THESIS

EYE'VE SEEN THIS BEFORE:
BUILDING A GAZE DATA ANALYSIS TOOL FOR DÉJÀ VU DETECTION

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2022

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ABSTRACT

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In order to expand the understanding of the phenomenon known as déjà vu, an investigation into the use of eyetracking was needed. Through the use of an advanced eytracking device, open-source software, and previous research into déjà vu, this thesis provides a discussion and analysis of the development for a standardized eyetracking set up for general gaze data collection and a novel gaze data conversion pipeline. The tools created for this thesis work in conjunction to collect and convert data into easier to comprehend formats and separates the results into simplified separate text files. This data analysis tool analyzes and formats files *en mass* in order to make the processing of high volumes of data easier. These tools are designed to be accessible to professionals within and outside of the field of computer science. With these tools researchers can develop their own projects and implement the eyetracking code over theirs and then pass the output data through the data analysis tool to gather all the information needed.

ACKNOWLEDGEMENTS

I would like to thank Nate Blanchard for being my advisor and helping me through all the trials and tribulations that came with this research. I would also like to thank Turguy Calgar for helping with this project and keeping all research protocols in line with research standards and expectations. I would like to thank Dr. Kat McNeely-White for introducing me to this project and giving me the resources and knowledge to perform this research. Finally like to thank all of the Communicating with Computers Lab for being the people who have helped me debug, test, and pilot my experiment and my code, and for all being wonderful friends and co-workers.

DEDICATION

I would like to dedicate this thesis to Les, my dad and sanity checker; Jil, my mother and ideas backboard; Michelle, my mother and editing specialist; and Rowan & Ailee, my sisters and first readers.

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Chapter 1

Foreword

1.1 Developing the Pipeline

This work went through a long developmental cycle. The work on this project began in the summer of 2021. During this time the development went through multiple reworks and developments. While there is an experiment being developed for this research this paper focuses on the development of the gaze data analysis pipeline that is being used by the experiment.

In order to make this tool viable for the project, the data processing pipeline needed to be designed to be lightweight, abstract, and easy to use. While the option of building a tool specifically for the purpose of collecting and analyzing the specific data of the experiment was an option, opting to build a tool that could be used with other experiments and designs was more in line with the interests of the project. For this project, certain decisions were chosen for ease of use. For example the code was developed focusing on packages and resources actively provided by the open source Psychopy research package.

The overall goal of this paper is to show the development of the gaze data analysis pipeline tools. No formal experiments were ran for the purposes of data collection for this paper. The results of this work and its viability are the fact that it is already in use within projects at CSU with more projects on the way.

Lastly in order to understand the development and purpose of the Gaze Data Analysis Pipeline, an understanding must be made of the original research that prompted the development of this tool. To this end the next section of the paper will cover the background and prior work that the pipeline was built for. After that the development of the pipeline will be explained including resources required to use the pipeline and all of the developmental challenges encountered in the process of creating the pipeline. Following that a short section on current user implementations will be presented. Lastly, closing remarks and future work and usage of this project.

Chapter 2

Introduction

2.1 Eye Gaze and déjà vu

Whether consciously or not, you've likely experienced a feeling commonly known as "Déjà Vu", or the sensation of having observed or experience an event or scenario before. For a long time, this sensation was associated with the concept of prophecy or foresight, some even going as far to say that they experience déjà vu on a regular basis. Mysticism and spiritualism aside, the feeling is a real sensation and the concept of it has been of great interest to researchers [2–4]. Studies over the past twenty years have found more information regarding the nature of déjà vu, and the causes the unusual sensation [2, 5–7].

One of the key theories related to déjà vu currently is the concept of memory retrieval failure [5, 6]. Memory retrieval failure in this contents is when a subject fails to recall information stored in their memory. In regards to déjà vu the memory recall failure occurs because the subject recognizes aspects of the scenario, but the scenario itself is new to the subject. In order to induce this, Dr. Anne Cleary developed a methodology of presenting environments and scenarios to subjects that would simulate this memory recall failure. The most recent variation of this comes from a study by Cleary and Claxton; this methodology uses a video walk through of a virtual environment, see Figure 2.1 [1]. In this variation, two versions of the scenes are presented: the study phase scene and the test phase scene. The layouts of the two scenes are identical with the exception that objects within one of the scenes are replaced by physically similar objects, e.g. ones that take up similar amounts of space and have relatively similar shapes and designs. Other aspects including floor, wall, and ceiling textures are also replaced. These subtle changes to the scenes create a new scene that is configurally similar to its base scene. For these walk throughs the subject's view point is panned through the scene and at a specific point in the video the camera makes either a sharp

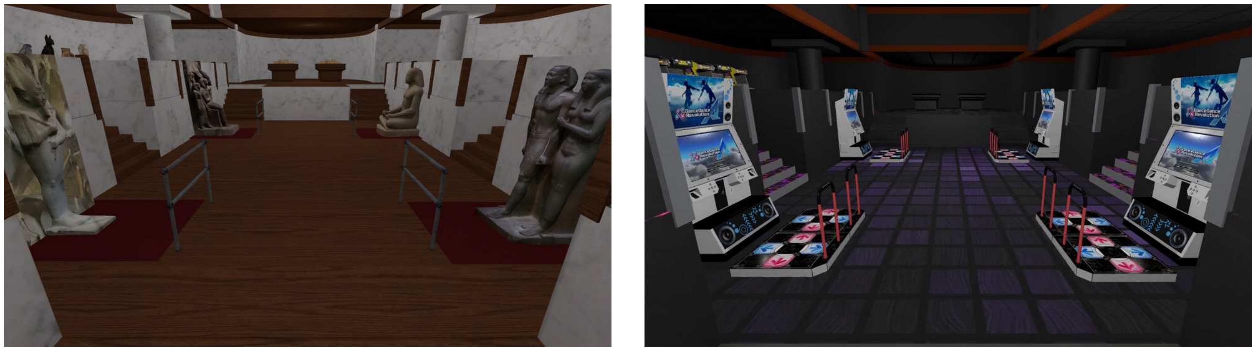

Figure 2.1: Screen snapshots of two videos from Dr. Cleary's experiments of the museum layout with museum elements (Left) and arcade elements (Right). Screen caps taken by Logan Seabolt pulled from the experiment by Dr. Cleary [1]

left or right turn; this turn is identical in both scenes. During the testing phase of the experiment subjects are presented with multiple sets of these videos and self report a variety of information: Experiencing the sensation of déjà vu, a rating of familiarity of the scene, which direction the scene will turn, how confident they are in that prediction, and if they know the name of the scene it reminds them of. This a data is then manually examined and computed to determine whether the subject actually experienced déjà vu.

2.2 The Eye and Previous research

"The eyes are the window to the soul" is a saying that many have likely heard, but there may be more to it than that. Our eyes are one of the most powerful parts of our body: not only are they one of five key sensory organs, but they are able to override and supersede other senses when our brain needs to make decisions. They are one of the fastest methods of data transmission in our body. Due to their swift processing speed the eyes often need to react to information and events before our brain fully has time to process it. This causes the eyes to perform a multitude of subconscious actions.

The field of gaze data research involves a variety of interests: Locating focus in stressful situations, using gaze to replace motor interactions in digital environments, or determining mental states through secondary subconscious activity to name a few. One study that drove the factor of including eyetracking in the déjà vu study was one done by Dr. Cleary in her work in “Tip-of-the-tongue” syndrome. A similar memory retrieval failure psychological event wherein a subject knows what the concept,word, or idea they are thinking of is but are unable to produce the word for it. In the research by Ryals, Kelly, and Cleary, they found that the pupils had increased dilation during “tip-of-the-tongue” states and even more so when full recognition was achieved [8]. This showed that there could be a possible link between the subconscious activity of pupil dilation and memory recall.

Combining these factors, a it can be hypothesised that the link between pupil dilation and tip-of-the-tongue syndrome, which is considered an instance of a memory recall failure, could be found similarly in the case of déjà vu, also considered an instance of memory recall failure. Originally only pupilometry was considered for the addition to the déjà vu research, however since the eye performs so many other interactions, a kitchen sink approach was adopted for the project. Not only was pupilometry included, but other factors of gaze analysis where considered to see what factors could be used to identify instances of déjà vu.

2.3 Eytracking and Mind Wandering

With the link between déjà vu and the human gaze being found in the connection between tip-of-the-tongue syndrome and pupil dilation, an expansion of Dr. Cleary’s déjà vu research became of interest. Not only was it important to update the project to more modern research technologies but the implementation of biometric data collection for both gaze data and facial recording were needed.

With the eyetracker used for the experiment we were able to collect data for gaze location, pupil size, fixations, saccades, gaze path, and blinks. Gaze location is simply put, where the user was looking at the monitor on a decimal scale of 0.0 to 1.0, With 0 being the top of the monitor on the Y axis and the left side of the monitor on the X axis. In order to accurately place the pixels when graphing the results, the data analysis tool multiplied the locations by the height and width of the monitor. The eyetracker could detect when the user looked outside of the monitor as well, in these instances the values could appear as negative or over a value of 1.0, though tracking outside of these ranges became unstable. Pupil size was measured in millimeters and could be used to observe pupil dilation events. Fixations are periods of data where the subject's gaze does not drift more than a certain distance away from a singular point. Because gaze never truly stays still, there is leeway in the computations for fixations that can be fine tuned to fit the scale of the data. A fixation is measured in both location and in duration. Saccades are rapid eye movements between two fixation points. They can be measured in number of occurrences in a time frame, or by the locations the saccade occurred between. Gaze path is the path of how the user's gaze moved throughout the duration of the experiment, and can be extremely useful when attempting to track how users perceive an environment or scene. Lastly, the tool we used allowed us to measure blinks, which are recorded via timestamps and number of occurrences in a time frame. Additionally, this tool can check for the validity of the position of the data, allow the researcher to check if the eyes were valid, e.g. the subject isn't looking at the screen or the subject is at an unusual angle to the eyetracker.

Even with all of the available gaze data there was still the threat of human error and attention. In order to combat this, it was necessary to see if subjects were actively paying attention during the experiment and if answers were coming from attentive subjects or inattentive subjects. Thus facial recording supported by the eyetracking data was needed in order to detect mind wandering during experiments. A subject that is not paying attention to the experiment could invalidate whether the subject actually experienced déjà vu or if the subject randomly selected the responses consistent with a subject experiencing déjà vu. Mind wandering in its simplest form is when the subject's thought process shifts away from the current task at hand. It has been found that up to 96% of American adults claim to experience mind wandering daily [9].

Mind wandering has been linked to eye gaze, mind wandering is also an internal phenomena, this gives us further confidence eye gaze will be linked to déjà vu [10, 11]. While not a problem by itself, mind wandering can become an issue if a subject experiences it during an experiment. This event could threaten the validity of the results or produce unexpected or unusual results in both the psychological and eyetracking data. Mind wandering can occur in a multitude of situations both intentionally and unintentionally, like intentionally thinking of things to bring their mind away from the task due to boredom, and unintentionally, like when a subject is doing their best to focus, but events outside the task at hand might distract the subject. The facial recording methodology was based off the work of Hutt et. al. who used both face recording and eyetrackers to detect mind wandering in students during an interactive lecture [11]. Although done in real-time rather than a post analysis, the theory and concepts provided can still be applied to a post data analysis methodology.

Chapter 3

Systems Design

3.1 Initial Experiment Design

The first step to this research was the development of the experiment that would be used to collect the data. The original experiment was one designed by Dr. Anne Cleary, however, this system was a web based tool and had not been updated in a few years. In order to properly integrate the biometric data, the experiment had to be redesigned and rebuilt to use newer tools. This process began by rewriting the experiment using the Psychopy Python package. Psychopy is a psychology research package for the Python language that allows users to design and run experiments. It is an open-source community developed package designed for the development of research experiments primarily in the field of Behavioral Research. The original déjà vu experiment by Dr. Cleary was closely analyzed and then replicated in Psychopy.

3.2 Tools and Supplies

Research equipment for this experiment was a unique challenge. Due to the initial nature of the partnership with the psychology department, two research systems were required for the project: one for the computer science department and one for the psychology department. This meant that any resources required for the experiment needed to be collected in double the amount. The first and foremost of required equipment was the eyetracker.

There are many types of eyetrackers some designed for personal use and others designed for high speed tracking for research. For the Psychopy package, four main brands were supported: GazePoint, Pupil Labs, SR Research, & Tobii. Many factors were included in the analysis and selection of the eyetrackers. GazePoint, although the lowest cost of the eyetracker options, its systems recorded at a lower rate, 60hz, and were not monitor mounted and instead used a tripod set up for placement, requiring the experiment runners to calibrate the position of the eyetracker consistently and an incidental collision with the tripod could invalidate the subject's data. These factors showed that GazePoint was not likely to fit the needs of the study.

The Pupil Labs options seemed to be more suited to the needs of the study. The camera used by the system is a high speed recording system at 200hz, and could be used to record gaze data with high accuracy. The one factor that challenged this model is that the model is a head mounted system. Due to a combination of health, safety, & sanitiation concerns and the desire for facial recording this model option was declined.

The SR Research EyeLink models. Was the highest quality option with a 2000hz camera and high speed motion tracking capabilities it made for the best high quality option. The price for a single unit was over US$30,000 and required a dedicated host computer for the system to run on, these two factors removed this option as a possibility.

Finally, the Tobii models. The basic model provided by Tobii was the "Tobii Nano" which was on par with the GazePoint model, with an equivalent 60hz recording speed and similar price point. The more advanced "Tobii Fusion" model was more in line with the quality level of the Pupil Labs and SR Research options. The Fusion was a flexible option with two camera options either 120hz or 250hz. These models were also monitor mounted which meant they could be used along with the facial video recording, and their price range was within the range of the grants available to our team. After careful consideration and comparing all options, The Tobii Pro Eye Fusion was chosen to be the tool used in this experiment. With a combination of key factors: the 250hz recording rate, built in pupilometry data collection, monitor based mounting, and grant applicable price range, this option was the choice that met the needs of the experiment the best.

The next tool needed was the research computer. Because this experiment needed to be performed in both locations with as similar environments as possible, the systems used for the experiments needed to be nearly if not completely identical. For this step, two computers were requisitioned from the computer science department and were upgraded with a few select parts. First, the systems were upgraded with higher performing graphic cards "NVIDIA 1030" models, the RAM memory of the systems were upgraded to 32GB in order to support all of the simultaneous streams of data input and output, and a higher capacity hard drive was installed in each to support the high number of read and write actions that were performed in the duration of the experiment.

The Psychopy package uses an advanced graphics package to draw the UI and video stream, because of these factors a new graphics card was required. Additionally, Psychopy required a minimum of 8GB of ram and Tobii eyetracker additionally required 16GB. This combination of factors meant that a significant upgrade to processing power was required to run the two simultaneously. Finally, a monitor mounted camera was used to record the faces of subjects for the purposes of mind wandering detection. The model used for this research was the "Logitech Brio 4k HD" webcamera.

3.3 Environment Set Up

For this experiment, the environment was set up with the intention of minimizing the need to reposition parts. The layout is as shown in Figure 3.1. The Eyetracker was mounted using a magnetic mounting plate. The Web camera was freely mounted and was placed on top of the monitor. To ensure consistency, the experiment set up that was originally placed in the computer science department was moved to the psychology department, with consideration that the lighting differences and environmental differences could possibly threaten the validity of the experiment.

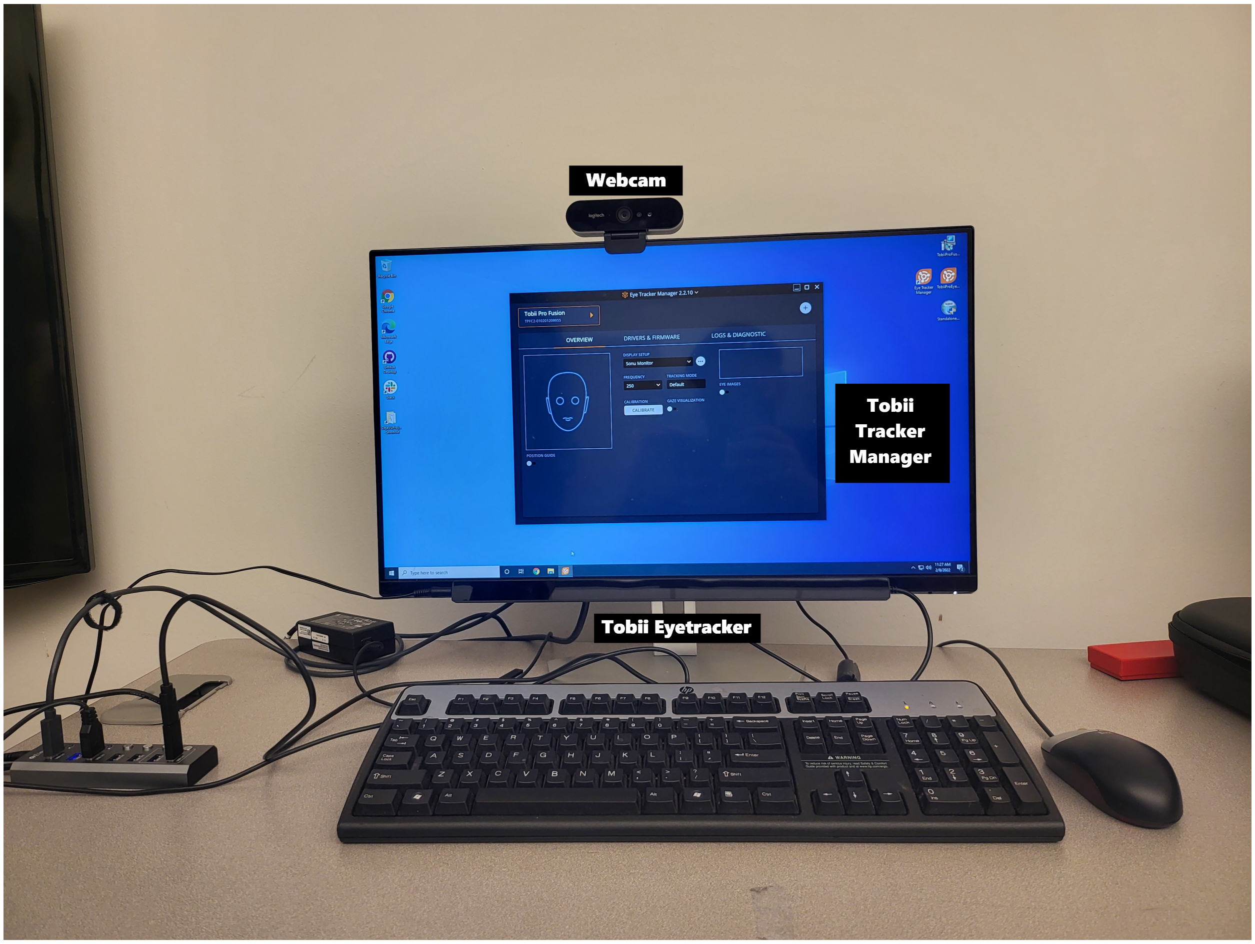

Figure 3.1: Computer monitor set up. The eyetracker is mounted to the bottom of the monitor using a magnetic support strip. The Camera is mounted to the top only using the camera's built in clamp. The Tobii Eyetracker manager program handles the calibration and monitor set up

3.4 Eyetracker Code Development

In order to perform accurate data analysis the camera and eyetracker needed to be started simultaneously. In order to record input from the webcamera the open-source Python package OpenCV was used. OpenCV is a open-source computer vision package that can be used it interface with all forms of visual media data. It can record data from webcamera or the screen, playback video or stream live video, edit or modify video data and more. This package is a commonly used package in the field of computer vision. Since the camera had to be recording along side the rest of the code a multi-threaded approach was taken. OpenCV does not use a callback method and instead directly outputs the data in a continuous stream, meaning in order for the code to continue to execute while simultaneously recording the user's face the facial recording needed to be performed asynchronously. Thus a simple multithread call was made to control the camera recording independently of the remaining code. Following this, in order to have the eyetracker record, a callback method was needed and the eyetracker had to "subscribed" to the method. The benefit of this style meant that the output of the eyetracker could be explicitly controlled and managed, the drawback to this style meant that the method had to be manually written, resulting in a steeper learning curve than normal. Since the data from the eyetracker and the camera were being saved to disk memory, this was a challenge to the systems available to the project originally. Higher quality hard drives were needed in order to support the number of read and write operations occurring during execution. These methods were written into an example file that could be given to new users for the eyetracker, allowing for any future users of these tools to quickly implement the eyetracking code using the data format expected by the data analysis tool ad described in Section 3.6.

3.5 Collecting Data

Data collection had to be as autonomous as possible to limit the level of human error in the data collection. Although a large portion of the experiment was capable of being automated, the eyetracker had to be manually calibrated for each test subject. This manual calibration led to some unique findings. First, not every person can use the eyetracker, two of the pilot subjects used during the development of the code could not be detected by the eyetracker. This meant that the subject could neither calibrate the eyetracker nor participant in sample data collection. Additionally, some participants were only detected by the eyetracker if their head was positioned in a specific angle, which prevented natural position and response during the study. Unfortunately no solution for this error was found, and instead subjects who could not calibrate the system were marked as such and continued with the experiment as normal without the eyetracking. Excluding the small error with facial detection for certain participant, the rest of the data collection was managed by an auto execution script that would start the experiment.

For the data output, 3 files of output were generated: a text file containing the gaze data, a video file containing the facial recording, and the psychology data stored in a CSV file. The CSV file containing the results of the experiment for the psychology department was automatically formatted by Psychopy. The file contains all of the results of the experimental questions as described in Section 2.1. This data was stored for use in future studies to create the baseline for training models for the detection of déjà vu. For the video file, the video stream had the timestamp in milliseconds attached. This time stamp and the time stamp of the eyetracking data are synchronized to allow researchers analyzing results to identify specific moments when subjects may have had mind wandering instances and compare what the resulting eyetracking showed or vice versa.

3.6 Gaze Data Analysis Pipeline

In order to analyze the resulting data in an effective manner, a program was needed to perform mass standardized conversion on the resulting gaze data. The gaze data pipeline was broken into two key parts: data conversion and data analysis. The conversion compiled the raw data files and separated them into sub files that could then be automatically analyzed by the open-source gaze analysis package PyTrack, which was modified and included in the gaze data pipeline github repository due to minor required changes in the original source code. The data analyzation method takes the output of the data conversion method and generates a file containing; the basic data output, and two image files: a heatmap of the experiment and the gaze tracking path. With these files, the user can investigate the data and even overlay the resulting data over the videos.

3.6.1 Gaze Data Conversion

For this method, the user enters the data folder, height, and width for their files. The system then process the files and creates an output folder for each unique user input file. The data conversion takes on average 3 seconds per file. During this process the method splits the files into sub-files for each individual eyetracker keyword toggle. The method has a preferred format in order to properly convert the data. The input files need to be formatted in the following way: Recording timestamp, Eyepos3d_Left.x, Eyepos3d_Left.y, Eyepos3d_Left.z, Gaze2d_Left.x, Gaze2d _Left.y, PupilDiam_Left, Validity_Left, Eyepos3d_Right.x, Eyepos3d_Right.y, Eyepos3d_Right.z, Gaze2d_Right.x, Gaze2d_Right.y, PupilDiam_Right, Validity_Right, Scene Name, Event value, Event message. The timestamp is stored in seconds using whichever logging program the user decides to use. The Data Conversion tool will convert the data over to milliseconds in order to be properly analyzed by Pytrack. The next 12 data values were key value points needed to pull any relevant information about the experiment. The last 3 values were used for determining the split of the data stream. Scene name is used for determining what the files would be called. The Event Value and Event Message were used for telling Pytrack when to start and stop its analysis. A value of 100 starts the analysis and a value of 200 stops it. Currently the code is set to use a message with the title "MYKEYWORD" in order to tell the program when a event value occurs. For an example of the output see Figure 3.2

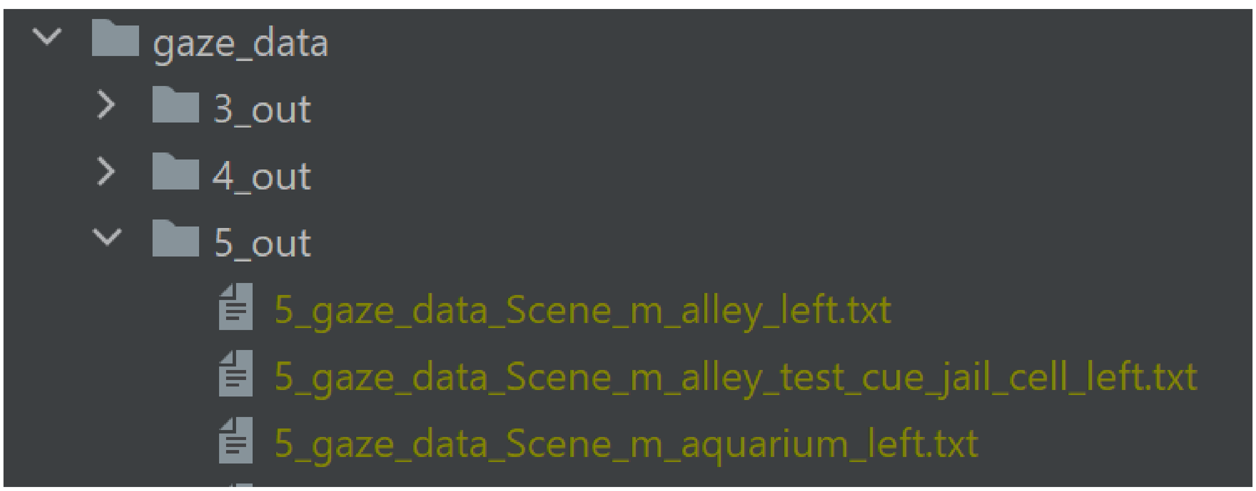

Figure 3.2: Resulting folders & Files from executing the Gaze Data Conversion method

3.6.2 Data Analysis

Once the data was formatted using the Gaze Data Conversion method the Data Analysis tool could extract key information about the resulting text files. The method pulled each of the directories in a folder specified by the user. The first step of the execution requires the method to read each of the text files generated by the Gaze Data Conversion method. It proceeds to generate a sub-folder, and 3 output files for each text file. The first output file is the basic text output file. This file contains information on the Gaze position extremes, Fixations data which includes: Count, Max Duration in milliseconds, average duration in milliseconds; Saccades data which includes: Count, List of durations in milliseconds, List of peak velocities, List of amplitudes; Blink data which includes: Count, Max duration in milliseconds, Average duration in milliseconds; and Pupil Data which includes: Pupil sizes through the duration of the experiment, Peak pupil dilation. time to peak pupil dilation from the beginning of the experiment in milliseconds, area under curve, slope, mean size, downsampled pupil size. This data could be used to investigate base results from the experiment. In the realm of the déjà vu experiment these factors could be used to determine if there are any differences between studied or unstudied scenes, or it could be used to see if there are any factors that occur in higher frequencies or in more extreme values in instances of déjà vu vs not.

The next two pieces of output were the heatmap and gazepath. These two pieces of data allowed for a visualization of the data. Pytrack originally provided code to generate both of these files, the code written for this project was rewritten to provide more useful and specific figures. The code was rewritten for two reasons: to allow the data to be saved in a more accessible format, and to reformat the output files to remove the axes and create a transparent background to allow the data to be overlaid. The first of the two files generated was the heatmap. For this project the heatmap visualized where clusters of the gaze points sit. See Figure 3.3 for an example of the heatmap.

These heatmaps could be compared to between experiment trials and subject to identify fixation points and possible areas of interest. In the original design from Pytrack, the heatmap was improperly coded had its axes flipped so the heatmap cut off its output at a width of the height of the screen. This meant that a significant portion of the heatmap was unavailable in the original design. Additionally, by removing the axes display and setting the background to transparent, the heatmap could be overlaid on the original video in order to show where the subject had their focus targeted. The gazemap code was functionally similar to the heatmap with the main difference being in that it follows the path of the saccades that occurred in the duration of the experiment. See Figure 3.4 for a sample output of the gazepath code.

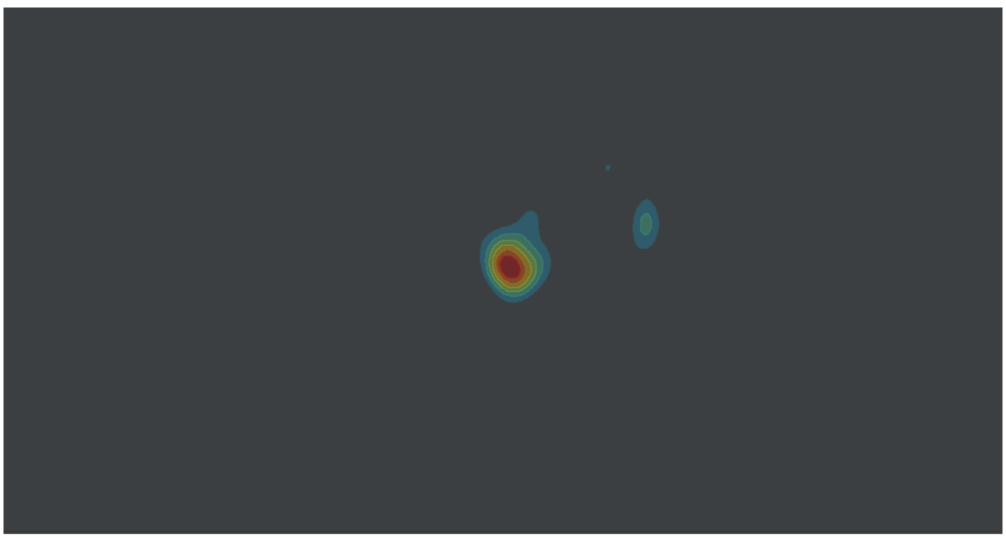

Figure 3.3: The resulting heatmap from sample data. The background is transparent allowing it to be overlaid onto other elements

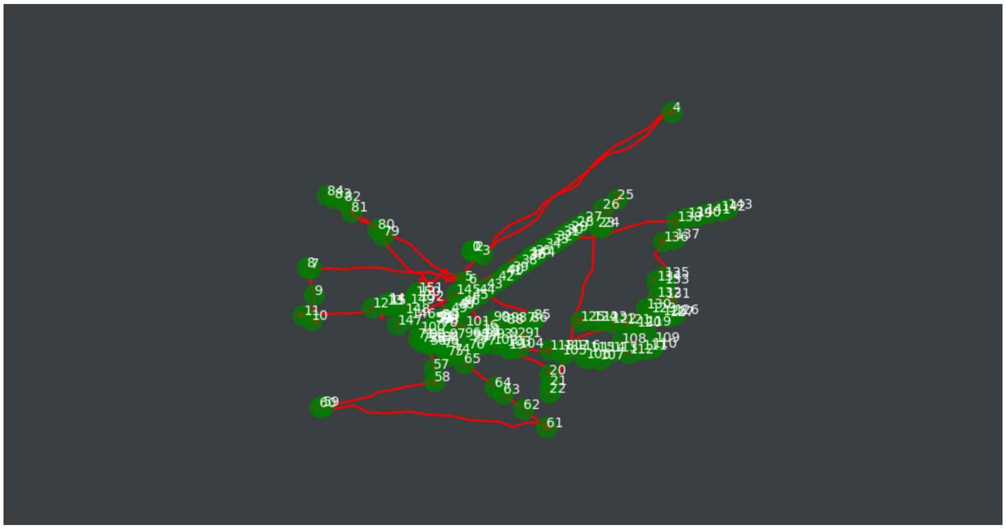

Figure 3.4: Gazepath of a single video. The background is transparent allowing it to be overlaid onto other elements

3.7 Video Overlay

In order to further understand the results of the previous code, a method was developed to overlay the results of the gazepath and heatmap with the original video. This allowed the users to observe the locations of saccedes and fixations within the boundaries of the video. Using OpenCV, it is possible to overlay multiple transparent images. In the process of this the colors of the original video become extremely faded. It is advised to use a single overlay at a time to avoid generating faded images. See Figure 3.5 for an example. With this tool a user could generate a visualization of where the subject's gaze was focused during the experiment and can look for any unusual visual outliers.

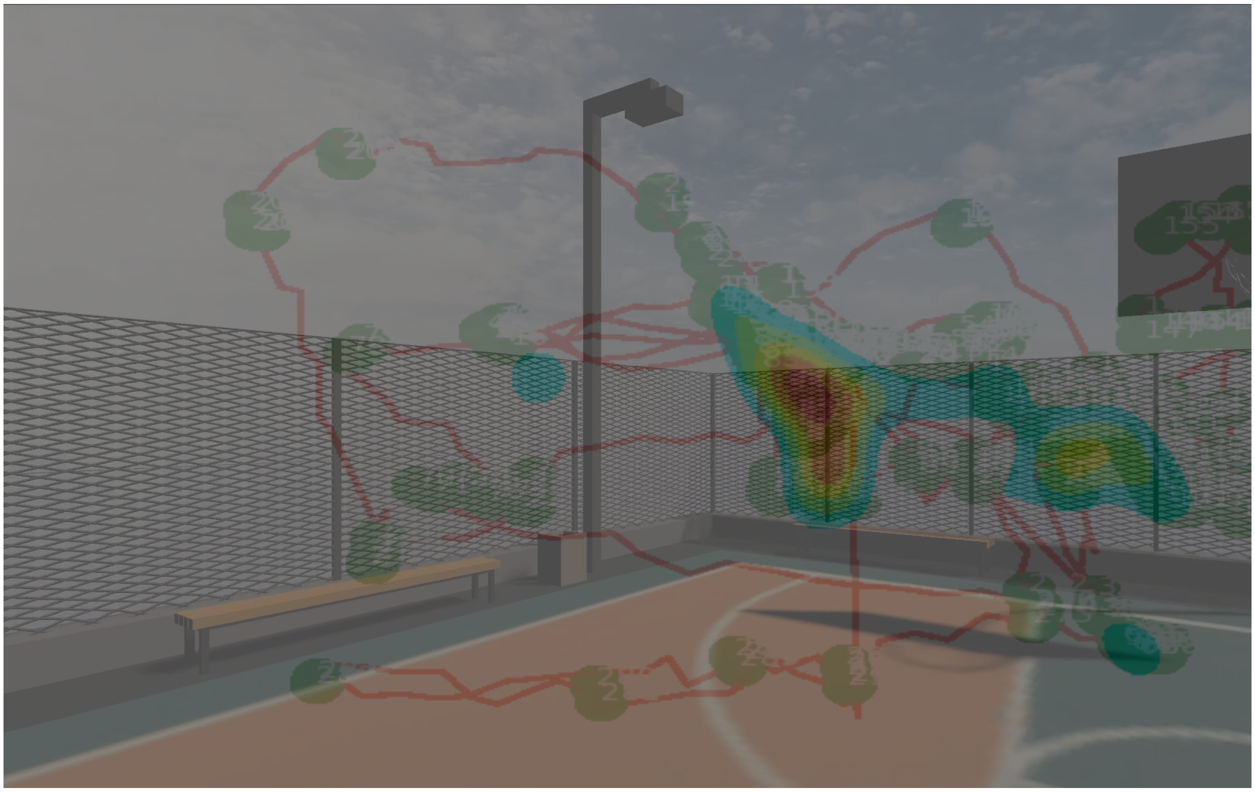

Figure 3.5: Video Overlay example using the basketball court video from Cleary & Claxton [1]

Chapter 4

User Use Cases

4.1 Current User Usage and Feedback

The Code developed for this project is already being integrated into projects at CSU. Early user feedback has opened new avenues for expanding on the Gaze Data Analysis Pipeline's code. As of the writing of this paper the code has only been tested with and used by computer science researchers. Although the intention for this project is to be used with minimal computer science knowledge, information and feedback is always of importance.

Currently there are 3 projects using this code and they are divided into two main categories. Projects using the eyetracking code and projects using the data analysis code. Although projects under category one will likely expand into category two. The focus of the category one experiments are on the capacity to collect data over the importance of results. Of the category one experiments, the first is a behavioral research project analysis user reactions to presented educational stimuli. This project is the first of the projects to implement the eyetracking code. Based on feedback from the lead researcher the installation was easy and straightforward thanks to the installation document. The second category one project is looking to use the eyetracking code in a unique way. The project is focusing on studying the interactions between a human and an artificial intelligence assistant. The goal of eyetracking in this project is to observe how the human subject reacts when the AI assistant provides information. In particular the researchers are interested on seeing if the human subject observes information outside of what the AI presents. While some modifications on the eyetracking code are needed, such as creating a spoofed eyetracker for where the AI is "looking", the implementation thus far has been trivial.

Looking at the category two experiment, it is an expansion on the déjà vu research focusing on developing a simple neural network to identify instances of déjà vu based on gaze data information. This project is already building off of the déjà vu research as described in section 3.1 which includes the eyetracking code. For this project the researchers are implementing the data analysis section of this project and have provided useful feedback on the tool. For one, there is no use document for the gaze data analysis tool. This was an oversight due to over confidence in code documentation, however users such as non-computer science end users or researchers attempting to quickly learn and understand a tool do not want to read code documentation to understand the tool. A user documentation guide has since been written with guidance and feedback from the initial users to make the implementation of the project easier and more streamlined for future researchers.

With these initial user responses a version 2 of the gaze data analysis pipeline is already under construction. Modifications planned for version 2 include: user instructions for converting input data from other eyetrackers into the proper format, a sample input file to test for proper installation, more documented README files with clearer instructions for installation, set-up, and use of the data analysis tool, and minor code modifications to improve data output clarity and viability.

Chapter 5

Conclusion

5.1 Future Work

There are many options to extend this research. While this code is based on déjà vu research, there are numerous possibilities to expand to foundations of the project. The first step is to finish the computation and analysis of the data for this experiment. With this tool, all the data can be translated into an accessible format that is ready to be analyzed. There are many pathways researchers could take with the déjà vu research this project is based on, one possibility is the addition of additional biological sensors.The code for the experiment was designed with the intent to add additional biological sensors including electroencephalograms used to detect neural activity or electrocardiograms used to measure pulse and heart rate with minimal rewriting of code. Additionally, the facial recording data can still be processed and analyzed to detect mind wandering and compare the resulting mind wandering instances with the gaze data. The next steps of this experiment involve the adaption of the experiment to virtual reality via the use of advanced VR headsets with built in eyetracking such as the HP Omnicept or the HTC Vive Pro Eye.

One of the key intents of this code is that it was designed so subjects could download, copy, and then paste the code into their own environment to implement eyetracking for any experiment. Additionally if subjects are using the layout designed by this research, then they can directly place their data into the folder for the data analysis tool and execute it to get full results and information regarding their experiments. This streamlines the process for new researchers and allow researchers independently of their skill level to implement eyetracking into any experiment.

Beyond its impact in the research on the the topic of déjà vu research, This has laid the foundation for more projects that would utilize eyetrackering technology. This project encompasses all the basic set up and execution code required for any experiment using eyetracking. With the code developed by this research, the gaze data analysis pipeline could be used to convert the data into visualized formats and provide researchers with the basic data needed for any form of eyetracking research. These tools could also be used to improve the capabilities of other field of research; It could be used in Education research to study focus and attention in different educational environments. The field of Human Computer interaction could use eyetracking to improve content flow interaction and even develop alternative methods of interacting with computers using only the eyes. In the field of Natural Language Processing eyetracking could be used to see how subject's read or analyze text. Lastly in Behavioral Science eyetracking could be used in conjunction with other physiological markers to detect differing states of mind or look for possible signs of certain mental or emotional disorders.

As for the pipeline itself, this version is the first version of it. As it stands it is already a viable research tool, with beginning usage cases with minimal issue. With the feedback collected from these users, a version two of the pipeline is already in the works with additional information for using other eyetrackers brands, a user guide, and improved overlay code for the heatmap and gazepath outputs for video overlay.

5.2 Closing Comments

This project laid the groundwork both in terms of physical tools and written code for the collection and analysis of eyetracking data. With this code new tools can be assessed and integrated with the code developed for this project to open a gateway to more development for the realm of human computer interaction, communication with computers, behavioral research, and even more so the integration of these fields. This project is the doorway to allowing others to experiment and use gaze data in their research without the need to design and develop their own tools, instead allowing them to implement an already created tool to streamline their process. This research can stand as the stepping stone for more work to come.

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