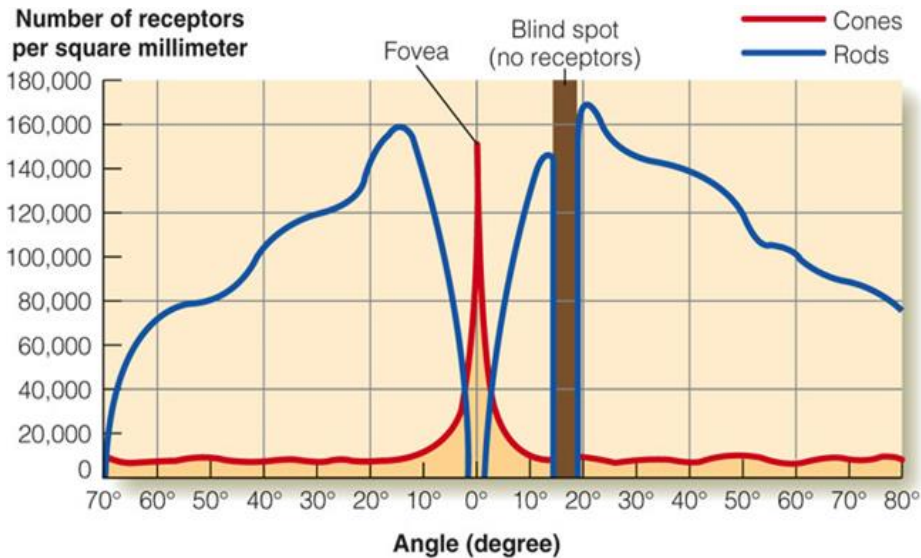
# The human eye



## Eye Tracking basics

# The human eye

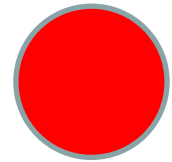
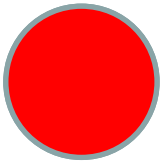
Density distribution of **rod** and **cone** receptors



## Eye Tracking basics

# Eye movements

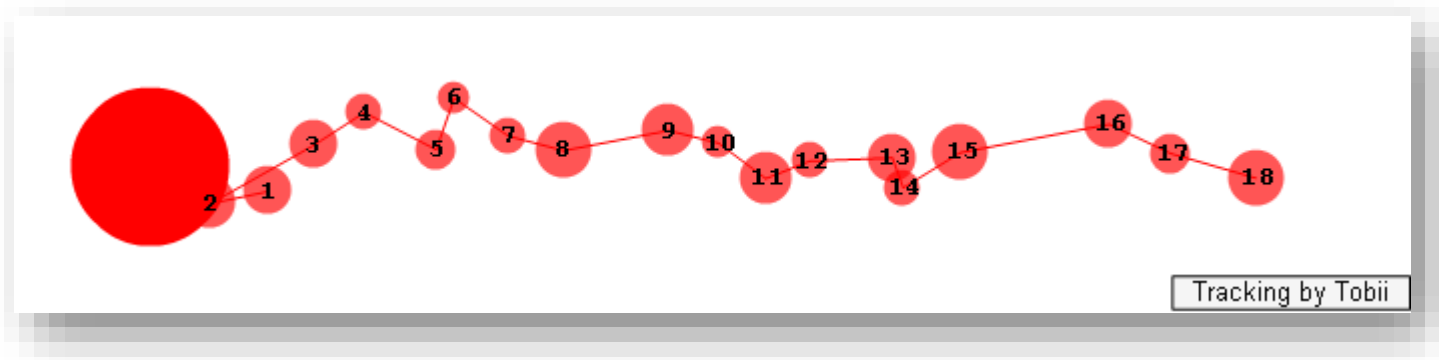
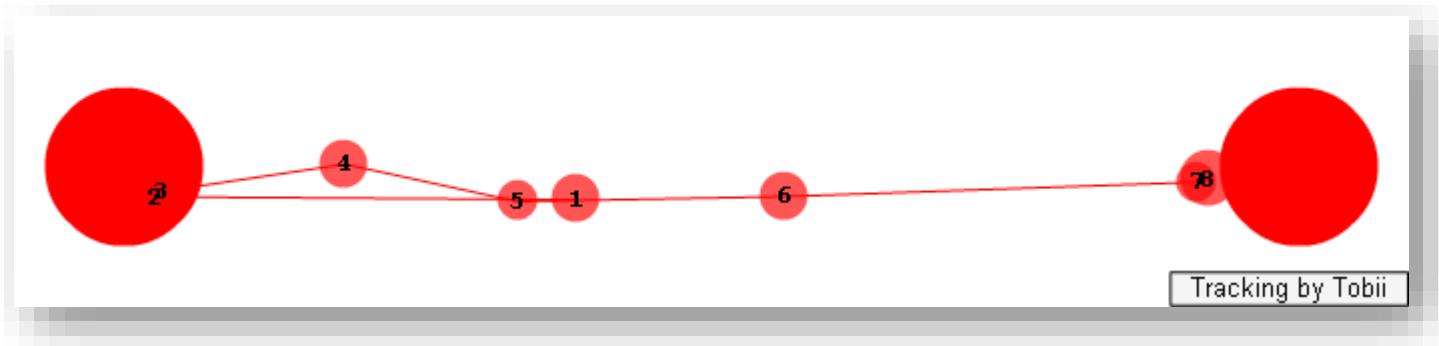
- Saccades
  - Very rapid eye movements ( $10 \div 100$  ms) to focus the area of interest on the *fovea*
  - During saccades the eye is "blind"
- Smooth pursuit
  - Only possible with moving targets





## Eye Tracking basics

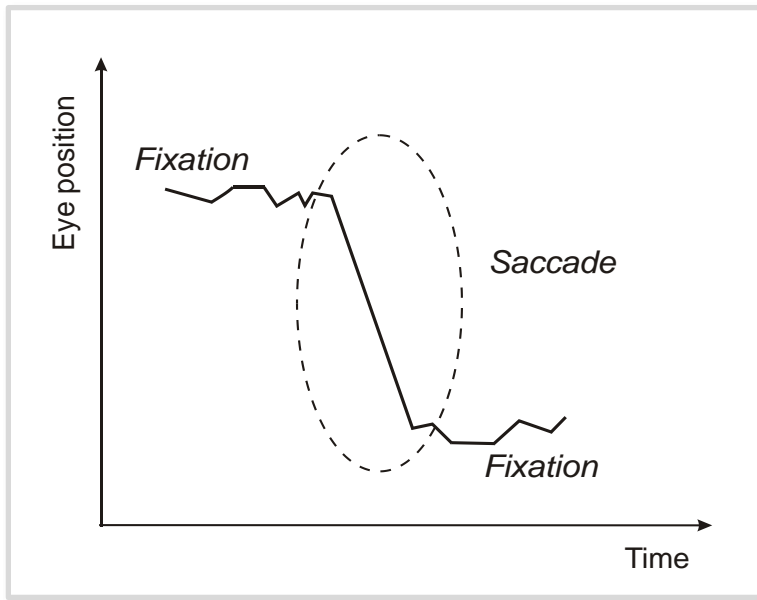
# Eye movements



## Eye Tracking basics

# Eye movements

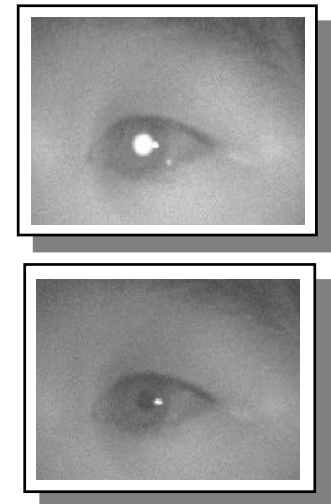
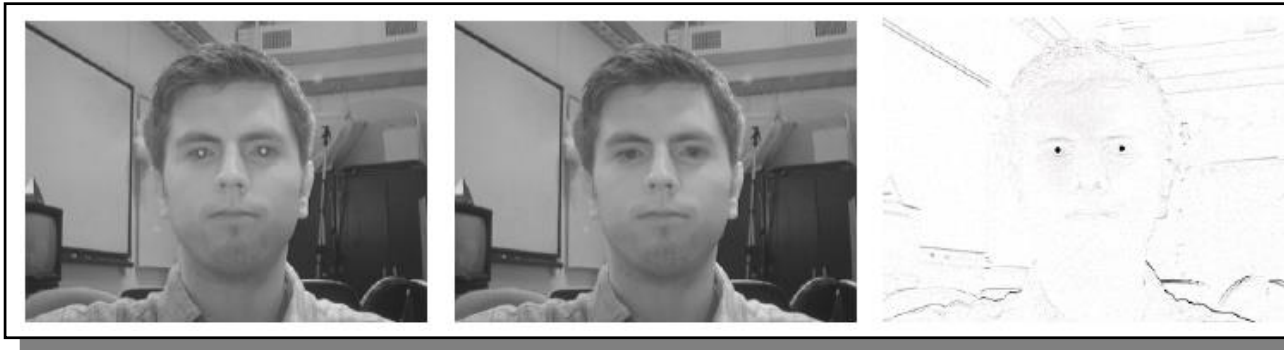
- Fixations
  - Small "movements" to stabilize the observed target on the retina
  - The eye is never still (there are always *microsaccades*)



## Eye Tracking technology

# How does it work?

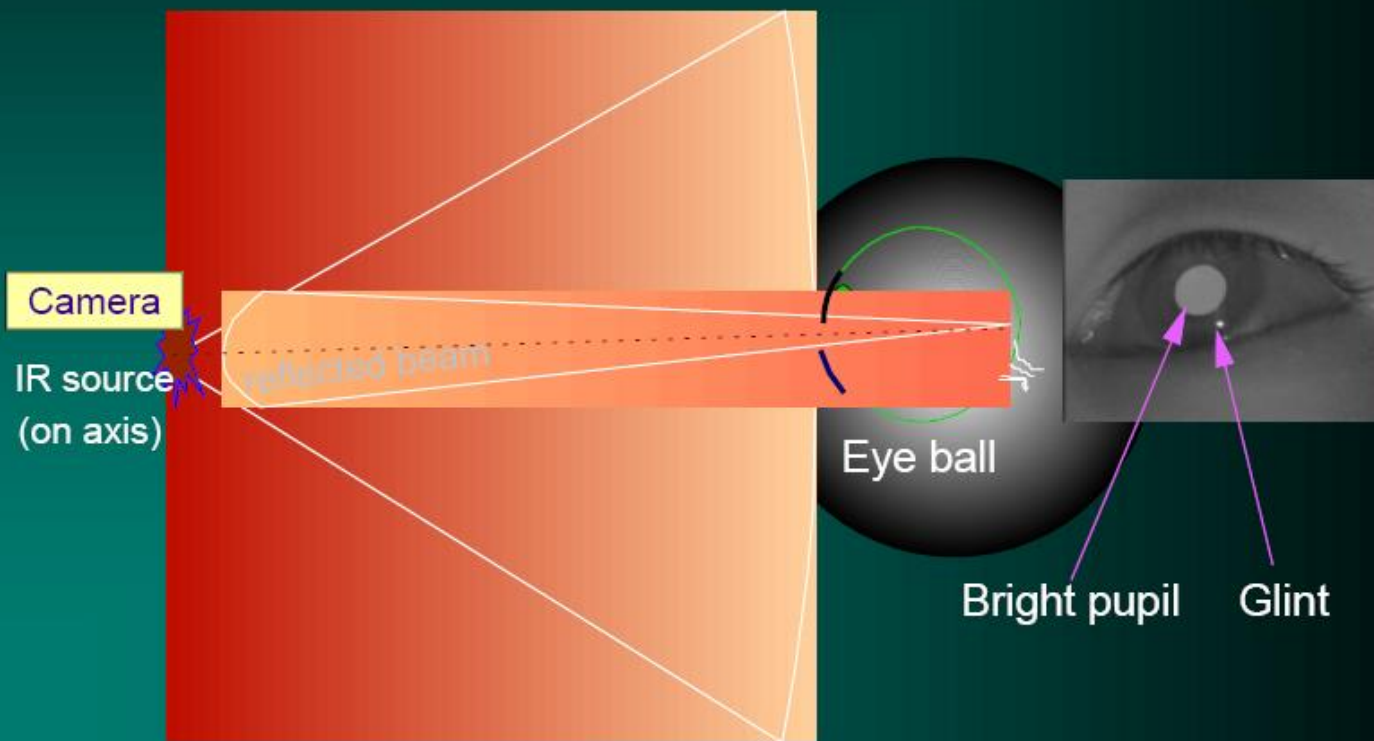
- Infrared (IR) or Near-Infrared (NIR) methods
- Eye detection: similar to the "red eyes effect" in flash photos...
  - on-axis light source → light pupil
  - off-axis light source → dark pupil



## Eye Tracking technology

# How does it work?

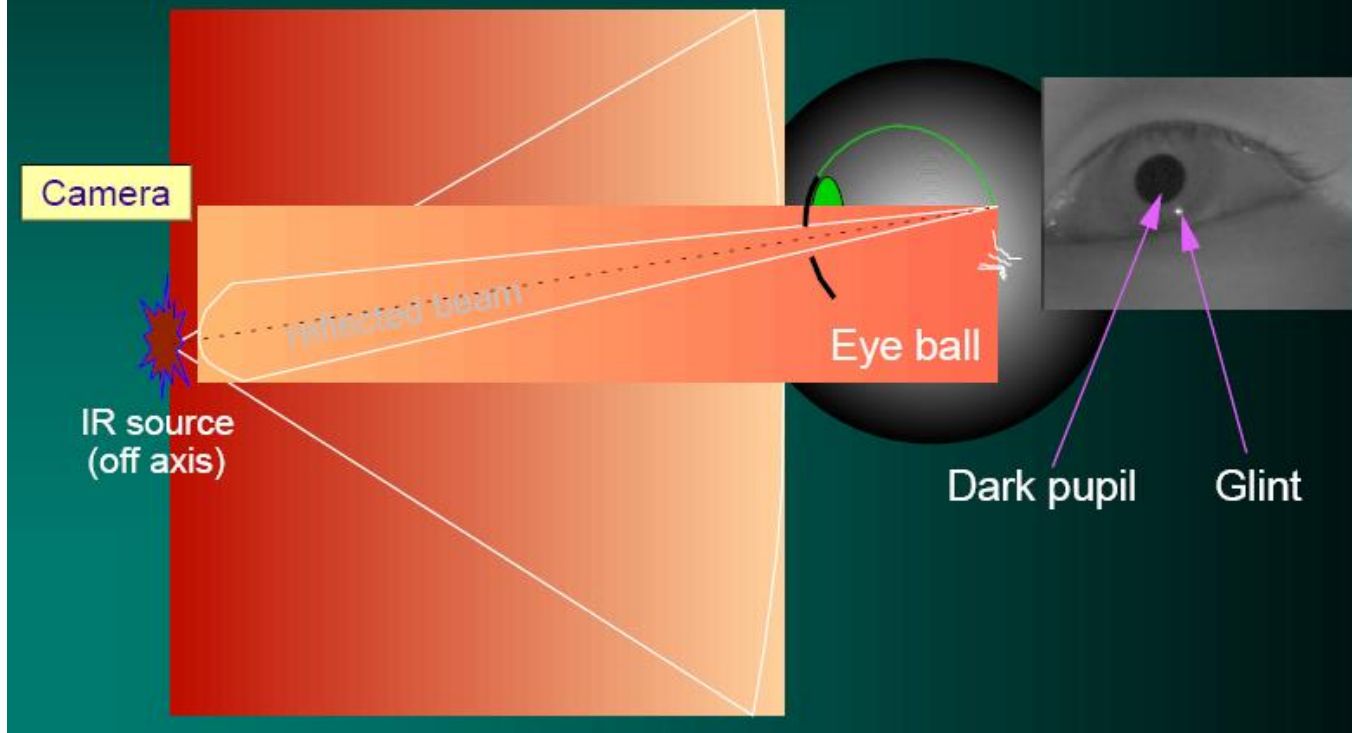
- *On-axis IR produces a bright pupil image*



## Eye Tracking technology

# How does it work?

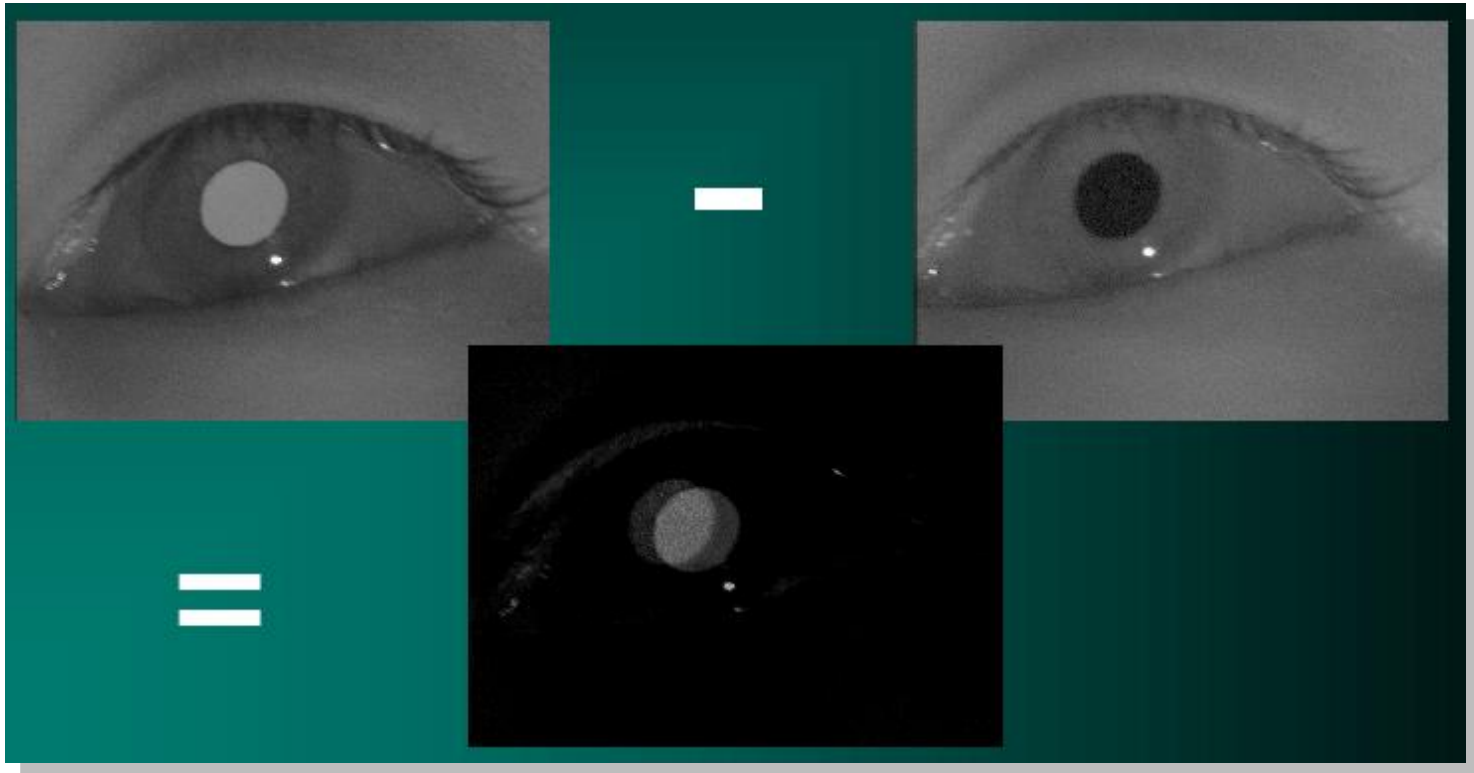
- *The off-axis IR produces a dark pupil image*





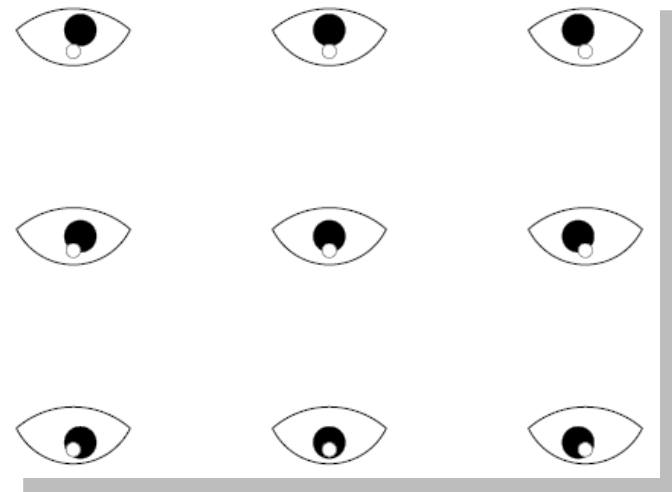
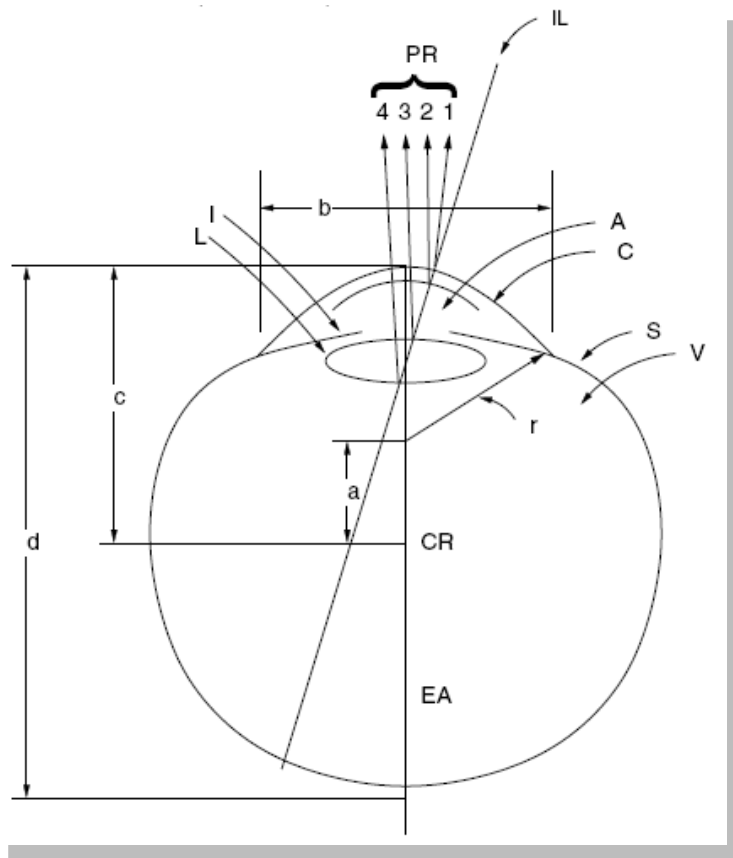
## Eye Tracking technology

# How does it work?



## Eye Tracking technology

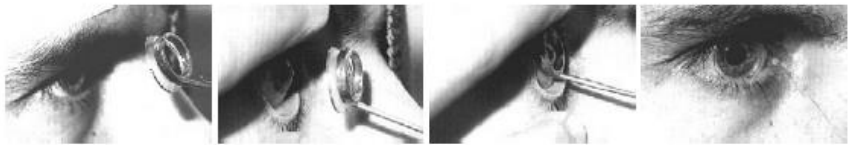
# Purkinje reflections



# Eye Tracking in practice

## Technologies

- 1<sup>st</sup> generation
  - scleral contact lens/search coil
  - electro-oculography (EOG)
- 2<sup>nd</sup> generation
  - photo and video oculography (POG and VOG)
- 3<sup>rd</sup> generation
  - pupil/corneal reflection (analogic)
- 4<sup>th</sup> generation
  - pupil/corneal reflection (digital) + possible face tracking



## Eye Tracking in practice

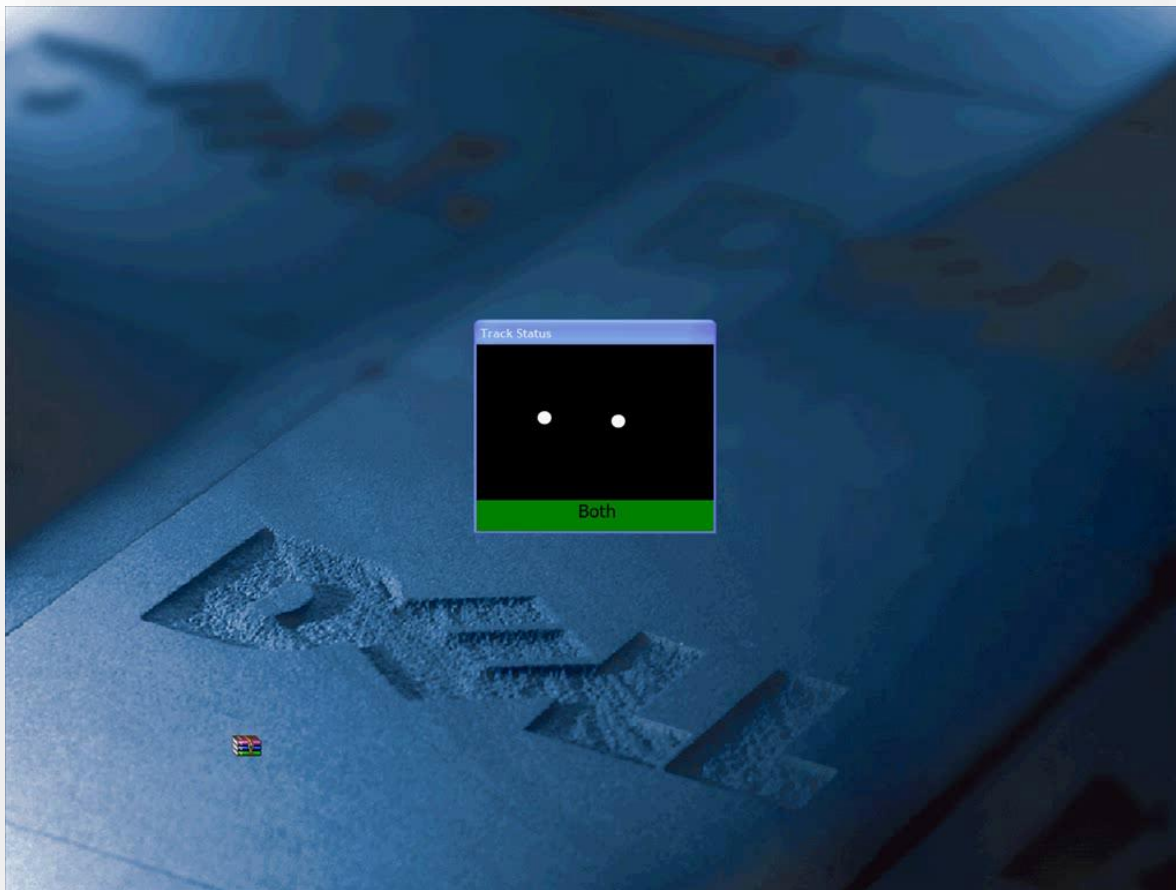
# Kinds of eye trackers

- Remote
- Wearable



## Eye Tracking in practice

# Calibration



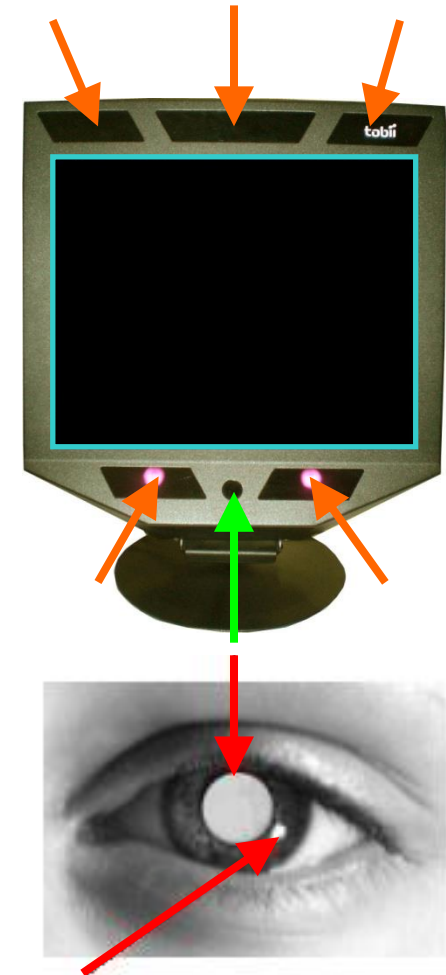


## Eye Tracking in practice

# The Tobii 1750 Eye Tracker

- Old eye tracker (~ 2005)
- Components:
  - screen
  - infrared emitters
  - videocamera
- Corneal reflection of infrared light
- Sampling rate: 50 Hz

December 2006:  
hardware +  
software ~  
30,000 Euro



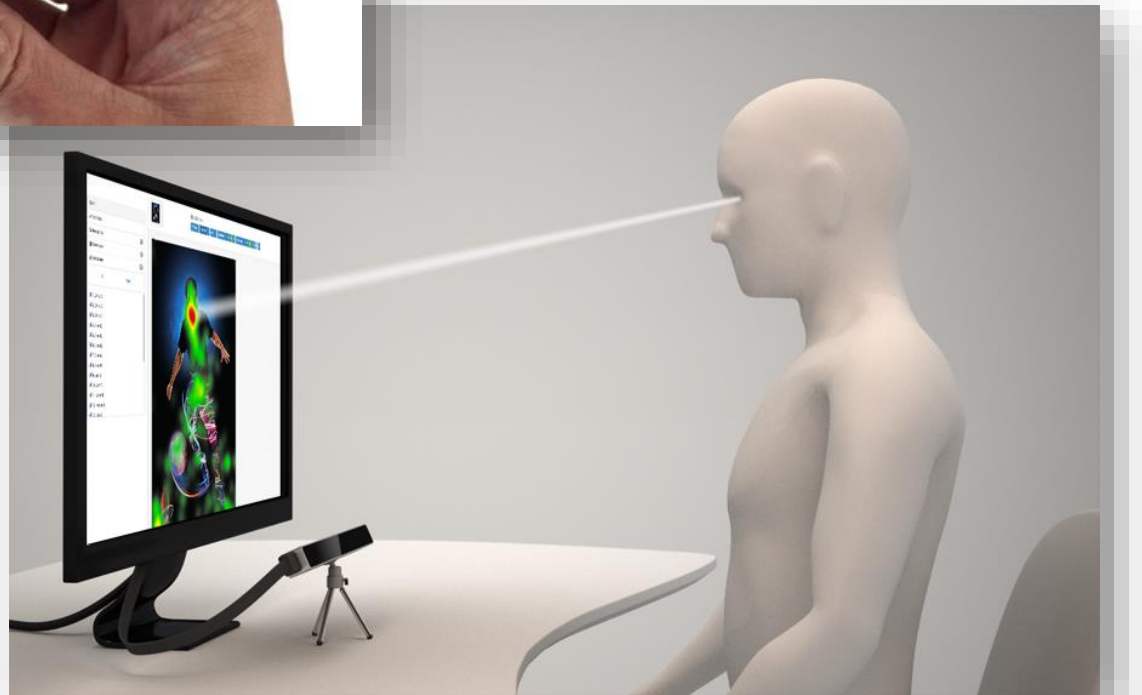
Eye Tracking in practice

# Cheaper solutions



 **THE EYE TRIBE**

Company acquired  
by Oculus  
(Facebook) in  
December 2016



Eye Tracking in practice

# Cheaper solutions



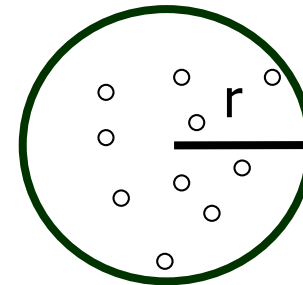
gazepoint



## Eye Tracking in practice

# Recorded data

- Gaze samples (e.g., 150 times a second)
  - X and Y coordinates
  - pupil size (left and right)
- Fixations
  - X and Y coordinates
  - start time
  - duration



## Eye Tracking applications

# Uses of eye tracking

- Usability studies
- User "behavior inspection"
- Marketing
- Human-Computer Interaction (HCI)
- Psychology/Linguistics
- Soft biometrics
- Intelligent e-learning
- ...



# Eye Tracking applications

# Usability studies

## Website evaluation

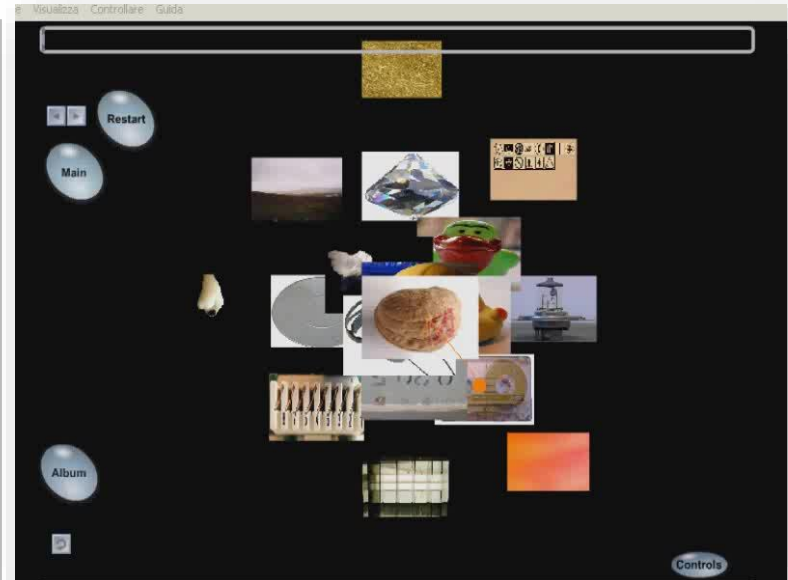


## Eye Tracking applications

# Usability studies

Information presentation

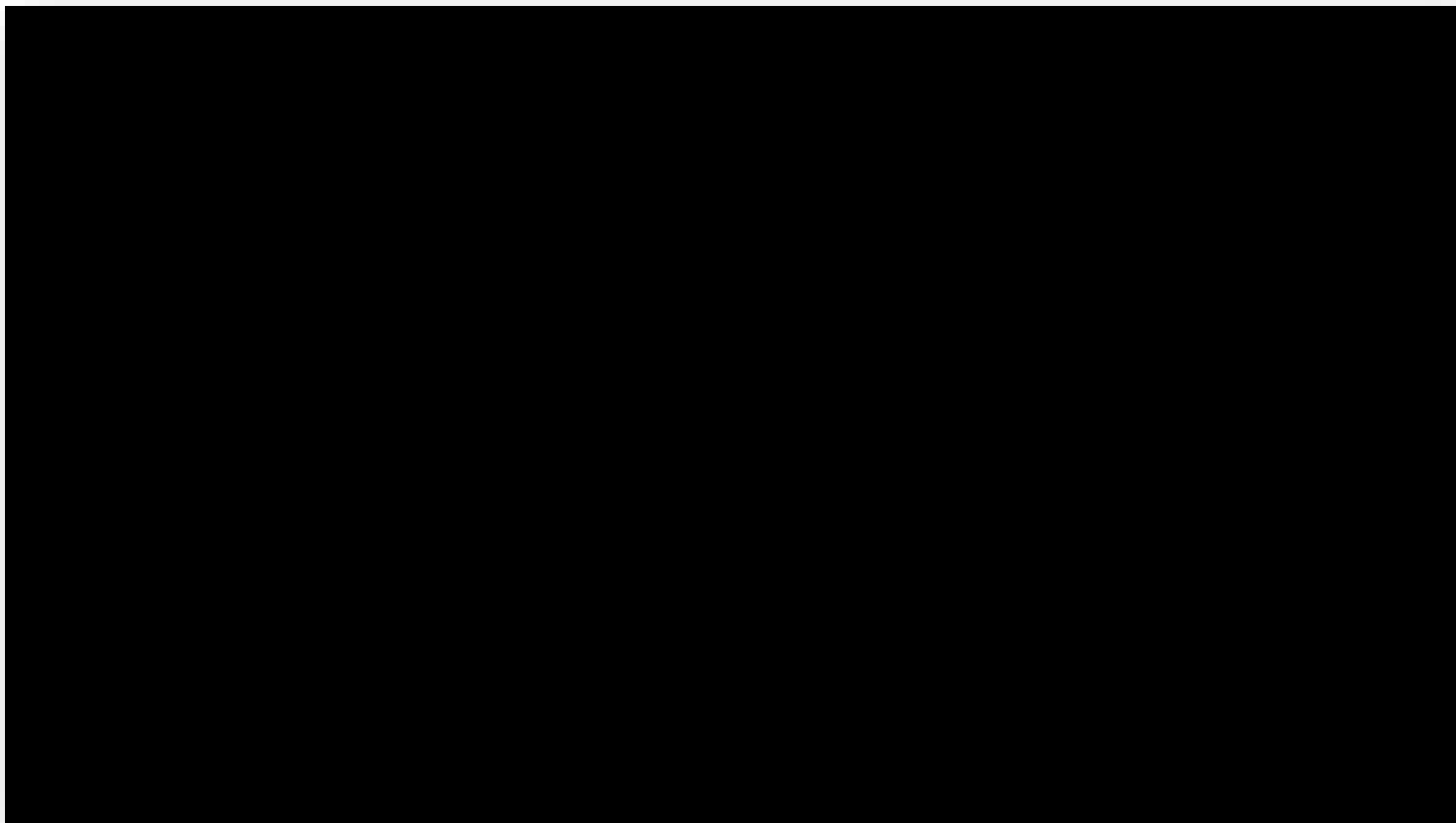
e.g., browsing of large collections of images



Eye Tracking applications

# User behavior inspection

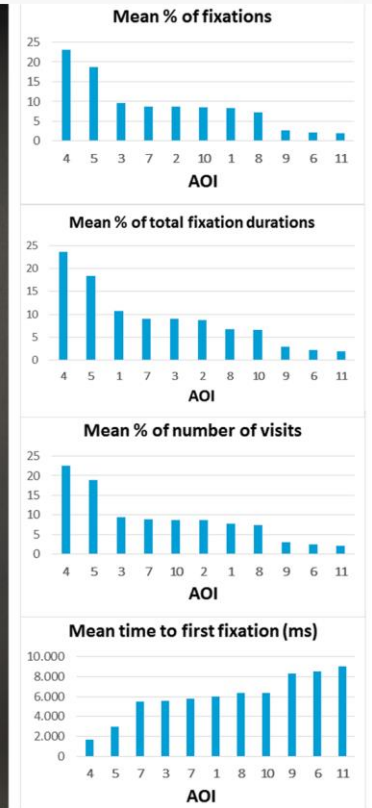
E.g., evaluating the **driver's performance**



## Eye Tracking applications

# User behavior inspection

E.g., what do **luthiers** look at?





# Eye Tracking applications Marketing





# Eye Tracking applications

# HCI

## Perceptive interfaces

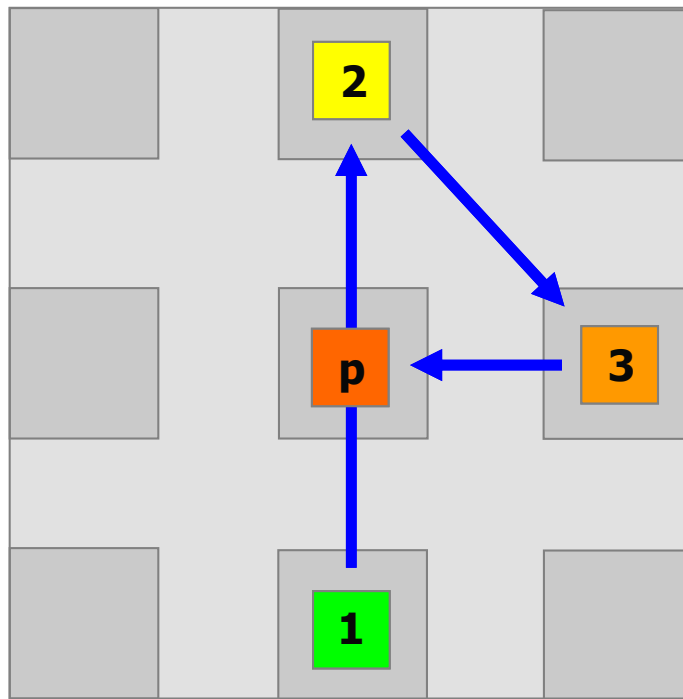
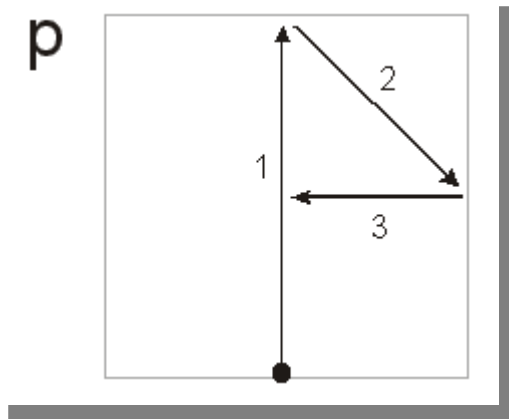
- **explicit** communication
  - ✓ eye-based interaction for disabled users (assistive technology)
  - ✓ eye-based interaction to be used along with ordinary input devices (keyboard, mouse, etc.)
- **implicit** communication
  - ✓ e.g., emotional state, cognitive load, stress, tiredness, etc.
  - ✓ e.g., learning constraints: has the user read an important part of a tutorial?



# Eye Tracking applications

## HCI

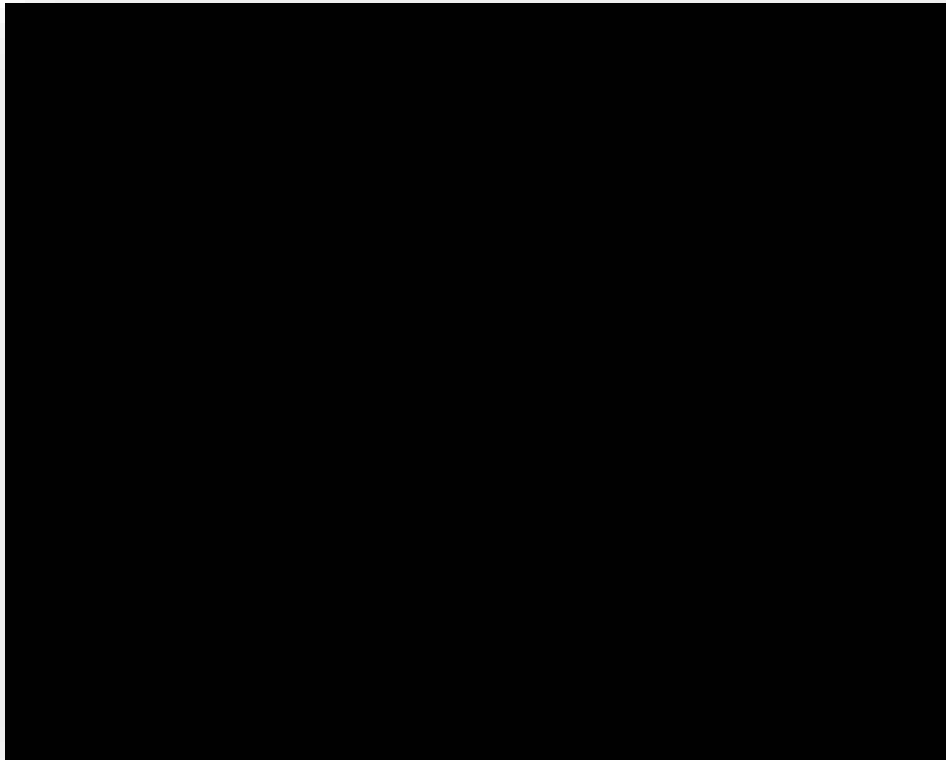
Eye writing: e.g., **Eye-S**



# Eye Tracking applications

# HCI

Eye writing: e.g., **Eye-S**



## Eye Tracking applications

# HCI

Pointer control: e.g., **ceCursor**



## Eye Tracking applications

# HCI

Playing music: e.g., **Netytar**

*"Playing music with the eyes  
through an isomorphic interface"*

## Eye Tracking applications

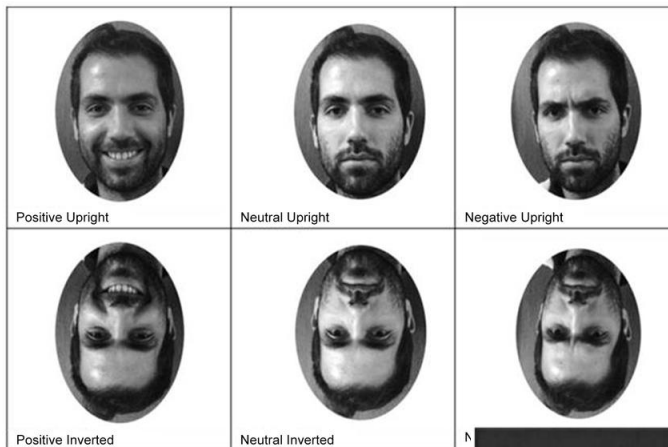
# HCI

Cultural heritage: e.g., the **Battle of Pavia exhibition**



## Eye Tracking applications

# Psychology/Linguistics



E.g., familiarity and face recognition

E.g., subtitling





## Eye Tracking applications

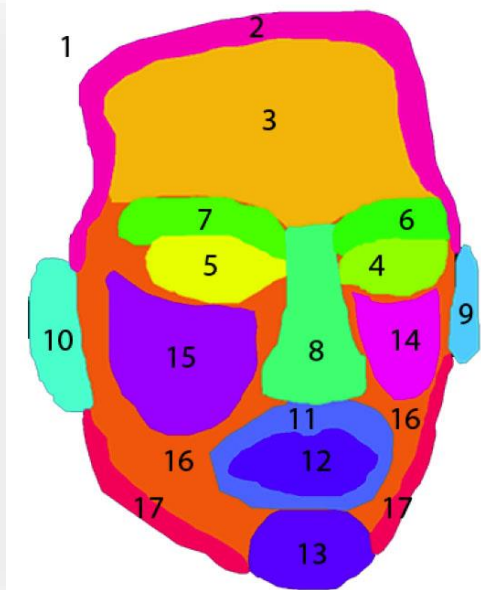
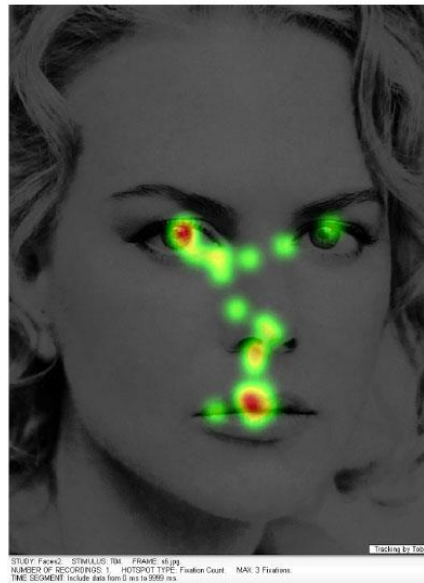
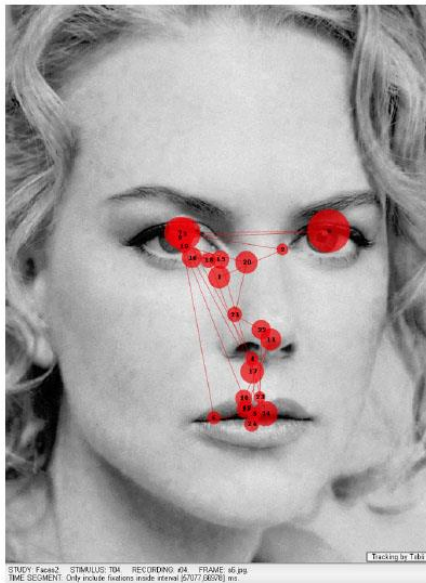
# Soft biometrics

- Not related to methods that analyze static aspects of the eye (e.g., iris-based techniques)
- Focuses on approaches in which the way a person looks at some stimuli can provide useful biometric information (**behavioral biometrics**)
  - Fixations and scanpaths
  - Eye/gaze velocity
  - Pupil size
  - Oculomotor features

## Eye Tracking applications

# Soft biometrics

E.g., **looking at faces** (GANT: Gaze ANalysis Technique for human identification)



Eye Tracking applications

# Soft biometrics

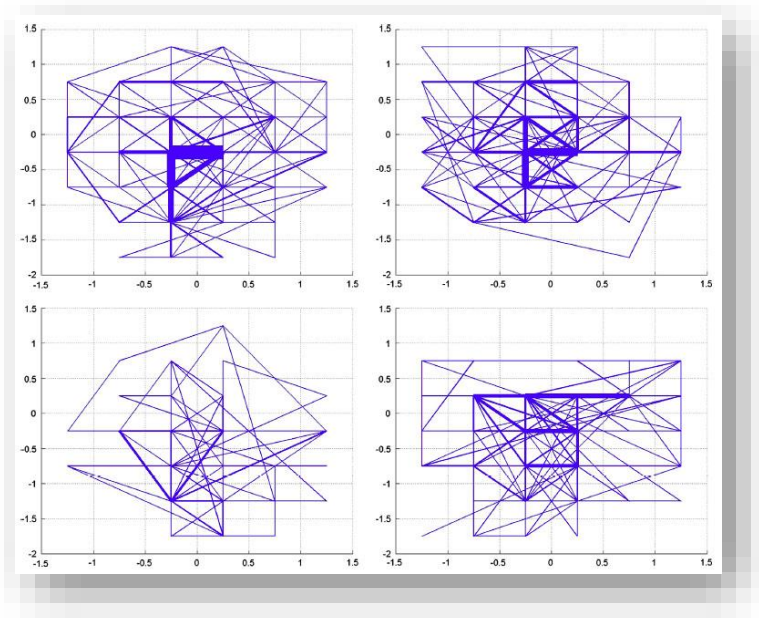
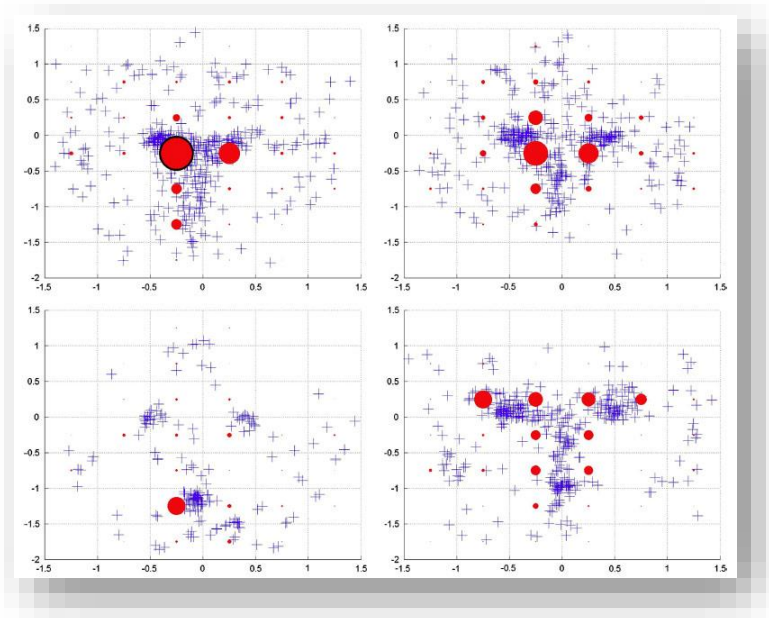
E.g., **looking at faces** (GANT)



Eye Tracking applications

# Soft biometrics

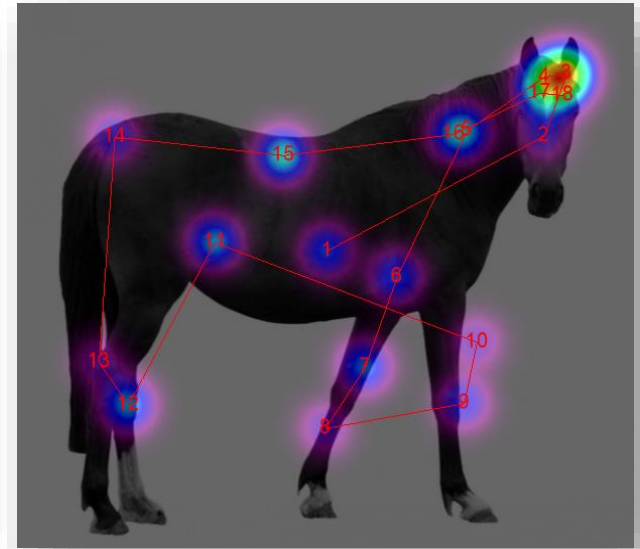
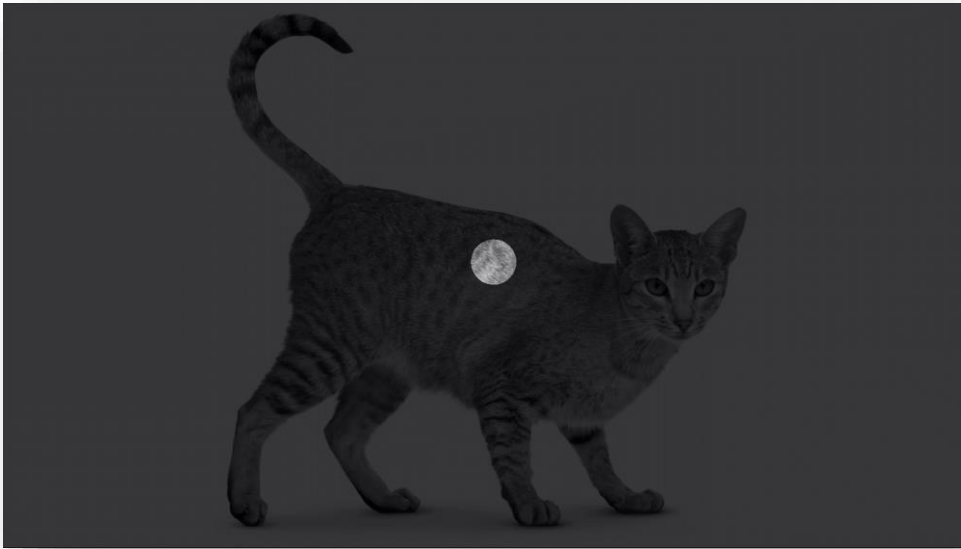
E.g., looking at faces (GANT)



## Eye Tracking applications

# Soft biometrics

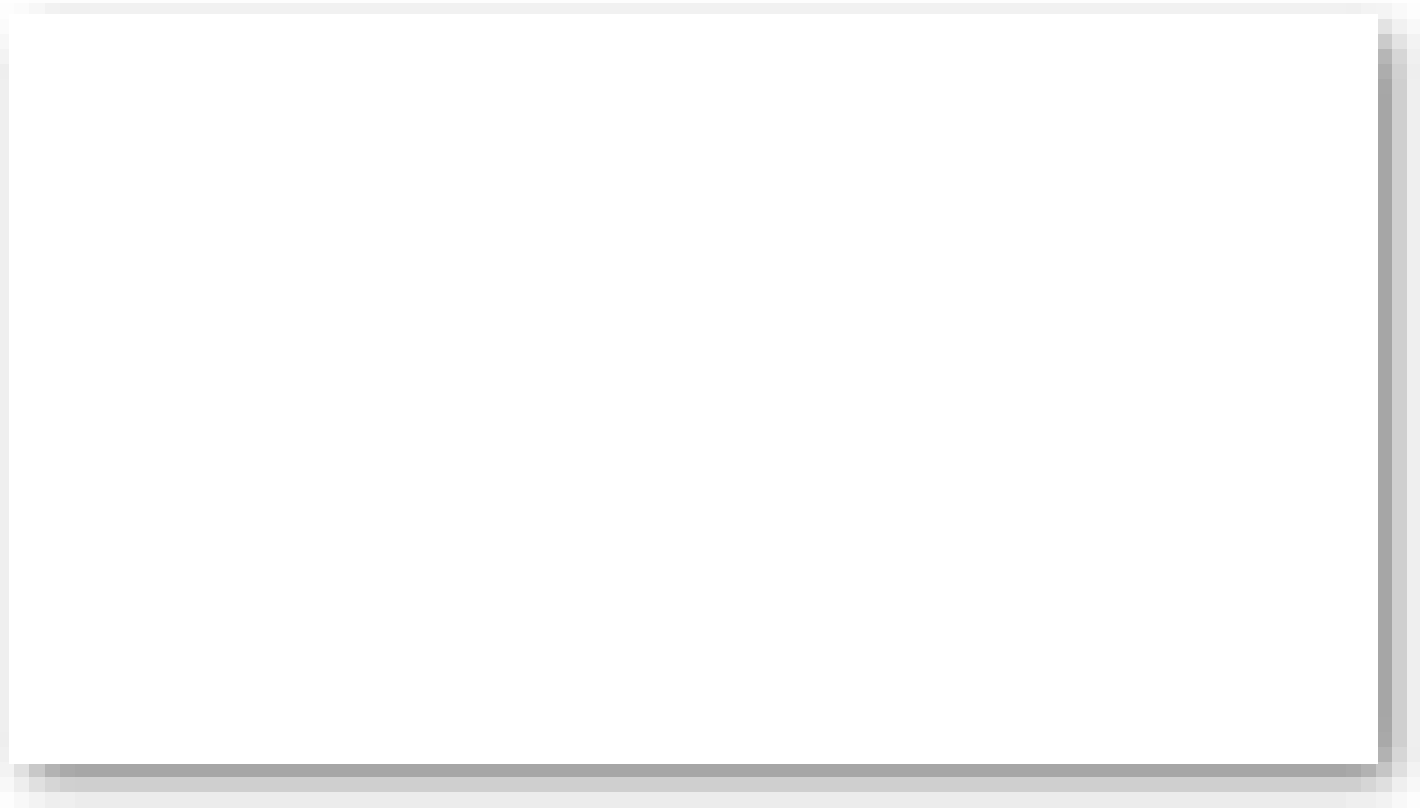
E.g., **looking at other kinds of static stimuli**



Eye Tracking applications

# Soft biometrics

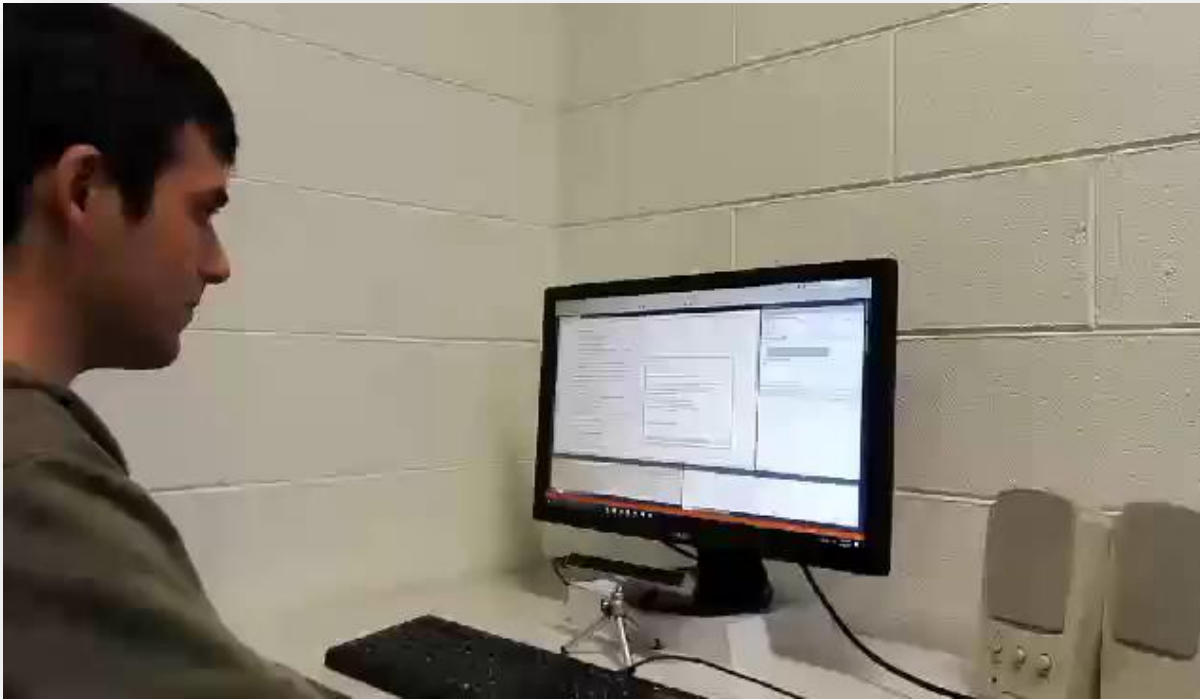
E.g., **looking at dynamic stimuli**



## Eye Tracking applications

# Soft biometrics

E.g., **Gaze PIN input**





## Eye Tracking applications

# Intelligent e-learning

### Experimental evidences (from psychology)

- mental workload depends on the fluctuation of the rhythm of the pupil area
- pupil size and blink rate increase in response to task difficulty

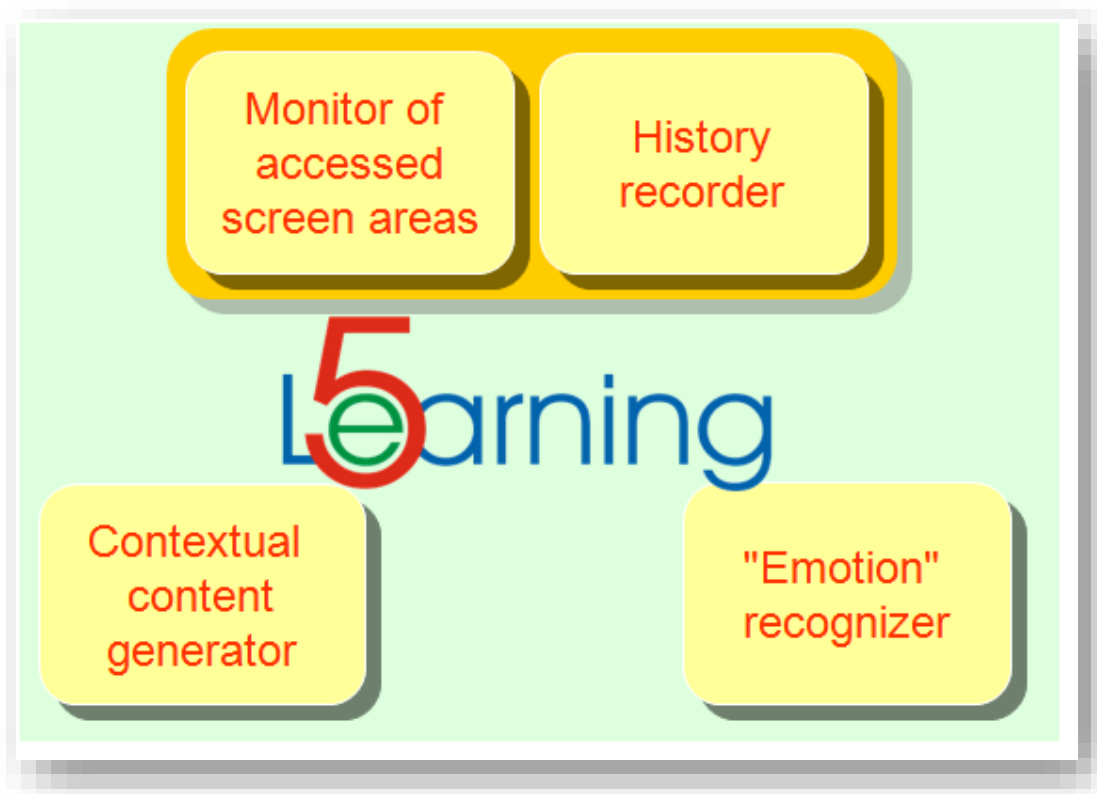


- saccade occurrence rate and saccade length decrease with increased complexity of the task
- saccadic and blink velocity decrease with increasing tiredness
- ...

Eye Tracking applications

# Intelligent e-learning

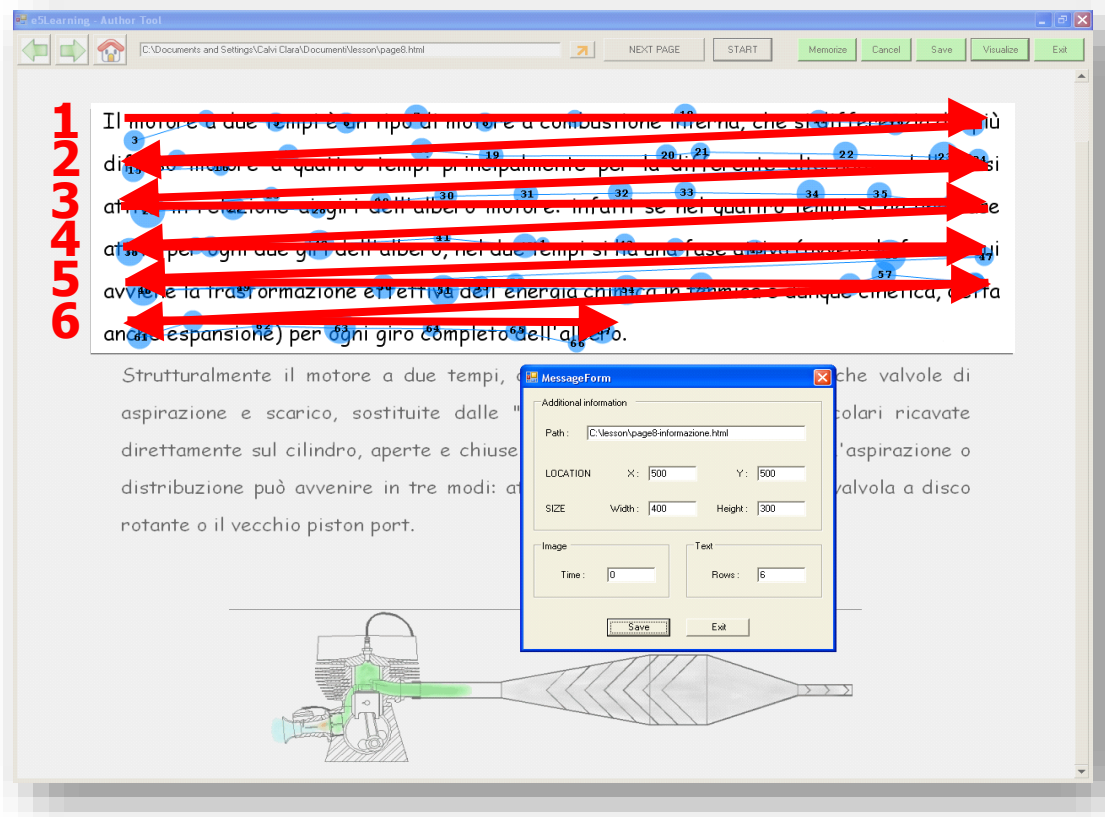
E.g., **e5-Learning** Project



## Eye Tracking applications

# Intelligent e-learning

## E.g., e5-Learning Project



The screenshot displays the 'e5-Learning - Author Tool' window. The main content area shows a text document with an eye-tracking overlay. Red arrows, numbered 1 through 6, trace the path of a user's gaze across the text. The text describes the operation of a two-stroke engine. A 'MessageForm' dialog box is open over the text, displaying fields for 'Path', 'LOCATION' (X: 500, Y: 500), 'SIZE' (Width: 400, Height: 300), 'Image' (Time: 0), and 'Text' (Rows: 6). Below the text, there is a diagram of a two-stroke engine.

1 Il motore a due tempi è un tipo di motore a combustione interna, che si differenzia dal motore a quattro tempi principalmente per la differenza di distribuzione degli organi del motore. Infatti se nel quattro tempi si ha una fase di aspirazione e una di compressione per ogni due giri dell'albero, nel due tempi si ha una fase di aspirazione e una di compressione per ogni giro completo dell'albero.

2

3

4

5

6

Strutturalmente il motore a due tempi, che valvole di aspirazione e scarico, sostituite dalle valvole a disco, distribuite direttamente sul cilindro, aperte e chiuse dalla distribuzione può avvenire in tre modi: a) a valvola a disco, b) a valvola a disco, c) a valvola a disco.

MessageForm

Additional information

Path: C:\Vesson\page8\informazione.html

LOCATION X: 500 Y: 500

SIZE Width: 400 Height: 300

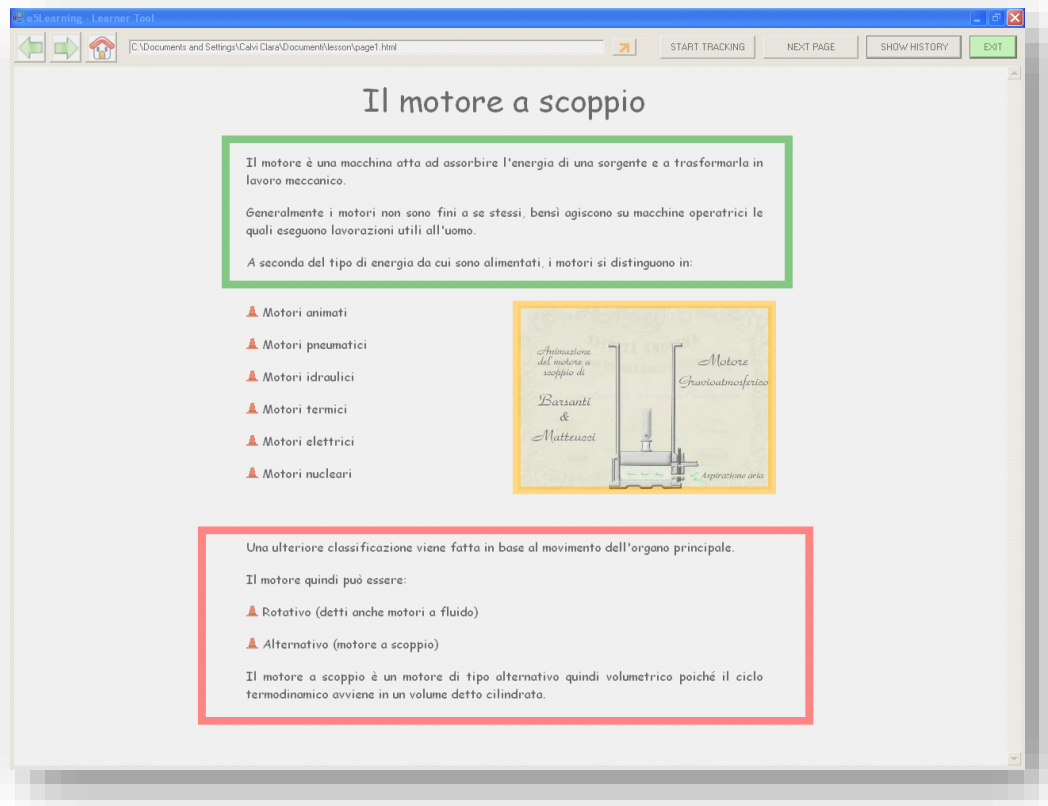
Image Time: 0

Text Rows: 6

Save Exit

## Eye Tracking applications

# Intelligent e-learning

E.g., **e5-Learning** Project

The screenshot shows a web browser window titled "e5Learning - Lesson Test". The address bar shows the file path "C:\Documents and Settings\Cabri Clara\Documents\Lesson\page1.html". The page content is titled "Il motore a scoppio" (The internal combustion engine). It includes a green-bordered text box with a definition of an engine, a list of engine types, and a diagram of an engine. A red-bordered text box at the bottom provides further classification and details about the engine cycle.

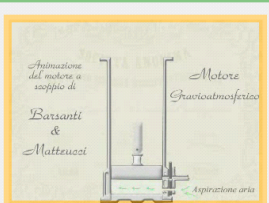
**Il motore a scoppio**

Il motore è una macchina atta ad assorbire l'energia di una sorgente e a trasformarla in lavoro meccanico.

Generalmente i motori non sono fini a se stessi, bensì agiscono su macchine operatrici le quali eseguono lavorazioni utili all'uomo.

A seconda del tipo di energia da cui sono alimentati, i motori si distinguono in:

- ▲ Motori animati
- ▲ Motori pneumatici
- ▲ Motori idraulici
- ▲ Motori termici
- ▲ Motori elettrici
- ▲ Motori nucleari



Una ulteriore classificazione viene fatta in base al movimento dell'organo principale.

Il motore quindi può essere:

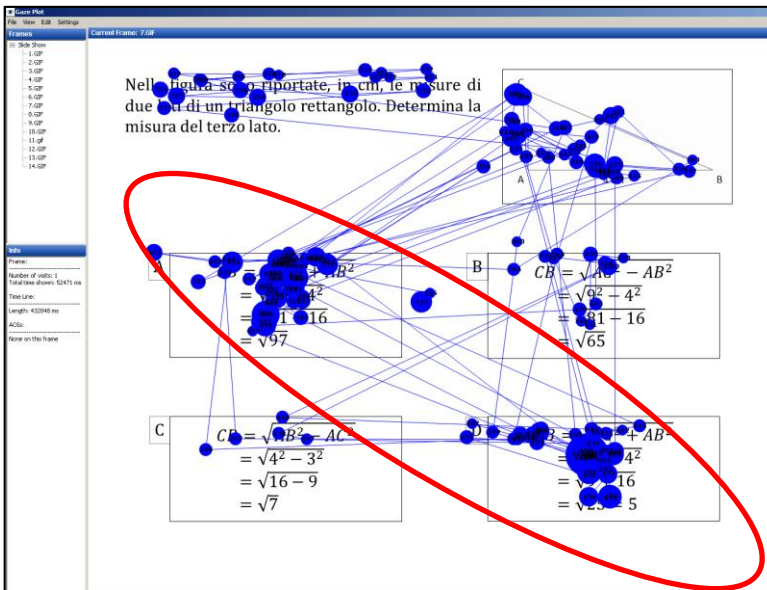
- ▲ Rotativo (detti anche motori a fluido)
- ▲ Alternativo (motore a scoppio)

Il motore a scoppio è un motore di tipo alternativo quindi volumetrico poiché il ciclo termodinamico avviene in un volume detto cilindrata.

Eye Tracking applications

# Intelligent e-learning

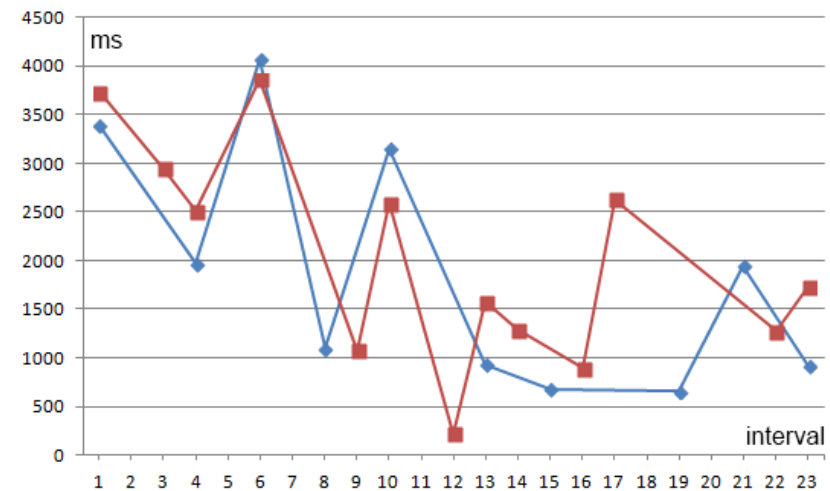
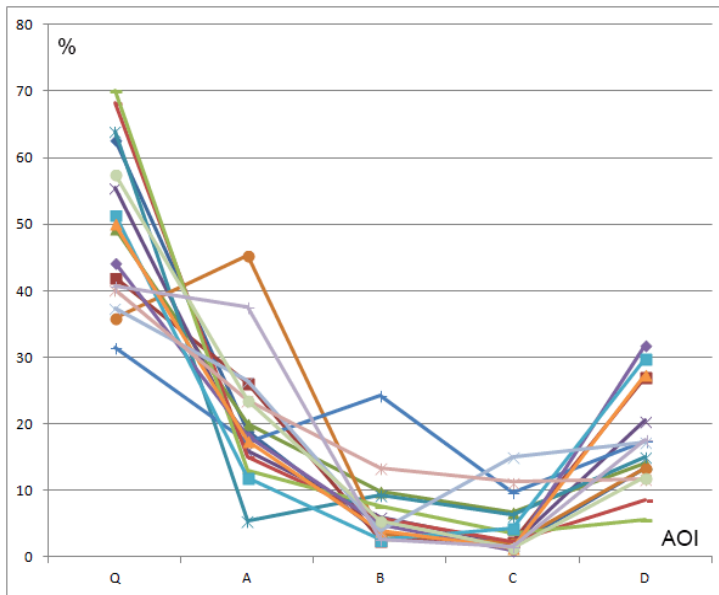
E.g., multiple answer tests



Eye Tracking applications

# Intelligent e-learning

E.g., multiple answer tests



## Eye Tracking applications

# Intelligent e-learning

E.g., generally **detecting understanding difficulties**

### Squaring an integer number

The *Duplex (D)* of an integer number is defined as follows:

- If the number is composed of a single digit  $a$ , then  $D = a^2$
- If the number is composed of two digits  $ab$ , then  $D = 2(a \times b)$
- If the number is composed of three digits  $abc$ , then  $D = 2(a \times c) + b^2$
- If the number is composed of four digits  $abcd$ , then  $D = 2(a \times d) + 2(b \times c)$
- If the number is composed of five digits  $abcde$ , then  $D = 2(a \times e) + 2(b \times d) + c^2$
- In general, if the number is composed of an even number of digits, its Duplex is the sum given by: two times the product of the first digit multiplied by the last one, plus two times the product of the second digit multiplied by the second last one, etc. If the number is composed of an odd number of digits, its Duplex is calculated like in the case of an even number of digits, but it is necessary to also add the square of the central digit

For example:

- The Duplex of 6 is  $6^2 = 36$
- The Duplex of 23 is  $2(2 \times 3) = 2 \times 6 = 12$
- The Duplex of 128 is  $2(1 \times 8) + 2^2 = 2 \times 8 + 4 = 16 + 4 = 20$
- The Duplex of 7346 is  $2(7 \times 6) + 2(3 \times 4) = 2 \times 42 + 2 \times 12 = 84 + 24 = 108$
- The Duplex of 37462 is  $2(3 \times 2) + 2(7 \times 6) + 4^2 = 2 \times 6 + 2 \times 42 + 16 = 12 + 84 + 16 = 112$

To calculate (for instance) the square of 234, take the following steps:

- Write the number and place at its left as many "dots" (which will be considered as zeros in calculations) as the number of its digits minus one : ...234
- Calculate the Duplex of 4:  $D = 4^2 = 16$ . Write 6 on one row and 1 on the next row, so that it is shifted to the left by one position
- Calculate the Duplex of 34:  $D = 2(3 \times 4) = 24$ . Write 24 so that 4 is at the left of 6 on the first row and 2 is on the next row, at the left of 1
- Calculate the Duplex of 234:  $D = 2(2 \times 4) + 3^2 = 25$ . Write 5 on the first row (at the left of 4) and 2 on the second (at the left of 2)
- Calculate the Duplex of .234 (where the dot is counted as 0):  $D = 2(0 \times 4) + 2(2 \times 3) = 12$ . Write 12
- Calculate the Duplex of ..234:  $D = 2(0 \times 4) + 2(0 \times 3) + 2^2 = 4$ . Write 4 (as 04)
- Now calculate the sum of the two numbers on the two rows: the result will be the square of 234, that is 54756

..234

6  
1

46  
21

546  
221

2546  
1221

42546  
01221

54756

### Question

Using the method just learned, calculate the square of:

**352**

**Important:** as soon as you think to have found the result, press any key to go on.

(It is not necessary that you look at the screen: you can also write on paper. Possibly, say what you are thinking)



## Eye Tracking applications

# Intelligent e-learning

- Typical gaze sample features:
  - Left/right pupil diameters
  - Product/ratio/difference of pupil diameters
- Typical fixation features:
  - Fixation count
  - Fixation duration
  - Scanpath length
  - Saccades velocity
- Features "extended" with basic statistics
  - e.g., Mean, Maximum, Minimum, Standard deviation, Median, Mad, Geometric Mean, IQR, Skew, Kurtosis, ...

What's the future of Eye Tracking?

# Conclusions

- The time seems ripe for a potential use of eye tracking as an "ordinary" technology
  - Usability studies
  - User "behavior inspection"
  - Marketing
  - **Human-Computer Interaction (HCI)**
  - Psychology/Linguistics
  - **Soft biometrics**
  - **Intelligent e-learning**
- Still open challenges (e.g., precision and need for calibration)

# Eye Tracking Technologies and Applications

# Thank you!

**Marco Porta**

Computer Vision & Multimedia Lab

Dipartimento di Ingegneria Industriale e dell'Informazione

**Università di Pavia (Italy)**

E-mail: *marco.porta@unipv.it*

Web: *<https://vision.unipv.it/people/porta/>*