

Visualisierung der menschlichen Sehbahn

Interaktive Simulation von Läsionen im menschlichen Sehbahn

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Visualizing the Human Visual Pathway

Interactive Simulation of Lesions in the Human Visual Pathway

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Erklärung zur Verfassung der Arbeit

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Kurzfassung

Diese Arbeit stellt eine interaktive Webanwendung zur Erkundung der Komplexitäten des menschlichen visuellen Systems vor. Die Software verfügt über ein dreidimensionales Modell, das mit einem abstrahierten zweidimensionalen Graphen des Systems verbunden ist, sowie eine Visualisierung des zugehörigen visuellen Feldes. Dies ermöglicht die Simulation der Auswirkungen von Läsionen auf die menschliche Sicht. Die realistische Modellierung der anatomischen Strukturen wurde durch die Synthese vorhandener Illustrationen erreicht und bildet somit eine Grundlage für das Verständnis des Systems.

Die Webanwendung, entwickelt mit TypeScript, D3.js und Three.js, bietet eine ansprechende Benutzeroberfläche, die eine intuitive Interaktion ermöglicht. Benutzer können zwischen den zweidimensionalen und dreidimensionalen Ansichten navigieren und Läsionen erstellen, um Defizite im visuellen Feld und pathologische Effekte zu beobachten.

Durch die Verbindung von anatomischem Realismus, interaktiven Visualisierungen und Läsionssimulationen schlägt das Projekt eine Brücke zwischen Theorie und praktischem Einblick. Die Anwendung stellt ein intuitives Bildungsinstrument dar, das das Verständnis für die Komplexität des visuellen Systems vertieft.

Die Arbeit umfasst anatomische Modellierung, Softwareentwicklung und Visualisierungstheorie. Die entwickelte Webanwendung birgt großes Potenzial für Bildung, medizinische Illustration und Forschung. Sie bietet eine intuitive Plattform für Studierende, medizinisches Fachpersonal und Forscher, um die Feinheiten des menschlichen visuellen Systems und seiner damit verbundenen Störungen zu erforschen und zu verstehen.

Abstract

This thesis introduces an interactive web application to explore the human visual pathway's complexities. The software features a three-dimensional model linked to an abstracted two-dimensional graph representing the pathway as well as a visualization of its associated visual field, allowing the simulation of the impact of lesions on human vision. The modeling of the realistic anatomical structures was achieved by synthesizing existing illustrations, forming a foundation for pathway understanding.

The web app, built with TypeScript, D3.js, and Three.js, offers an engaging interface enabling intuitive interaction. Users can navigate the two-dimensional and three-dimensional views and create lesions to observe visual field deficits and pathology effects.

By uniting anatomical realism, interactive visuals, and lesion simulations, the project bridges theory and practical insight. The app provides an intuitive educational tool, deepening comprehension of the visual system's complexity.

The thesis covers anatomical modeling, software development, and visualization theory. The developed web application holds significant potential for education, medical illustration, and research, offering an intuitive platform for students, medical professionals, and researchers to explore and comprehend the intricacies of the human visual pathway and its related disorders.

Contents

Kurzfassung	vii
Abstract	ix
Contents	xi
1 Introduction	1
2 Related Work	3
2.1 Anatomy of the Human Visual Pathway	3
2.2 3D Models of the Human Visual Pathway	5
2.3 Visual Abstraction	6
3 Design Choices	9
3.1 Realistic Model	10
3.2 Abstracted Model	12
3.3 Interaction	14
3.4 User Interface	16
4 Results	19
4.1 Scenario 1: Lesion simulation in the right optic nerve	19
4.2 Scenario 2: Simulation of a vision loss in the visual field	20
5 Conclusion	23
List of Figures	25
Bibliography	27

Introduction

The human visual pathway is a complex system that enables us to perceive our surrounding world. In this thesis, we propose an innovative approach to explore this pathway by creating a web application featuring an interactive three-dimensional viewport. By additionally offering an abstracted two-dimensional visualization of the pathway and its corresponding visual field, linked with the three-dimensional representation, the application aims to simulate lesions by visualizing their impacts on vision to enhance our understanding of visual defects.

The primary contribution of this thesis was to realistically reconstruct the structures of the human visual pathway by analyzing numerous illustrations and descriptions in the existing literature. By synthesizing and integrating information from diverse sources, we developed our own comprehensive and cohesive interpretation of the true anatomical structure. This anatomically realistic model forms a solid foundation for studying how the visual pathway functions.

To make the study more accessible, a web application was developed using TypeScript, along with visualization libraries like D3.js [d3j23] and Three.js [Thr23]. This interactive tool allows users to explore the visual pathway and understand its two-dimensional representation in a dynamic and engaging way. One of its unique features is the ability to simulate lesions within the pathway, helping users observe the effects on the visual field and study the impact of specific pathologies on vision.

By combining realistic anatomy, interactive visualization, and lesion simulation, this project aims to bridge the gap between theory and practical understanding of the human visual pathway. The web application offers an intuitive and educational experience, empowering users to explore the complexity of the visual system.

This thesis examines the methodology of creating web applications and the theoretical underpinnings of simulating lesions in the human visual pathway. We start by examining research in areas such, as visual abstraction in 2.3, the anatomy of the human visual

pathway in 2.1, and current three-dimensional models of the pathway in 2.2. Following chapters discuss decisions made during the design phase including implementation details in 3, present the results of our investigation in 4 before ultimately concluding our work in 5.

In conclusion, this thesis contributes significantly to visual neuroscience by providing an immersive and interactive tool to study the human visual pathway. The ability to explore anatomical structures, understand their functions, and simulate the effects of lesions offers a comprehensive examination of this critical system. Through this work, we hope to enhance our understanding of human vision and inspire further research and advancements in the field.

Related Work

2.1 Anatomy of the Human Visual Pathway

The visual pathway is a system that plays a vital role in processing visual information from the optic nerves in our eyes to the visual cortex in our forebrain, by forwarding this information in the form of nerve impulses [Bor23]. Understanding the structure of this pathway holds importance in fields, like neuroscience and ophthalmology. In this chapter, we delve into the anatomy of the pathway and examine how its retinotopic organization significantly influences our perception of vision.

The human visual pathway, as detailed by Joukal [Jou17], starts with about one million axons in the optic nerve, comprising nearly 40% of all cranial nerves' axons. The retina consists of millions of rods and cones and is responsible for detecting information. These cells act as sensors for sight. When light waves enter the eye they are converted into changes in membrane potential, by cells called photoreceptors. This conversion happens through the release of a chemical called glutamate. The processed information is then transmitted from these cells to the bipolar cells and eventually to a group of nerve cells called retinal ganglion cells within the retina. The axons of these ganglion cells transit the nerve with some axons crossing over at a point called the optic chiasm. These nerve fibers create the optic tract, reaching the lateral geniculate body in the thalamus. Starting at this point, neurons within the lateral geniculate body project their axons via the optic radiation, concluding in the primary visual cortex situated in the occipital lobe. The initial analysis of visual information occurs in the primary visual cortex before subsequent processing occurs in additional visual areas found in the occipital, parietal, and temporal lobes. Figure 2.1 shows a representation of the visual pathway from the referenced work from Joukal.

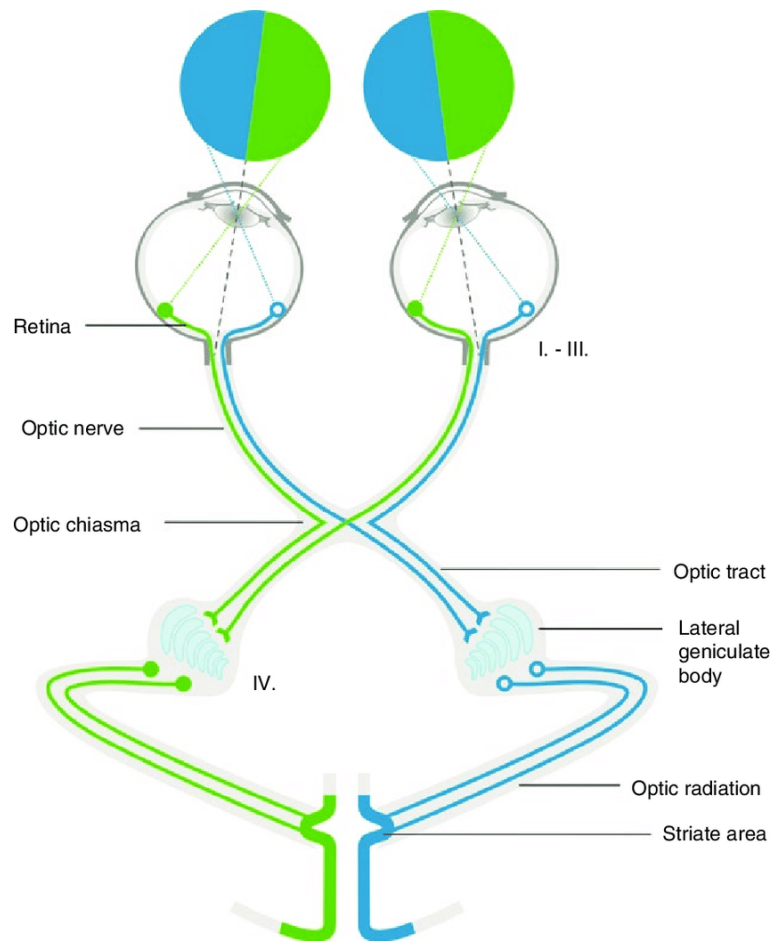
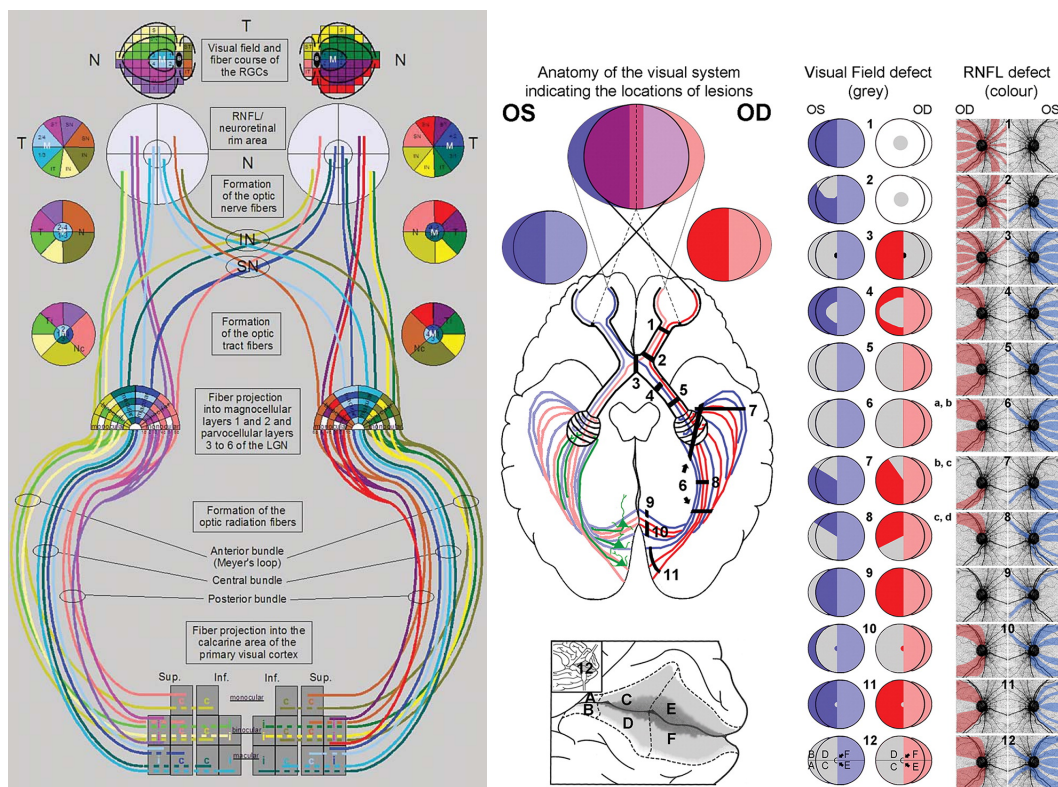


Figure 2.1: Schematic drawing of the visual pathway and its neuronal composition [Jou17]

O’Leary et al. [OM05] authored a paper detailing the processes involved in the development of "retinotopic maps," which establish a correspondence between locations in the visual field and specific points within the brain. Neighboring points in the visual field are processed by neighboring neurons in the visual pathway, leading to an ordered representation of the visual world in the brain. This anatomical arrangement plays a crucial role in our visual perception and can explain symptoms that arise when any part of the optic pathway is damaged. Understanding this retinotopic organization is essential for researchers to accurately pinpoint the location of damage based on specific visual symptoms which forms the main focus of the software being developed for this bachelor thesis.

In their article Warntgas and Michelson [WM13] offer insights into how the human visual pathway is represented in detail. They provide a visualization, shown in Figure 2.2a that combines multiple partial graphics, including crosscuts and the visual field, aiding in understanding the correspondence to multiple fibers. Their research serves as a reference, for our project as we create a graph based on their findings.



(a) Visual pathway with crosscuts and the resulting visual field [WM13] (b) Visual field deficits for lesions located in the visual pathway [ZWK⁺17]

Figure 2.2: Illustrations of the visual pathway and its retinotopic mapping

Additionally, Zangerl et al. [ZWK⁺17] reviewed thousands of patient records with lesions along the visual pathway. Their study aimed to enhance our comprehension the correlation between visual field impairments and patterns within the retinal nerve fiber layer in the context of retrograde degeneration, facilitating consistent predictions of visual deficits resulting from different lesions in the visual pathway.

2.2 3D Models of the Human Visual Pathway

Dixit and Dascalu, have skillfully constructed an extensive three-dimensional model depicting the human visual pathway, as detailed in their referenced work [DD19]. This representation that can be seen in Figure 2.3 uses only four different colors to subdivide the visual field.

The inferior pathway comprises a mere four fibers per side; however, it remarkably diverges into a richly detailed optic radiation, giving rise to a multitude of fibers that navigate their way into the expanse of the visual cortex with precision. This model is accessible through an interactive web application, providing users with a seamless ability

to navigate its architecture. Significantly, this application refrains from incorporating a lesion simulation component, thereby ensuring an undistracted exploration of the model's structural complexities.

While a multitude of three-dimensional models depicting the visual pathway are available on the internet, our search did not uncover any applications that offer an interactive platform for simulating lesions while simultaneously visualizing the resulting visual impairments.

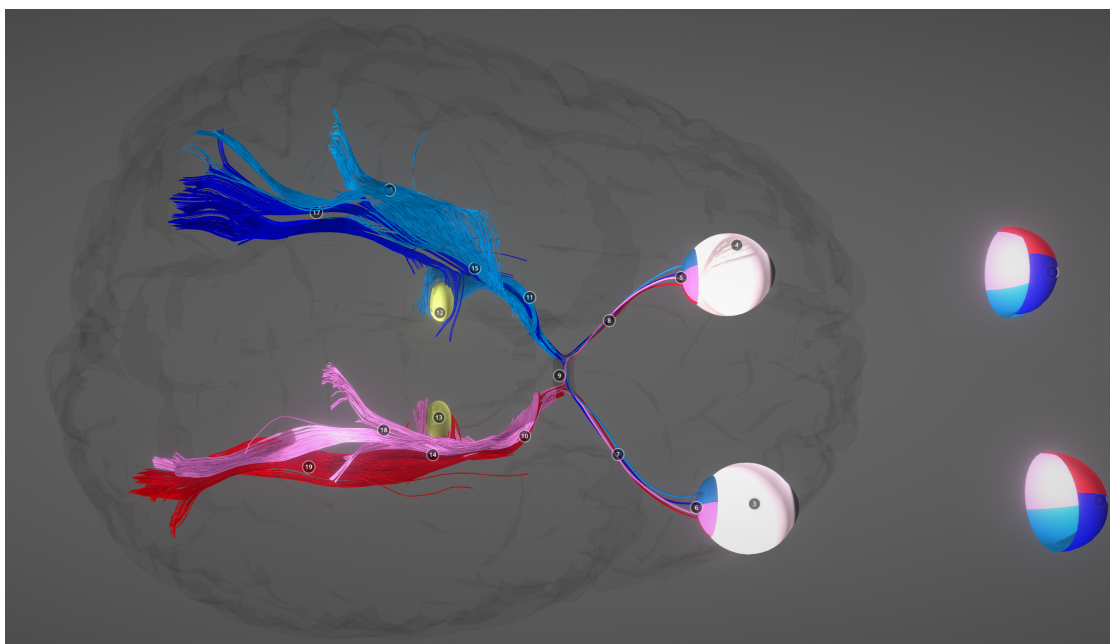


Figure 2.3: Three-dimensional model of the human visual pathway [DD19]

2.3 Visual Abstraction

According to one of the definitions by Viola et al., "A meaningful visual abstraction is a visual abstraction such that, for a given point-of-view and for a given purpose or goal, key aspects of the underlying referent thing are preserved in the visual representation so that the cognitive load when perceiving it as a stimulus is significantly reduced." [VCI20, p.2]

In order to enable an easily understandable representation with intuitive interaction, the complexity of the anatomical structures of the human visual pathway has to be reduced. This chapter delves into different methods for abstracting and simplifying intricate anatomical structures.

The Kyoto Encyclopedia of Genes and Genomes (KEGG) [Kan23] serves as an illustrative example. Although KEGG is a database containing hand-drawn pathway maps focusing on genetics and molecular biology, its visualization techniques can provide insights for

developing representations that allow studying interactions, reactions, and relationships within complex systems such as the human visual pathway.

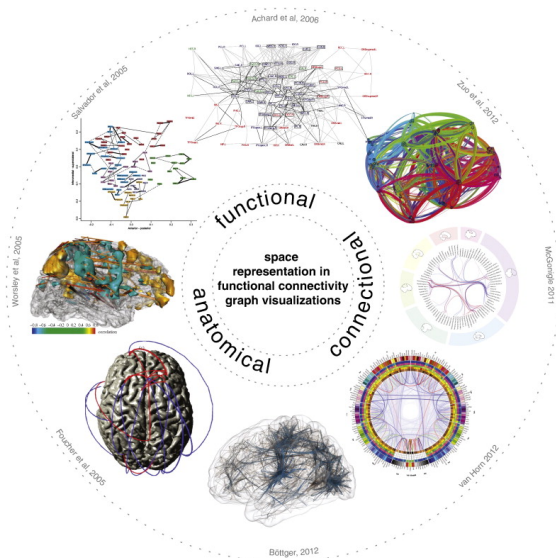


Figure 2.4: Representation of space in functional connectivity graph visualizations [MBWG13]

Moving into the realm of neural connections, Margulies et al. [MBWG13] present a method for visualizing the human connectome — a comprehensive neural connection map. Their exploration of spatial representation within functional connectivity graph visualizations informs our approach to depicting intricate networks, much like the human visual pathway. As illustrated in Figure 2.4, selecting visualizations for connected functional connectivity graphs, akin to those of the human visual pathway in this study, hinges on the intended purpose, necessitating prioritization of functional, connectional, or anatomical aspects.

Another notable illustration stems from the Circos visualization tool [KSB⁺09] which was originally developed by Martin Krzywinski et al. at the Genome Sciences Center in Vancouver with the intention of aiding in cancer research. It generates an ideogram layout that visually represents relationships between elements by using ribbons to visualize information such as position, size, and orientation. Beyond its original purpose, this method proves adaptable for depicting connections among elements and elucidating the complexities of the human visual pathway.

Furthering our exploration, Miao et al.’s work [MMNG16] stands as a significant exemplar in standardized anatomical visualization of cerebral vasculature. Focusing on the Circle of Willis (CoW), a critical brain arterial structure, their automated approach not only visualizes CoW’s configuration but also supports direct patient comparisons. Their integration of advanced imaging and visualization techniques exemplifies the potential of combining 3D and 2D representations to depict intricate vascular structures. This emphasis aligns aptly with our study’s objective—visualizing the human visual pathway

2. RELATED WORK

and interactively simulating lesions within a unified application. The CoW visualization technique introduced in their work serves as a fitting reference, given its prowess in representing intricate anatomical details, in harmony with our overarching aim of anatomical visualization. A screenshot of their user interface can be seen in Figure 2.5.

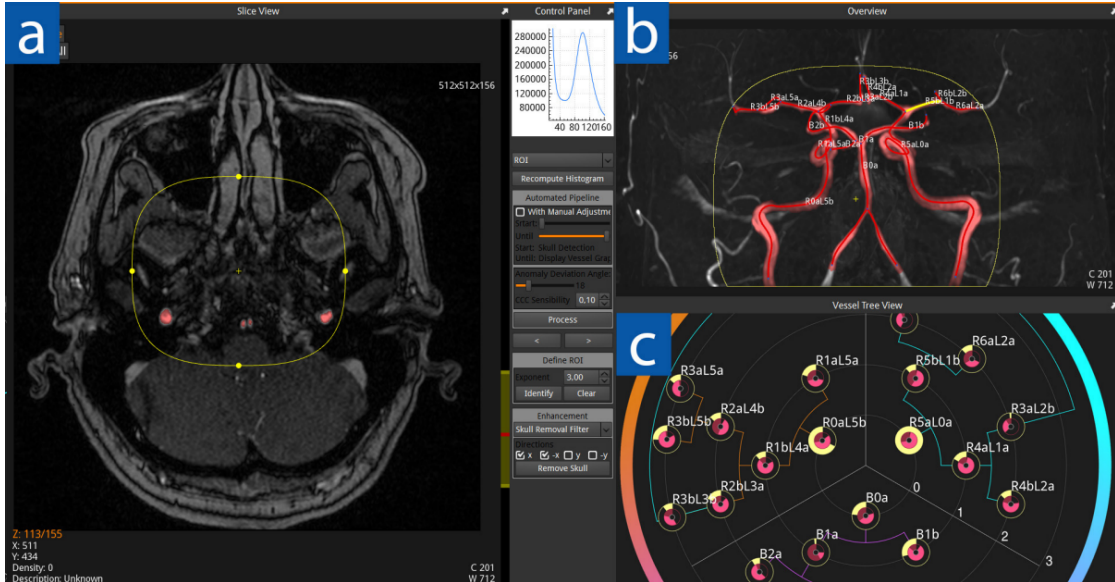


Figure 2.5: Screenshot of the graphical user interface developed by Miao et al. [MMNG16] (a) displays a multi-axial slice view. (b) displays a 3D MIP with the vessel graph overlay. (c) shows the corresponding CoWRadar.

Design Choices

The developed web application consists of two representations of the human visual pathway: an abstracted two-dimensional curve graph (Figure 3.1a) and a realistic three-dimensional model (Figure 3.1b). The abstracted graph includes curves for the fibers, arcs for the crosscuts as well as multiple squares representing areas of the human visual field. The named elements can be clicked with the mouse to create and delete a lesion on the fiber or a loss of sight of a specific area in the visual field. Lesions are immediately presented to the user by changing the color of all corresponding shapes, as well as the matching parts of the three-dimensional model, to black. Those two models of the human visual pathway function as a dualistic model, as all changes of one fiber are reflected on all other representations of this specific fiber in real-time. The models permit the users to create lesions and see their effect interactively as described in the interaction section 3.3.

When creating the abstracted two-dimensional graph representing the human visual pathway our main focus was to enhance interaction by ensuring the clear distinguishability of all fibers. We prioritized the functional and connectional aspects while somewhat disregarding strict anatomical accuracy. The goal was to facilitate ease of hovering or clicking on specific curves for improved user experience. Redundant information was intentionally omitted to avoid overstimulating the user's perception.

On the other hand, when developing the three-dimensional model, our primary objective was to achieve anatomical correctness as accurately as possible. We aimed to represent the visual pathway in a realistic manner to provide users with a comprehensive understanding of its anatomical structure. While we still aimed to avoid unnecessary details, we ensured that the essential anatomical features were present to convey an accurate representation.

Overall, both representations were tailored to optimize their respective purposes while maintaining usability and clarity.

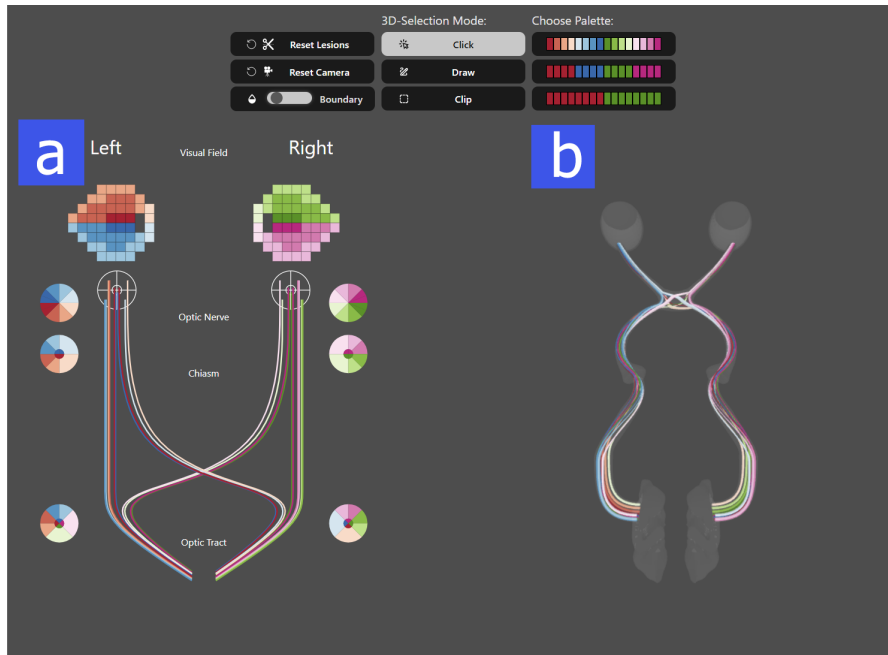


Figure 3.1: Screenshot of the graphical user interface. (a) abstracted two-dimensional SVG graph including visual field. (b) three-dimensional viewport with the model.

3.1 Realistic Model

Modeling the realistic model constituted a significant aspect of this project. Given the considerable diversity in the comprehension of fiber distribution in the human visual pathway documented across various studies, multiple feedback iterations were undertaken in collaboration with the project advisor, Assistant Professor Renata Raidou, and Dr. Berthold Pemp, a neuro-ophthalmologist from the Medical University of Vienna involved in this bachelor thesis.

For the purpose of abstraction, eight fibers per eye were used to represent the human visual pathway, extending from the eyeballs (Figure 3.2a) to the visual cortex of the brain (Figure 3.2c). These fibers initially traverse the optic nerves and converge at the optic chiasm (Figure 3.2b), where solely the nasal fibers cross over before proceeding through the optic tract and the optic radiation to enter the visual cortex. Notably, the fibers originating from the macular region split at the optic chiasm, resulting in two distinct fibers, one crossing and one non-crossing. Consequently, the posterior pathway comprises a total of ten fibers per side, unlike the inferior visual pathway which retains only eight fibers.

A critical aspect of our work was in accurately representing the optic chiasm. This step posed a challenge due to varying depictions in existing literature, particularly regarding the concept of "Wilbrand knees" [SQH⁺14]. Dr. Berthold Pemp provided insightful feedback that clarified this matter. He explained that the notion of "Wilbrand knees"

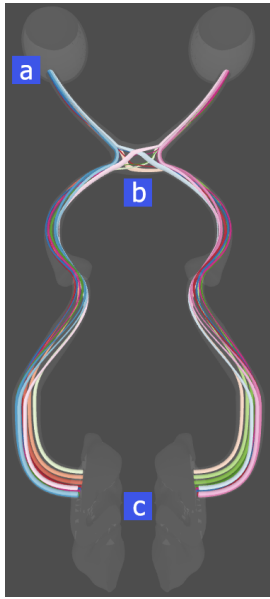


Figure 3.2: Realistic 3D-model of the pathway. (a) eye balls and starting point of the optic nerve. (b) optic chiasm. (c) visual cortex.

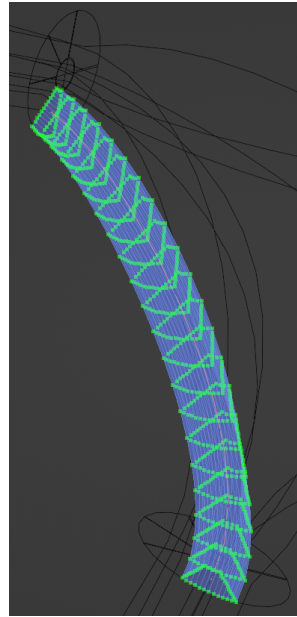


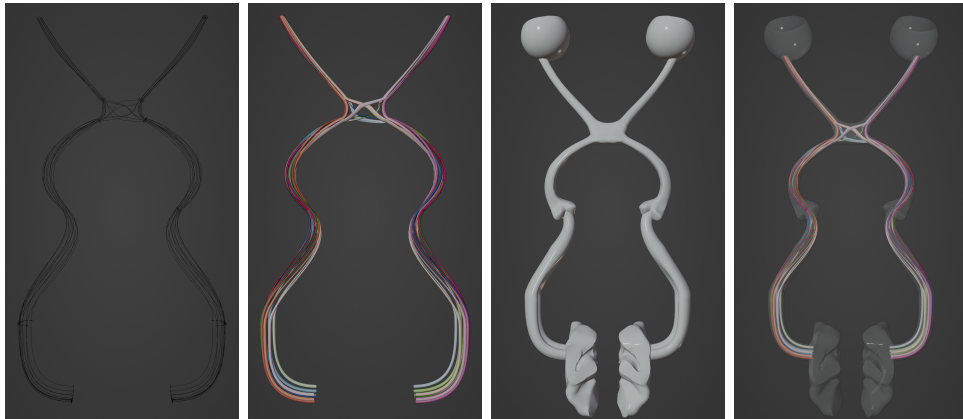
Figure 3.3: Mesh generation using curve-to-mesh add-on [Mar23] with sweep- and profile curves

is based on misconceptions from earlier anatomical studies. In reality, the structure is smoother and lacks clear divisions. This feedback guided us in creating a more accurate representation of the optic chiasm.

To aid in understanding the anatomical layout, we also modeled a transparent boundary object, which can be seen in Figure 3.4c. This surrounding mesh was constructed by connecting multiple anatomical models acquired from a free-to-use database [Lif23]. This helped in visualizing how different parts of the visual pathway are connected.

The modeling process was accomplished in Blender [ble23] by using multiple Bezier curves [Dun05] to generate the mesh with the "Curves To Mesh" add-on [Mar23], developed by Mark Kingsnorth. Each fiber was constructed using a single Bezier curve as the sweep curve. The sweep curve serves as a guiding path along which the shape is extruded or "swept" to form a new three-dimensional structure as depicted in Figure 3.3. This process involves taking one or multiple two-dimensional curves and moving them along the path defined by the sweep curve. As the profile curve moves along the sweep curve, it generates new points in space, creating a mesh that follows the path of the sweep curve. We used six profile curves per fiber to define the desired shape at various cross-sections. By adjusting parameters such as the number of subdivisions, the mesh generation process ensured an evenly distributed vertex arrangement. The add-on's algorithm smoothly interpolated the profile curves to ensure a seamless transition in the shape of the fiber. However, challenges were encountered in ensuring that the meshes do not intersect while avoiding the creation of unrealistic gaps between them.

Figure 3.4 displays model screenshots at different stages in Blender, while Figure 3.4a showcases the defining Bezier curves for mesh shaping. To generate the mesh of a single fiber, the "Curves To Mesh" add-on takes a curve as sweep curve as well as a collection of multiple curves as profile curves defining the fibers' crosscuts at various positions. The primary aspect of the modeling process involved creating meshes for multiple fibers, ensuring these meshes did not intersect with others and were free from artifacts or unnecessary gaps. Subsequently, adjustments were made to the curves before regenerating the meshes. The final mesh with assigned materials is depicted in Figure 3.4b. Anatomic models from the database were connected to form the boundary mesh in Figure 3.4c. For the presentation of the generated fibers within the boundary mesh, a transparent material was assigned to the surrounding object. This final depiction closely resembles the final models visualized in the software, as illustrated in Figure 3.4d.



(a) Sweep- and profile curves (b) Generated mesh (c) Boundary model (d) Combined model

Figure 3.4: Modelling of the visual pathway in blender

All the fiber meshes were exported as a single .obj file, excluding material information. The Three.js library [Thr23] was employed to load and display the .obj files in the three-dimensional viewport. After loading the models the materials were assigned as Phong materials with the option to select from three different color palettes. To facilitate viewport navigation the application utilized the OrbitControls feature also provided by the Three.js library.

3.2 Abstracted Model

The process of crafting the abstracted model was marked by careful consideration aimed at achieving the objective of enhancing the visualization of the human visual pathway while ensuring its comprehensibility through a simplified two-dimensional graph. This chapter explores the thoughtful design choices that contributed to shaping the final representation which can be seen in Figure 3.1a.

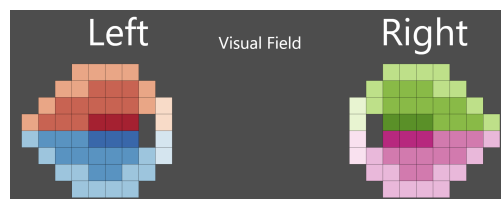
Drawing inspiration from a wide range of visualization techniques and visual abstractions, an extensive exploration of authoritative sources within the field was undertaken. The insights gathered from these sources, as discussed in chapter 2.3, laid the groundwork for informed decision-making.

The final outcome of these insights materialized in the form of an interactive SVG (Scalable Vector Graphics) graph, thoughtfully fashioned using the D3.js library [d3j23] — a highly regarded tool for creating interactive data visualizations. This choice was motivated by a dual purpose: to ensure user engagement through interactivity and to guarantee the adaptability of the visualization across diverse screen sizes.

Ten cubic basic splines per eye with five control points each were used to abstract the fiber distribution in two dimensions. Those smooth curves follow the neural fibers, guiding the viewer’s gaze along the complex path that visual stimuli follow. Circles with multiple arcs inside represent crosscuts within the pathway acting as focal points that reveal the interwoven nature of the visual pathway.

Additionally, squares within each eye’s domain add depth to the visualization (Figure 3.5). Positioned purposefully, these squares offer windows into the visual field, each one mapped to a specific area within the neural architecture. This design choice enhances user understanding by providing relatable reference points. This approach of dividing the visual field into squares differs from the use of subdivided circles in other visualizations. The decision to use squares was driven by their clarity and precision, making it easier for users to identify and select specific areas of interest.

The user is able to interact with all of the named elements as described in section 3.3. Altogether the abstracted model is very similar to the illustration from Wärntgas and Michelson’s [WM13] which can be seen in Figure 2.2a.



(a) Visual field



(b) Visual field with deficits indicated with black squares

Figure 3.5: Visual field

3.3 Interaction

The software developed for this thesis offers intuitive user interaction, allowing users to explore and simulate lesions within the human visual pathway. The interaction with the software involves several actions, enabling the creation and removal of lesions in both the two-dimensional SVG graph and the three-dimensional model.

In the simplified two-dimensional graph, users have the ability to create lesions by clicking on the squares that represent specific areas in the visual field (Figure 3.6a). This action causes the corresponding fibers to turn black in both the two-dimensional graph and the three-dimensional model. Furthermore, it also affects the arcs in the crosscuts associated with those selected fibers. If users click on these squares again, they can remove the lesions and restore the original color and functionality of those fibers. Additionally, users can interact with the simplified two-dimensional SVG graph by clicking on curves that represent different fibers of the visual pathway (Figure 3.6b). By selecting these curves, users can create lesions that are visually indicated in both the two-dimensional graph and the three-dimensional model. The arcs in crosscuts associated with these affected fibers also reflect these lesions when selected (Figure 3.6c). Special hover effects are applied to all designated components within the SVG graph. When hovered over, squares representing areas of the visual field change color to a subtle shade of grey. Similarly, arcs present in crosscuts expand their radius while curves representing fibers increase their stroke weight, resulting in a more prominent appearance with bolder lines.

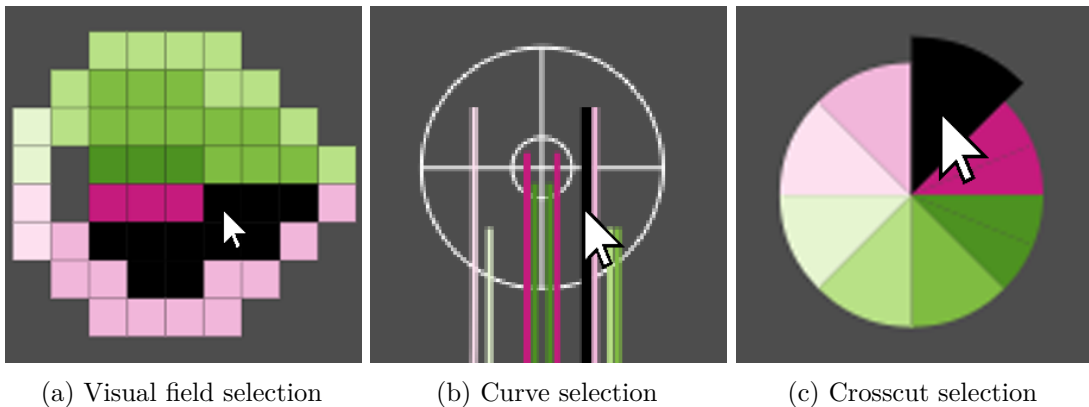
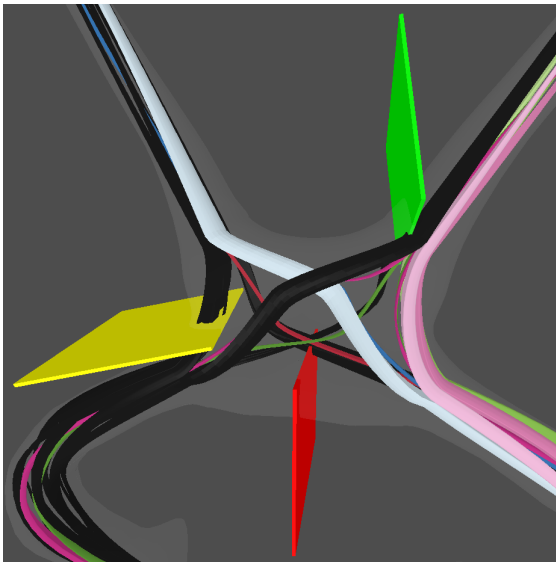


Figure 3.6: Interaction with the SVG graph

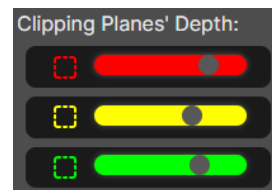
The user interaction extends beyond the abstracted two-dimensional SVG-graph by also enabling direct interaction with the three-dimensional model. Three different selection modes for creating lesions within the viewport were implemented using the raycaster functionality from the Three.js library:

- The "click" mode allows the user to create a lesion on the first fiber intersecting the ray if the left mouse button is clicked.

- The "draw" mode enables the user to create lesions on multiple objects intersecting the ray (excluding the boundary mesh) by continuously holding down the left mouse button.
- The "clip" mode (Figure 3.7) involves instantiating a plane at the first intersection point instead of creating a lesion directly on the intersected fiber. This plane was then utilized to identify all fibers intersecting it and subsequently create lesions on those fibers. In order to identify all fibers that intersect, a grid-like arrangement of 80 rays is cast across the plane. When the plane is instantiated, a user interface element appears, showing the plane index and providing a slider to adjust the plane's depth (local z -coordinate), allowing users to customize the lesion's impact (Figure 3.7b). Remarkably, any lesions resulting from the cutting planes remain irreparable through alternative selection modes or clicking on the corresponding shapes in the two-dimensional representation, as long as the cutting plane continues to intersect with those fibers.



(a) Three clipping planes affecting fibers in the optic chiasm



(b) Sliders to adjust the planes' depth

Figure 3.7: Selection mode "clip"

The creation of a lesion was implemented by storing all affected fibers in an array and setting the color of all corresponding fibers, curves, squares, and arcs to black. This enables the identification of the lesions in all implemented visualizations of the visual pathway and the visual field.

The developed software employs the principles of focusing and linking [BMMS91] to enable an interactive and comprehensive data visualization experience for the user. By integrating these principles, the user interface achieves a delicate balance between

simplicity and functionality. Focusing techniques, such as zooming on specific parts of the model or using single crosscuts in the graph, allow users to narrow their focus and delve into specific areas of the visual pathway. The linking aspect ensures that the selected data points in one view are highlighted or correlated in other views simultaneously, facilitating the understanding of relationships and patterns across different dimensions of the dataset. The software enables users to create lesions by selecting elements in one representation, leading to synchronized visual cues in both graphical dimensions. This seamless coordination between multiple views provides users with a coherent image of the entire anatomy of the human visual pathway.

To facilitate viewport navigation, the application utilized the OrbitControls feature, provided by the Three.js library. Because lesion creation is triggered by a click on the left mouse button, camera control can be accomplished without employing this button to prevent unintended lesion generation. Rotating the camera involves dragging the mouse while simultaneously clicking the right mouse button. Panning, which entails moving the camera and its rotation center, necessitates holding down the right mouse button while also pressing the shift button and then moving the mouse. Zooming happens naturally by using the mouse wheel. On touch screen devices, camera rotation is executed by swiping a single finger, panning requires a swipe of two fingers, and zooming is achieved by moving two fingers closer together or farther apart, mimicking the functionality found in most applications.

By incorporating these interactive features, users can simulate lesions within the visual pathway, gaining insights into the effects of these lesions on the visual field and the associated fibers. This interactive environment enhances the educational value of the software, enabling users to explore and understand the consequences of specific lesions within the human visual pathway.

3.4 User Interface

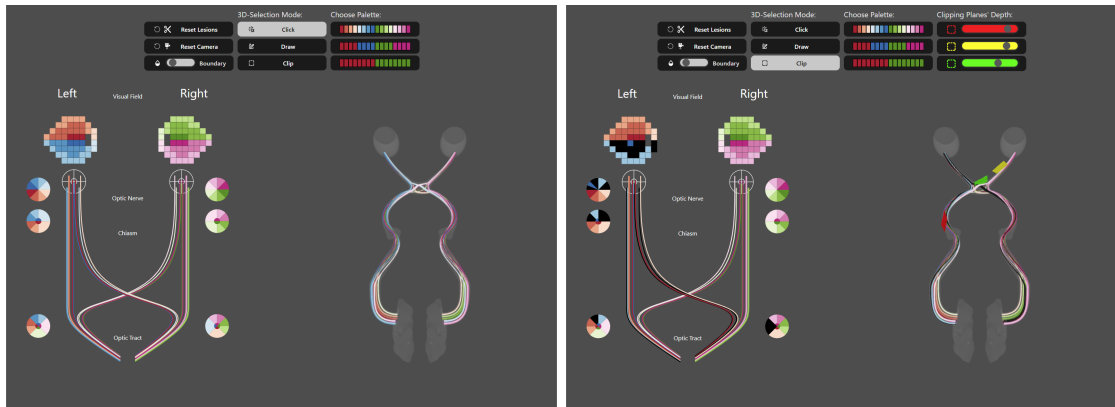
The software interface developed for this bachelor thesis is designed to offer simplicity and an effective overview, while also enabling detailed selections in both the three-dimensional viewport and the two-dimensional graph. The layout of the interface scales responsively with the user's screen size and consists of several components:

- **Interactive SVG Graph:** Positioned on the left side, this graph presents an abstracted model of the pathway, including crosscuts and the visual field. Users can interact with this graph.
- **Three-dimensional Viewport:** On the right side, there is a three-dimensional viewport displaying the three-dimensional model of the pathway. Users can manipulate and explore the three-dimensional model here.
- **Top-Section:** Positioned above the three-dimensional viewport, there are multiple buttons and sliders with different functionalities:

- Reset Lesions Button: When clicked, this button resets all lesions and deletes associated lesion boxes while maintaining the current camera rotation in the viewport.
- Reset Camera Button: This button resets the position and rotation of the camera.
- Boundary Opacity Slider: This slider allows the user to control the opacity of the boundary mesh.
- Three-dimensional-Selection Mode: Users can choose between three different selection modes for interacting with the three-dimensional model.
- Color Palettes: Three buttons with different color palettes are provided. Clicking on any of these buttons allows users to choose a specific palette for the colors of the three-dimensional model, abstracted graph, crosscuts, and visual field. The first color palette with 16 different colors was chosen from a website called "colorbrewer2" [col23] by selecting a diverging and colorblind-friendly color scheme for each eye. The other two palettes utilize a subset of colors derived from the first palette.
- Clipping Planes' Depth Slider: If the "clip" selection mode is enabled clicking on the model will create a plane to cut the fibers. A slider appears next to the buttons allowing users to adjust the local z-coordinate (depth) of the plane.

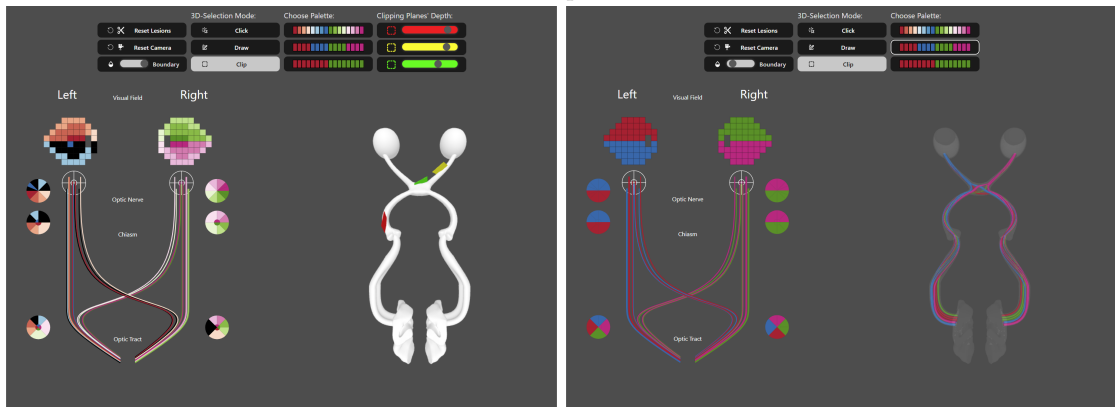
The user interface aims to strike a balance between ease of use and providing users with comprehensive control and visualization options to explore the pathway data effectively. Figure 3.8 shows multiple screenshots of the user interface of different states of the software.

3. DESIGN CHOICES



(a) User Interface after the page was loaded

(b) User interface after instantiating 3 clipping planes



(c) User interface with opaque boundary

(d) User interface with changed colors

Figure 3.8: User interface

Results

This chapter thoroughly examines the different methods through which users can interact with the software's features. Additionally, it provides distinct user interaction scenarios that showcase its flexibility. These examples illustrate how individuals with diverse interests can make optimal use of the software. Figures 4.1 and 4.2 show screenshots of the user interface in different states of each scenario.

4.1 Scenario 1: Lesion simulation in the right optic nerve

In the first scenario, we delve into the perspective of a student aiming to enhance their comprehension of the human visual pathway's functionality. Through the creation of a simulated lesion within the 3D model, this student can effectively observe resultant visual deficits on a two-dimensional representation of the visual field. For this example, the user wants to create a lesion in the right optic nerve to analyze its function.

To simulate a lesion for all fibers in the right optic nerve, the user decides to use the "clip" selection mode (Figure 4.1a). A click on a fiber instantiates a clipping plane on the position of the fiber (Figure 4.1b). The depth of the instantiated plane can be adjusted using the corresponding slider (Figure 4.1c). Now, as the plane is positioned correctly, the user can observe the resulting deficits in the visual field and also analyze what fibers are affected by looking for fibers colored in black in all representations (Figure 4.1d). The student understands that cutting the optic nerve on one side only causes visual impairments of the visual field of the same side.

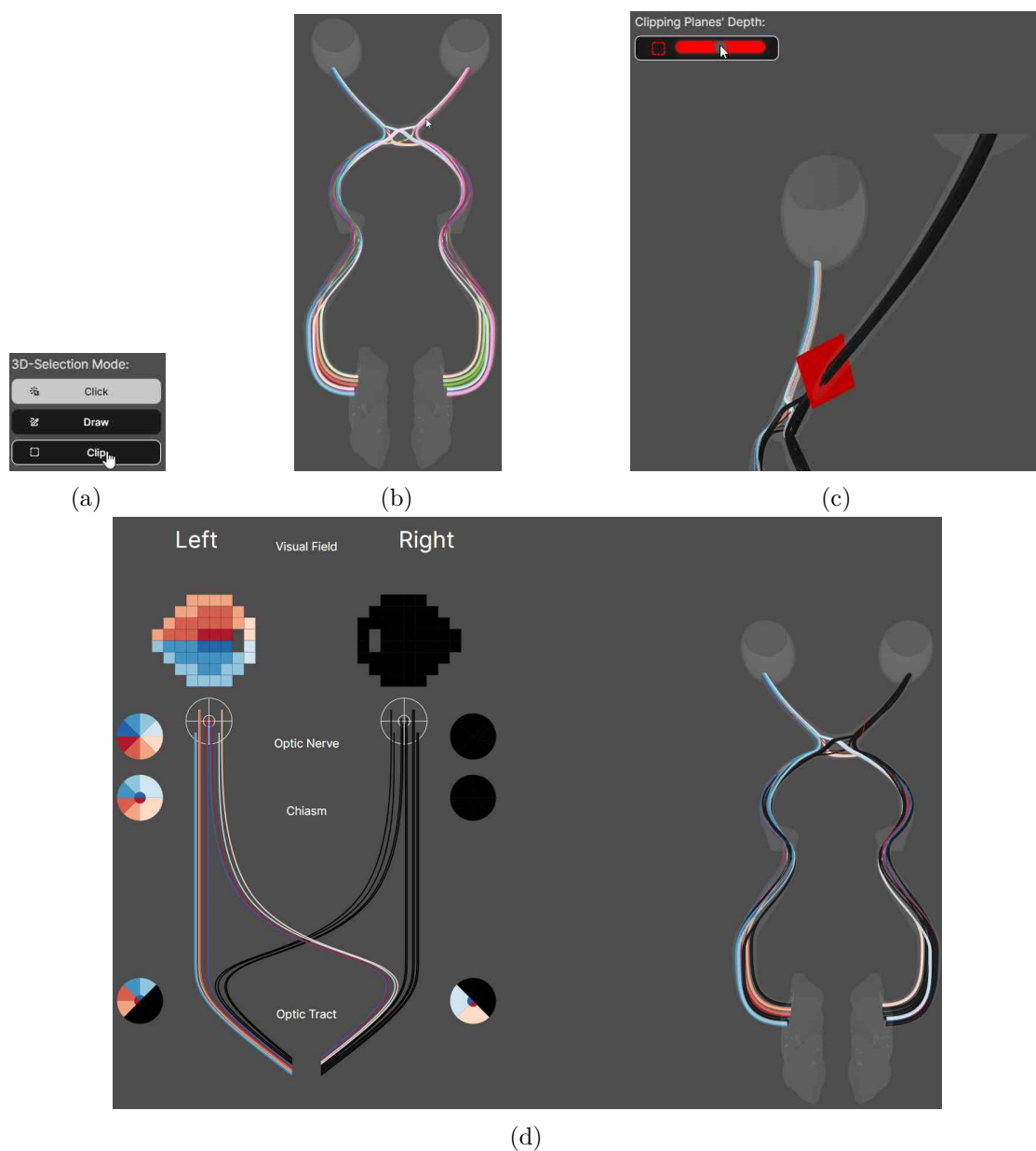


Figure 4.1: Scenario 1: Lesion simulation in the right optic nerve

4.2 Scenario 2: Simulation of a vision loss in the visual field

In the second scenario, a user with a different objective employs the software to pinpoint the fibers associated with specific visual deficits. Through a user-friendly interface, this individual designates areas of the visual field to induce deficits and subsequently observes

the corresponding affected fibers. This approach empowers users to make informed assumptions about the lesion locations responsible for the chosen visual impairments.

To create visual defects the user simply clicks on specific areas in the visual field, for example, temporal areas of the left field and nasal areas of the right field (Figure 4.2a). Now the user can find the corresponding fibers that are involved in the perception of the chosen areas of the visual field. Those fibers are colored black in all representations. (Figure 4.2b) To enhance the understanding of the visual pathway, the user can also remove some lesions by either clicking on the black fibers or on the selected areas in the visual field. Figure 4.2c shows the two representations after removing the lesions from the two lower fibers of the left optic radiation. Those fibers correspond to the upper temporal area of the visual field of the left eye and the upper nasal area of the visual field of the right eye. To explore the effect on vision, the user wants to set additional lesions to all fibers that correspond to the right half of the first crosscut of the left optic nerve. After simply clicking on the arcs, the corresponding visual field and fibers are colored black (Figure 4.2d).

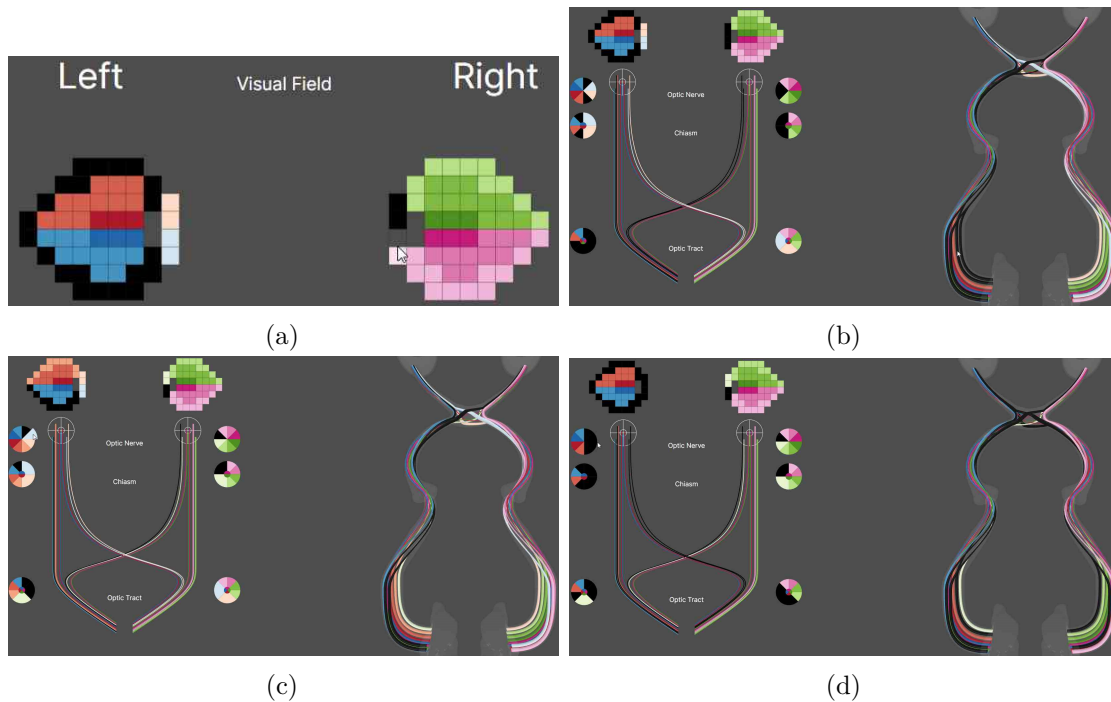


Figure 4.2: Scenario 2: Simulation of a vision loss in the visual field

These different interaction scenarios together show the versatility of the software to respond to the different needs of the users and to help in understanding the anatomical bases of visual defects.



Conclusion

The primary objective of this thesis was to create an interactive web application, available at <https://visual-pathway.sebastianantes.at/> that faithfully represents the human visual pathway, allowing users to explore its anatomical structures, understand its functions and simulate the effects of lesions. In this chapter we present the results obtained from the development and utilization of the web application, discuss the significance of the findings and consider potential implications.

To realistically reconstruct the structures of the human visual pathway, an analysis of existing illustrations and descriptions was conducted. By synthesizing information from diverse sources, we successfully developed a comprehensive interpretation of the true anatomical structure of the visual pathway. The realistic model served as the foundation for the subsequent stages of the project.

The creation of the interactive web application was a multi-faceted endeavor involving the integration of various technologies. TypeScript, D3.js, and Three.js were utilized to provide an engaging and dynamic interface for users to explore the visual pathway. The application enables users to navigate through the anatomical structures, zoom in to examine finer details and interact with different components of the pathway. The user-friendly design and intuitive controls facilitate an immersive learning experience.

One of the distinctive features of the web application is the capability to simulate lesions within the visual pathway. Users can select specific regions to simulate lesions and observe the resulting effects on the corresponding visual field. This functionality enables users to gain insights into the consequences of various pathologies, enhancing their understanding of how disruptions within the pathway can lead to visual impairments. The simulation aspect provides a unique opportunity for users to explore hypothetical scenarios and visualize the complex relationship between structure and function.

By combining anatomical realism, interactive visualization, and lesion simulation the web application successfully bridges the gap between theoretical knowledge and practical

5. CONCLUSION

understanding of the human visual pathway. Users can engage with the pathway's details in a way that goes beyond traditional static illustrations or textual descriptions. This approach encourages active learning and empowers users to grasp the complexity of the visual system more comprehensively.

The developed web application holds significant potential across various domains. In education, it can serve as a valuable teaching tool for students studying visual neuroscience and related fields. Additionally, it could aid medical professionals in explaining visual impairments to patients by visually demonstrating the impact of different pathologies. Moreover, researchers can utilize the application to test hypotheses and explore novel avenues of investigation related to visual processing and its disorders.

In conclusion, this thesis has successfully realized an innovative approach to studying the human visual pathway through the development of an interactive web application. The project contributes to visual neuroscience by offering an immersive and educational experience that deepens our understanding of human vision and paves the way for further advancements in the field.

List of Figures

2.1	Schematic drawing of the visual pathway and its neuronal composition [Jou17]	4
2.2	Illustrations of the visual pathway and its retinotopic mapping	5
2.3	Three-dimensional model of the human visual pathway [DD19]	6
2.4	Representation of space in functional connectivity graph visualizations [MBWG13]	7
2.5	Screenshot of the graphical user interface developed by Miao et al. [MMNG16]	8
3.1	User interface with annotations	10
3.2	Realistic 3D-model of the pathway	11
3.3	Mesh generation using curve-to-mesh add-on [Mar23] with sweep- and profile curves	11
3.4	Modelling of the visual pathway in blender	12
3.5	Visual field	13
3.6	Interaction with the SVG graph	14
3.7	Selection mode "clip"	15
3.8	User interface	18
4.1	Scenario 1: Lesion simulation in the right optic nerve	20
4.2	Scenario 2: Simulation of a vision loss in the visual field	21

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