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In this session we are going to first look into the eye anatomy and then learn about eye trackers and their evolution. Afterwards, we will study different ways that eye trackers use to collect data from human eyes. Finally, we will see how we can analyze those raw data in the best way with one good activity.

Eye Anatomy:

In the following figure, you can see a few essential parts of the human eyes. Then, you can find the short summary of their functionality and how they work together as a vision system.

Iris: The iris is the colored part of the eye. It is a circular muscular ring located in front of the lens and regulates the amount of light entering the eye by contracting and relaxing. This action will change the size of the pupil.

Pupil: The pupil is the black hole at the center of the iris which actively adjusts its size to maintain a constant level of light entering the eye.

Cornea: The cornea, the front transparent layer of the eye, refract light to focus the image on the retina.

Lens: After passing through the cornea, light will reach lens to be more focused. Lens, by changing shape, bend lights to focus the sharp image of the surrounding objects in different distances on the retina and fovea.

Retina: The retina is a thin layer of cells located on the inner surface of the back of the eye. It consists of photoreceptive cells, which are responsible for the transduction of light into nervous impulses.

Fovea: The fovea is the region in the center back of the eye and it is responsible for acute vision. When you bring your gaze to an object to examine it intently in bright light, the eyes orient so that the object's image falls on the fovea.

In short, first the amount of the light that reflected from objects will be normalized by iris muscles that change the size of the pupil. Afterwards, this light will be bent first by cornea and then by lens to focus light on retina or fovea. Finally, light will be changed into nervous impulses which will be transmitted to nerve cells and lastly brain to be processed.

Visible Light Region of the Electromagnetic Spectrum:

In physics, light includes every known radiation field, also called the electromagnetic spectrum. The light we can see with our eyes is called visible light. Visible light represents a narrow group of wavelengths between about 380 nm and 730 nm.
Two Types of Eye Movements:

**Fixation:** Fixation will happen when having the visual gaze on a single location. For example as you viewed a picture and your eyes noticed interesting parts. Most of the visual processing happen at this step.

**Saccade:** Saccades are quick movements made by the eye, characterized by a sudden change from point to point or between two or more phases of fixation. Sometimes these movements are small, like the ones your eyes are making as you are reading right now. They can also be bigger, like when you’re looking at a large painting hanging on the wall. Although some saccades can be done on purpose, most of the time they are a reflex that happens without awareness. Not much visual processing happen at this step, so it should be very fast in order to have smooth vision.

One reason for the saccadic movement of the human eye is that the central part of the retina known as the fovea which provides the high-resolution portion of vision is very small in humans, only about 2 percent of vision, but it plays a critical role in resolving objects. After seeing the small part of a scene with great resolution you need to move your eyes to see the whole scene in high resolution. To illustrate better you can think of fixation and saccade as using flashlight to see a dark environment. At a time it can only illuminates a small spot which has light on and then by moving flashlight around you can see the whole place. Finally, by putting these information together you can perceive the entire environment. That’s how our visual perception work.

**Yarbus’ Eye Tracking Research:**

Alfred L. Yarbus was a Russian psychologist who studied eye movements in the 1950s and 1960s. Yarbus invented a suction cup, which can be attached by suction to the human eye to study visual perception. Yarbus was one of the first scientists who attempt to study saccadic eye movements during scanning of complex image. He recorded the eye movements performed by observers while viewing natural objects and scenes. Yarbus demonstrated that the trajectories followed by the gaze depend on the task that the observer has to do. There is a gaze duration of least 200 milliseconds on each spot, but it might be longer depending on the task that is performing. Whereas saccades are very quick like 120 milliseconds. If the observer was asked specific questions about the images, his eyes would concentrate on areas of the images which is related to the questions.

*Figure 3 Two of Yarbus’s suction caps, together with the recording device.*

*Figure 4 This study by Yarbus (1967) is often referred to as evidence on how the task given to a person influences his or her eye movement.*
New Eye Tracking Experiments:

New eye trackers are both non-invasive and non-intrusive. One of the most popular technique that is used by modern eye trackers is using camera to record a video of movements of one or both eyes when the user is looking at some kind of stimulus and then analyzing the recorded data in a meaning full way. Also, they use the center of the pupil and infrared or near-infrared light to compute the gaze direction. A simple calibration procedure of the individual is usually needed before using the eye tracker.

There are many applications for eye trackers, for example advertising pretesting. It could be helpful to decide where to put advertisements to be seen. Eye tracking data is also can be used in psychology researches, usability studies and HCI researches. In the following you can become familiar with two ways of doing so.

Scan Path:

Scan path, which is also referred as gaze plot, can show where people exactly look at when they are viewing an image. It is made of a series of short stops which is also called fixations and fast movements of an eye which is also called saccades.

In the following image fixation are visualized by circles and the numbers inside the circles indicate the order of elements which the eyes move between fixations, for example the first spot that the user looked at is marked with 1. Also, radiuses of circles are proportional to the duration of the fixation. All the saccades are showed by straight lines that connects two circles. It means that users’ eyes are following those paths to see one spot after another one.

Attention Heatmap: (ADDITIONAL EXAMPLE)

Attention heatmap tries to use color gradient as an indicator of which area grabs more attentions or in the other words has more or longer fixations. It differentiates between different elements of image as hot spots with more attention and cold spot with less attention. The following figure displays the results of eye tracking of 40 viewers and shows which areas of the image attracts more attention. The heatmap colors range from green through yellow to red and respectively they are representing low, medium and high level of attention. Any area with no color means that it’s been overlooked by viewers.
Analyzing eye tracking data:

Eye tracking data are consists of some positions in the form of x, y coordinates of different spots that have been looked at by the subject, order of these spots, and the amount of time that the subject has been looked at each one which is also known dwell time. One visual representation of these data is scan path. Based on this information there could be two different analysis:

1- Spatial Analysis:
   
   This analysis can be used when the spatio spread of the locations is more important as opposed to the order of them. For instance, when the question is which part of the image is more interesting, this analysis can answer the question by using spatial clustering. There are two approaches to this analysis:

   i. Saliency map
      
      This map is of the same size of the original image and is similar to likelihood map which means that region with higher values are more have been looked at and regions with lower values have been overlooked most of the time. This map can be convert to histogram which is more useful data type for data mining and data analysis.

   ii. Grid based map
      
      This map is made by dividing image to certain parts which is also called area of interests (AoI). Then counting the number of data points that falls into each part.

2- Spatio/Temporal Analysis:

   This analysis can be used when both locations of the spots and the order that they have been looked at are important. This data can be represented by using ordered vectors data structure. Then we can use distance vector metric to compare two different scan paths.

In class activity:

This activity was based on reading the experiment 1 part of this paper * and then finding the best way of analyzing the eye tracking data including methods, conceptual diagrams and hypothetical results. Also, more information about methods for comparing scan path and saliency map are provided in paper **.

Selected Method and conceptual model:

Selected method is using spatio analysis and selected conceptual model is using grid based map for each face in the dataset. The most important five main facial AOIs are eyes (green), upper nose (blue), lower nose (orange), upper lip (red), and nasion (purple) because they are accounted for more than 88% of all fixations. And then put all the fixations frequencies into a histogram.
Hypothetical results:

For each region, fixation rates on emotional faces (those with 20%, 40%, or 60% emotional intensity) were submitted to one-way ANOVA with emotion block as a factor. Figure 10 shows fixation rates for each face region across the six emotions. Distinct fixation patterns appeared for each emotion, such as a focus on the lips for joyful faces and a focus on the eyes for sad faces. These patterns were strongest for emotional faces but were still present when viewers sought evidence of emotion within neutral faces, indicating a goal-driven influence on eye-gaze patterns.

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