3D Visualization and Simulation of the Human Navigation System

Henrik Hjelle

NTNU
Norwegian University of Science and Technology

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Author:
Henrik HJELLE

Supervisor:
Dr. Ekaterina
PRASOLOVA-FØRLAND

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Abstract

The aim of this thesis is to investigate how 3D visualizations and virtual reality can be used to make the human navigation system understandable for the general public.

To do this, a 3D visualization of the human navigation systems components in the brain was created using Second Life. In addition, a simulation of how the cells in this system works was created with the same platform. These two visualizations were used to see if they gave any learning outcome in relation to the human navigation system to a set of evaluation participants from the general public.

The evaluation was divided between a qualitative and a quantitative part, where participants conducted both the visualization and the simulation. After the conduction, they answered on some questions from a questionnaire or through an interview.

The results in this thesis is based on these evaluations. The results show that both the visualization and the simulation does contribute in giving the general public an understanding of the human navigation system.

Based on the experiences and lessons learned though the project, a nine point recommendation for creating educational 3D visualizations for the general public was created.

Abstrakt (norsk)

Målet med denne oppgaven er å undersøke hvordan 3D-visualiseringer og virtuell virkelighet kan brukes til å gjøre det menneskelige navigasjonssystemet forståelig for allmennheten.

For å gjøre dette ble en 3D-visualisering av det menneskelige navigasjonssystemeet og dets komponenter i hjernen laget ved hjelp av Second Life. I tillegg ble en simulering av hvordan cellene i dette systemet fungerer laget med samme plattform. Disse to visualiseringene ble brukt for å se om de ga noen læringsutbytte i forhold til det menneskelige navigasjonssystemet til noen evalueringsdeltakere fra allmennheten.

Evalueringen ble delt mellom en kvalitativ og en kvantitativ del, der deltakerne gjennomførte både visualiseringen og simuleringen. Etter gjennomførigen svarte de på noen spørsmål fra et spørreskjema eller intervju.

Resultatene i denne oppgaven er basert på disse evalueringene. Resultatene viser at både visualiseringen og simuleringen bidrar i å gi allmennheten en forståelse av det menneskelige navigasjonssystemet.

Basert på erfaringer fra prosjektet ble en ni punkts anbefaling for hvordan lage pedagogiske 3D visualiseringer for allmennheten laget.

Acknowledgements

I would like to thank my supervisor Ekaterina Prasolova-Førland, who gave me good feedback along the way and gave me a little push when I needed it.

I would like to thank the evaluations participants for giving me useful feedback and the experts at the Kavli Institute for Systems Neuroscience for taking time to evaluate my work.

I would also like to thank my family and friends who have supported me through the this thesis.

Acronyms

HUD - Heads-Up Display

SL - Second Life

HMD - Head-Mounted Display

VW - Virtual World

SME - Subject Matter Experts

HNC - Human Navigation Center, a implementation of the human nvavigation system in Second Life

LI - Land Impact

NTNU - Norwegian University of Science and Technology

HiST - Sør-Trøndelag University College

SP - Specialization Project

Contents

List of Figures

List of Tables

1 Introduction

The first part of this chapter describes the motivation of this project. The second part describes the research questions and learning goals for this project. The third part describes the research methods used, while the last part describes the thesis structure.

1.1 Motivation

3D virtual environments and virtual reality have already been used for anatomical visualizations[7]. Some physiological concept is hard to represent with simple 2D models. Therefore, there is a need for new ways of visualizing complex concepts, especially for non-specialist users. They need to be explained this complex concepts in an easy and understandable way.

One of those complex physiological concepts is the human navigation system, which consists of different parts of the brain that are hard to represent anatomically. The basic components are small cells that are even hard to see in a microscope. Therefore, some additional novel way of visualizing this human navigation system is a requirement.

The topic and a need for explaining the human navigation system as a concept is current because of the Nobel Prize Award in Physiology or Medicine in 2014. The prize was given to May-Brit Moser, Edvard Moser and John O'Keefe for their "discoveries of cells that constitute a positioning system in the brain"[8].

As it can been seen from the literature, this concept is not very intuitive, so it is hard to understand for the general public. So far, mostly simple 2D images have been used to explain this concept[38].

From this, the main research question arises: How can 3D visualization and virtual reality be used to make the human navigation system understandable for the general public?
3D virtual reality have already been used in combination with the human navigation system[36], but not for educational purposes.

1.2 Research questions and learning goals

The main research question, "How can 3D visualization and virtual reality be used to make the human navigation system understandable for the general public", led to an initial study on the human navigation system itself. The research questions in this initial study were:

- How does the human navigation system in the brain look like

- How does the human navigation system work

The results of this study were then set in context with virtual reality and visualizations, which formed the learning goals of the implementation, used to be able to asses the research question later on.

LG1: The implementation should give user a understanding of how the human navigation system is structured anatomically in the brain.

LG2: The implementation should give user a understanding of how cells in the human navigation system works in relation to human spatial navigation.

Literature studies on virtual reality, visualizations and related work led to two different visualization approaches to visualize the two learning goals, one visualisation and one simulation. These two different visualization approaches led two sub-questions:

RQ1: What are the requirements needed for creating 3D visualizations of the human navigation system?

RQ2: What visualisation approaches are most efficient and preferable for understanding the human navigation system among general public?

1.3   Research methods

The research methodology of this thesis is a combination between quantitative and qualitative data collections.

1.3.1   Quantitative data collection

The quantitative data collection consisted of nine questions or statements found in appendix A. Some of the questions were reused from the specialization project, with the intention of having a comparison basis for this master thesis.

Most of the questions in the questionnaire were related to the learning effects of the implementation.

The conduction of the quantitative data collection were done on two Saturdays in May. The total of 21 participants from the general public conducted a tour in the implementation of the human navigation system and filled out a questionnaire related to the implementation afterwards.

1.3.2   Qualitative data collection

The quantitative data collection consisted evaluations conducted both by the general public and Subject Matter Experts (SME) from the Kavli Institute for Systems Neuroscience.

In both evaluations, the participants conducted a tour through the implementation of the human navigation system.

In the general public evaluation, six students from the general public conducted the tour one by one, followed up by a group interview. This interview

was based on the interview guide found in appendix B. It was taped by a recording device for further analysis.

In the expert evaluation, three SME were present at the conduction of the tour. Feedback from experts was given on the fly as the tour progressed. Most of the feedback was related to the correctness of the implementation in relation to how the human navigation system is in real life.

Both the evaluation of the general public and the experts were taped by a recording device for further analysis.

One final evaluation from the expert were given, based on the interview questions presented in appendix C and screenshots of changes made from the last expert evaluation.

1.4   Thesis structure

Chapter 2 describes the specialization project and the relation to this thesis.

Chapter 3 presents relevant theory and related work.

Chapter 4 describes the requirements and the implementation done based on these requirements.

Chapter 5 describes the evaluation process.

Chapter 6 presents the results of the evaluations.

Chapter 7 provides a discussion of the results.

Chapter 8 concludes the thesis and gives directions for further research.

2   Specialization Project

This chapter gives an overview over the specialization project and the relation to this thesis. The first section below describes the specialization project and the relation to this project. The next two section summarizes some of the feedback from the students and the expert provided during the evaluation stage of the project. This feedback will later be used in the requirements design of this thesis.

2.1   General

This master thesis is based on the specialization project with title "Visualization of grid cells and the brain's navigation system", which includes an evaluation conducted by seventeen nursing students in the autumn semester in 2014[28].

These nursing students completed an implementation of the human navigation system made in Second Life (SL) called Human Navigation Center(HNC). After the tour, they made an quantitaive and qualitatve evaluation of the HNC.

The expert evaluation of the specialization project was conducted in January 2015, with a basic tour through the HNC and a qualitative feedback session afterwards.

The sections below describes some of the feedback the nursing students and the expert provided. This feedback is used in the designing of the requirements in this thesis. The purpose of this section is to give the reader an overview of the knowledge gained after the evaluation from this previous experiment which is used during further development of the HNC.

2.2   Feedback from students

The students felt that the brain model had more room for improvements than the simulation of cell activity. The lack of anatomic depth and details in the brain model was some of things they missed most in the model. This could be improved to make it more interesting. In addition, they thought that it was hard to navigation inside the human brain on their own, as they struggled with the SL navigational "flying mode".

In the simulation of cell activity, the activation of the HUD created the most problems. The information provided was not understandable to participants. The students also thought that the use of HMDs made it hard to read information on the posters.

2.3   Feedback from expert

The expert thought that the brain model was to inaccurate. The anatomic shape of the hippocampus and the entorhinal cortex models did not create a realistic visualization of the brain components structure compared to the real life, since they both had an oval shape. The expert also mentioned that the cell model should be placed inside the brain model.

In the simulation of cell activity, the objects in the cubicals should be placed near the center for the activation of the place cells. This should be done to prevent any confusion between the place and the border cell activity.

The number of objects in the cubicles should also be reduced to one, or be pointed out that one single place cell is firing at one location, not at many locations as the HUD might suggest.

The HUD in the simulation should not contain a square grid pattern, because it can prevent the understanding of the hexagonal grid cell pattern presented in the simulation.

3   Theory and related work

This first part of this chapter describes the initial study conducted on the human navigation system. The second part of the thesis. The following parts present some background information of scientific visualizations, serious games, virtual worlds and Head Mounted Displays (HMDs). Throughout these sections, relevant work from the literature is presented.

3.1   Human Navigation System

What is the shortest way home? In our daily life, spatial environment navigation decisions are made by our brain constantly[53]. Inside the brain, both the hippocampus and the entorhinal cortex are key regions to understand how the navigation system can influence the decision about which way to take. The hippocampus consist of special neurons cells called place cells. They are responsible for recognition of landmarks. Inside the entorhinal cortex, neurons called grid cells are responsible for recording the brains spatial position, just like how a GPS device works[17]. Because of these cells, we can as humans in a spatial environment make unconscious spatial decisions that benefits our self. This means that we can take the shortest way home, return to a specific position or go a specific distance in a specific direction, without having technological aids available.

The subsections describes the key components in the human navigation position.

3.1.1   The Limbic System

Throughout the years, brain researchers have been divided over which components the limbic system consist of [19]. Even today, with more than a half century of researching, the researchers still lacks the criteria that defines the components of the limbic system [44]. Seen in a wider perspective, the system can be defined as a set of interconnected regions located in the medial portion of the brain, just above the brain steam and below the celebral cortex [37]. In this wide perspective, the regions defining the system are associated with emotion, behaviour, drives and memory [11].

The limbic system consist of five main regions: the Amygdala, the Hippocampus, the Hypothalamus, the Orbitofrontal gyrus and the Cingulate gyrus. These regions are, among other things, connected to the Thalamus and the Celebral cortex.
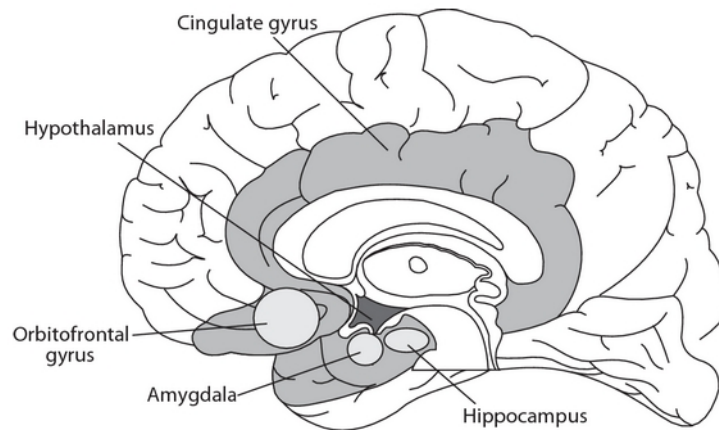
Figure 1: Anatomic representation of main regions in the Limbic System [48]

3.1.2 The Hippocampus

The hippocampus is formed as a horseshoe and consists of two mirrored pieces that are separated from each other. Each part is present at one side of the brain, opposite of the other.[55]. The hippocampus is responsible for handling long term memory and navigation[54].

Figure 2: Hippocampus, marked in red, seen from below[21]

3.1.2.1 Place cells

The hippocampus consist of small special neural cells called place cells. They are called place cells because their activity are correlated with certain places [33]. Cells that are located close to each other in the hippocampus represent places that are close to each other in the environment. A network of place cells can be seen as a cognitive mapmaker of certain places. An example of this is

7

given below.

If you have a man walking around in a town, one certain place cell are responsible for firing when the man is at the cinema, another cell is responsible for firing when the man is at the store and so on. Together these network of cells forms a cognitive map of the town. This map is stored inside the brain for further use.

3.1.3 The Entorhinal Cortex

The entorhinal cortex is a component within the brain mainly responsible for the communication between the hippocampus and the celebral cortex [10]. It is located in the caudal end of the the temporal lobe.
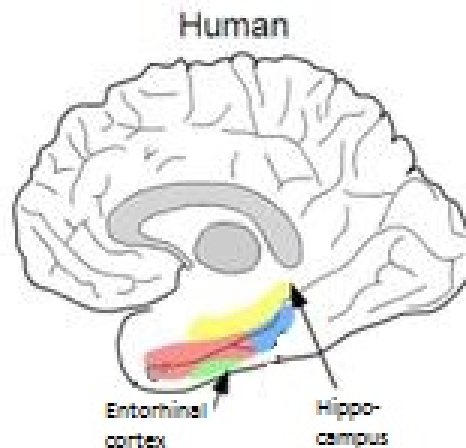
Figure 3: Entorhinal cortex, marked in green[41]

3.1.3.1 Grid cells

Inside the Entorhinal cortex there is special neurons called grid cells. These cells are called grid cells because they are active in hexagonal patterns related to the spatial position in the environment [18]. Because of their striking mathematical accuracy in the distance and the direction between each time the cells strikes, they are often "compared to a GPS device" [17]. Different grid cells have different distance between each strike, making some cells cover small areas and other cells larger areas. In that way, the network of grid cells together forms a positioning system of the human inside the brain.

Figure 4 illustrates the grid cell activity of a rat running around in a box formed room. Red indicates high activity, while blue indicates no activity. "The firing is spaced with regular distance and forms a triangular or hexagonal pattern in the box" [66].
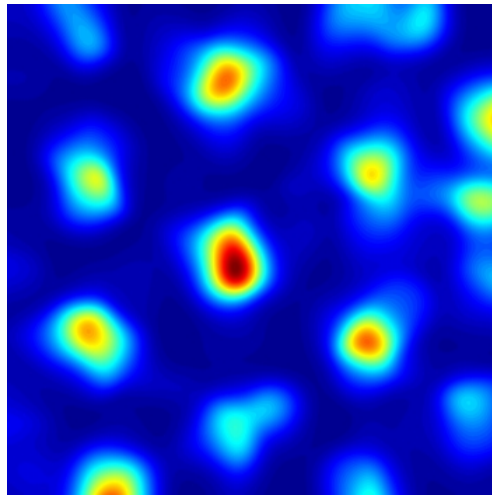
Figure 4: Grid cell firing pattern

3.1.4   Other types of cells

In addition to the place cells and grid cells, the human navigation system consist of other types of cells that record and react to certain spatial behaviour.

3.1.4.1   Border cells

Border cells are neurons found in both the hippocampus and entorhinal cortex. The border cells are responsible for responding to the presence of a physical boundary, like a wall or cliff [61].

3.1.4.2   Head direction cells

Head direction cells are neurons located in the hippocampus and in the entorhinal cortex. These cells are responsible for responding to change in direction of the head, independent of the place it is located in the environment. It can be compared to how a compass works, with an increase activity rate when the head points in a certain direction [4].

3.2   Scientific visualizations

Scientific visualizations are "branches of computer graphics and user interface design that are concerned with presenting data to users, by means of images" [14]. These images gives users the possibility to interpret and perceive the phenomenon or data set being studied. The goal of the visualization is to bring insight to the user, on a possible complex research area.

Current visualization technology provides a full range of visualization types, from two-dimensional plots, to interactive three-dimensional images, to large screen fully immersive systems that "allows the user to interact on a human level" [32].

3.2.1   Scientific visualizations for the general public

The visualizations for the general public stands out from visualisations aimed at specialist in that it should not require any prior knowledge about the subject being visualized for the user to understand the visualization[40].

Below is some examples of educational visualizations for general public within the field of medicine, biology and physiology presented.

Genome Island[1]
Genome Island is a virtual laboratory consisting of multiple interactive biological related experiments[12]. Each experiment do not require prior knowledge to the experiment topic, since background information is given if needed. The experiments include some data sets to provide useful experiments. Figure 5 shows some of the the different experiments inside the Genome Island. One is related to dna structures, another to molecules and a third to the Mendels experiment with genetics.
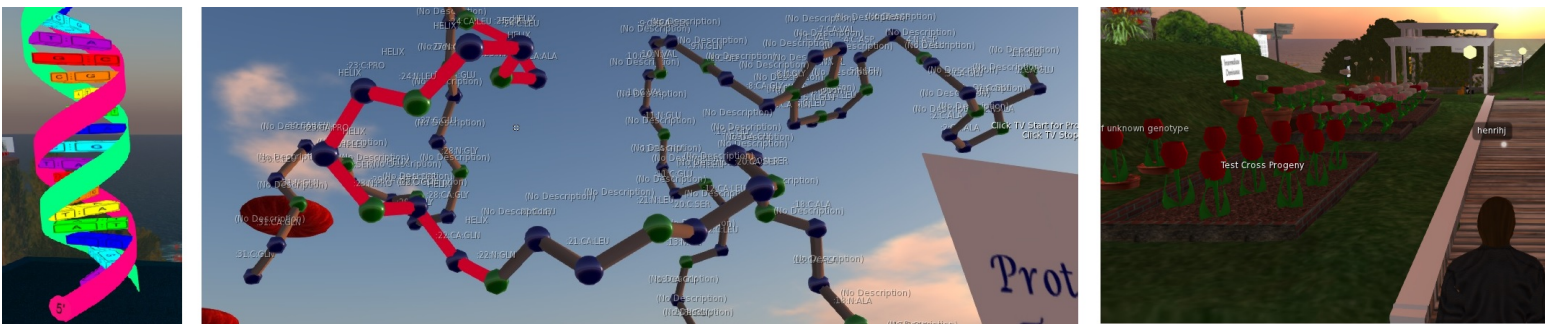
Figure 5: Genome island

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[1]URL: http://secondlife.com/destination/genome-island

3D Brain[2]

3D Brain is a interactive 3D visualization of the human brain that is accessible from a web-browser, developed by G2C Online. The visualisation works as a brain atlas, where you can select brain region from a drop-down menu. It provides both a rotatable visualization of the brain region selected, and some basic information about it from a text box to the left of the visualization.
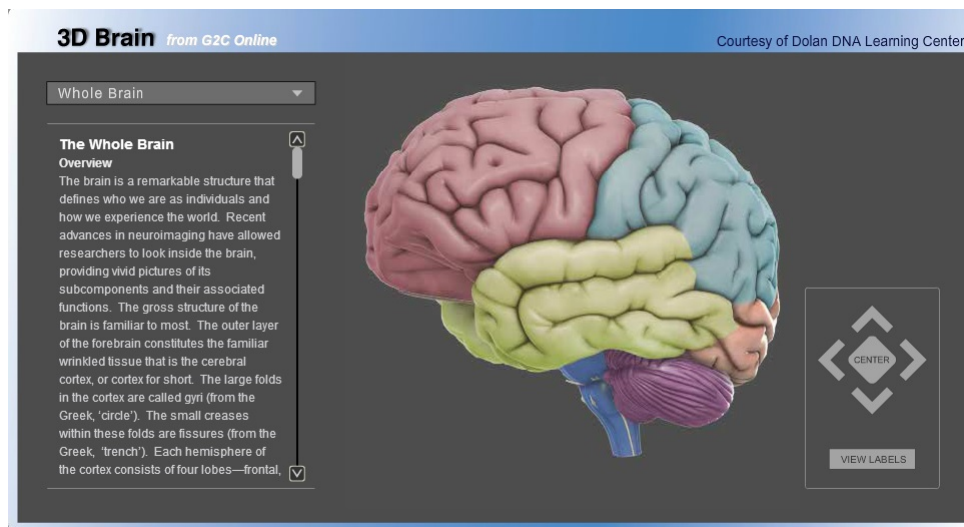
Figure 6: 3D Brain

Testis tour[3]

Testis tour is an 3D automated guided tour through the male reproductive system, developed by Ohio State University in SL. The automated guided tour offers voice based and text based information to be presented to the user. The tour takes you through the layers of this reproductive system, with both visualizations and animations methods applied.

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[2]URL: http://www.g2conline.org/chop.html
[3]URL: http://maps.secondlife.com/secondlife/University%20of%20KY/123/40/1001
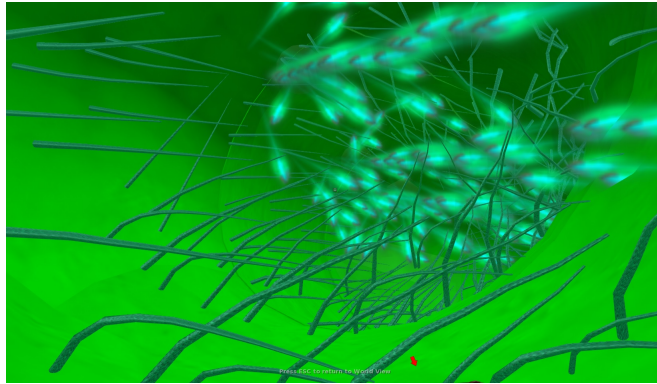
Figure 7: Testis Tour

Virtual Hallucinations[4]

Virtual Hallucinations is a SL project developed by UC Davis Health System that seeks to educate people about the mental illness schizophrenia. The project let you experience hallucinations in form of collapsing floors, flooded rooms and non stop slapping computers. The project also let you hear never ending internal voices like: "you are nothing", "do it", "take the gun", "you are the most evil person in the world" and "you are a load on their lives". This is done by activating a HUD[5].

Figure 8: Virtual Hallucinations

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[4]URL: `http://slurl.com/secondlife/Sedig/27/44/22`

[5]HUD: Heads-Up Display. It presents data to the user without the user having to look away

3.2.2   Scientific visualizations for professionals

The use of visualisation and simulation for professionals are often used for educating uses in form of decision making training, planning and to give insight into physical phenomenon[9]. They have often have higher requirements for the realism of the visualisations, than those aimed at the general public. Below is an example on a visualization aimed at medical professionals.

Cranial Nerve Skywalk[6]
The Cranial Nerve Skywalk is an interactive 3D visualization of cranial nerves developed by the University of Kentucky[7] in SL. In this project, the user can explore different cranial nerves by selecting a mode from an inbuilt option mode panel in front of the model. When changing mode, the craniel nerves model gets manipulated dependent of what mode you selected. You could for example add and remove the skull to see internal structures of the craniel nerves.
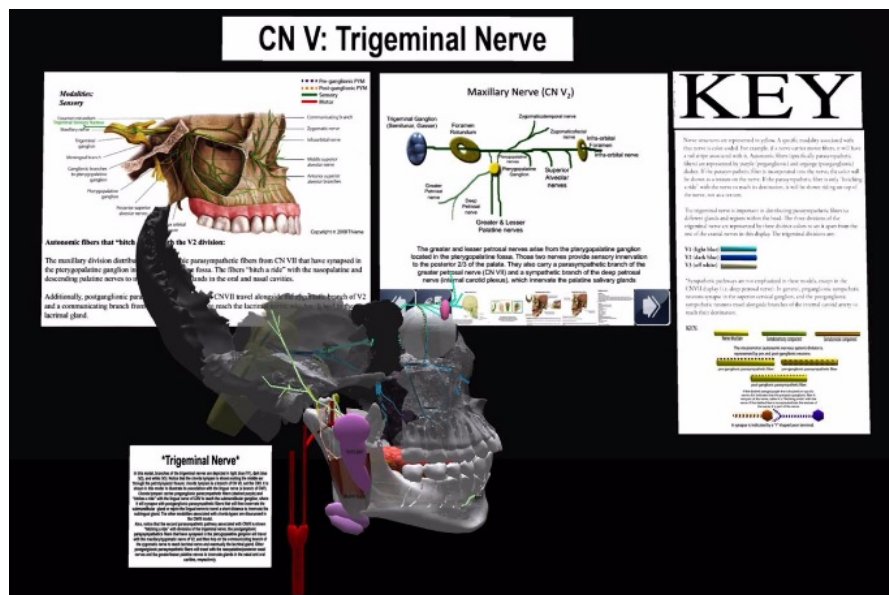
Figure 9: Cranial Nerve Skywalk

3.2.2.1   Anatomic visualizations and medical imaging   Since the late 1800s, the use of visualizations and visualization techniques has been widely utilized in a medical context [67]. These visualizations of the human body are often called medical images. The medical images creates visual representations of the interior of a body for clinical analysis and medical intervention [23]. They are allowing doctors to find disease earlier and improve patient outcomes.

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[6]URL: `http://maps.secondlife.com/secondlife/University%20of%20KY/123/40/1001`

Ultrasound

Ultrasound is a medical imaging technique that uses uses high frequency sound waves and their echoes [24]. The ultrasound machine works by sending out sound signals with a probe, receiving the same signals (echoes), calculate the distance between the probe and the tissue and display the distances and intensities of the echoes on the screen, forming a two dimensional image like the one shown in Figure 10.

Figure 10: Ultrasound image of a baby [50]

CT

Computed tomography (CT) uses X-rays in order to present cross-sectional images or slices of the body [27]. An X-ray ring rotates around the body, making it possible to create 3D images of the body by putting the slices together. Figure 11 shows an 3D image of a skull.
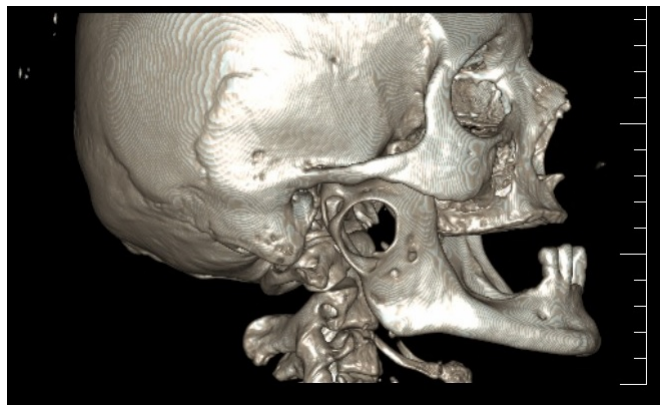
Figure 11: CT scan of a skull[20]

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[6]Available   at: http://www.ejbi.org/en/ejbi/article/
17-en-temporomandibular-joint-prosthesis-3d-ct-reconstruction-before-and-after-treatment.
html

MRI

Magnetic Resonance Imaging (MRI) is an imaging modality that uses magnetic fields and radiation to create useful images [35]. The hydrogen atoms inside the human body will align with this magnetic field, making it possible to image soft tissue in the body.
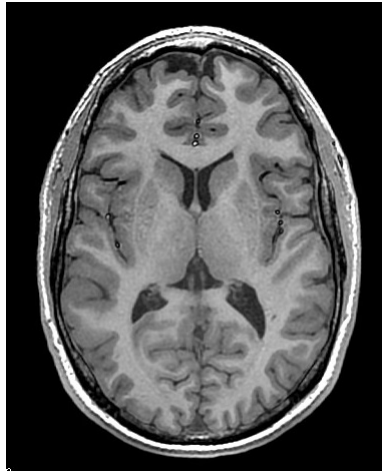
Figure 12: MRI scan of a skull[31]

3.3   Serious games

Serious games stands out from entertainment games by focusing on problem solving rather than entertainment [62]. They are made by applying games and simulations technology to non-entertainment domains to create a pedagogical platform within the game [68]. This platform is created by adding certain learning outcomes and goals to the game [56]. These type of games have the potential to be an important teaching tool because they are interactive, engaging and immersive activities [65].

3.3.1   Immersiveness

Immersive serious games gives the intended target the subjective impression that it is participating in a comprehensive, realistic experience in a virtual environment [39]. The immersion includes the "targets willing suspension of disbelief, and the design of immersive learning experiences that induce this disbelief draws on sensory and symbolic factors" [13].

Immersion can contribute to better understanding of a concept by applying a multiple perspectives approach. [16].
The multiple perspectives includes the ability to change the frame of reference, often used in understanding of complex phenomenons. It can for example be used to illustrate a how a house looks like. Figure 13 shows an example of how a house can look like, with different perspectives.
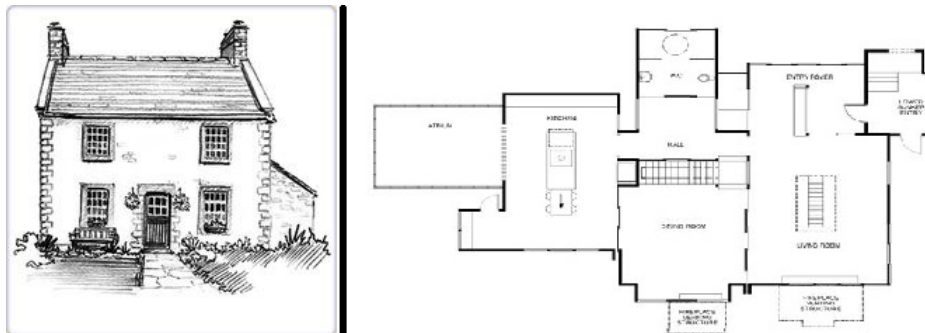
Figure 13: Multiple perspectives

3.3.1.1   Medical use of immersive serious games

In the healthcare sector, there are a number of serious games which offer great potential for the training of basic skills and techniques to health related staff [57]. One study from the Karolinska University Hospital shows a positive correlation between experience in computer games and performance in endoscopic simulation by medical students [43]. Another study from Salento University

shows an increase in performance for radiologist in needle placement procedure, after having completed a virtual game scenario beforehand [22].

3.3.2   A-Mazing Race

A-Mazing Race [42] is a 3D browser-playable computer game developed by NTNU in cooperation with the NTNUs Kavli Institute for Systems Neuroscience.

In this game you are in control of a rat in a laboratory and the goal of the game is to find a key to a big cheese. To do so, you have to actively use the information provided of your grid, place and border cells, and use this to navigate yourself to the key and back to the cheese again.

Figure 14: A-Mazing Race

3.4 Virtual Worlds

A virtual World (VW) is a computer-based, simulated multi-media environment, where users can interact with each other [46]. Each user is represented in the virtual environment with a graphical self representation known as avatars. Many VW platforms exists today, including popular platforms as Second Life (SL) [45], The Sims [58] and World of Warcraft [51]. Although there exists many purely entertainment based VWs, like World of Warcraft, many VWs are becoming a part of the technological educational landscape.

A study done by the MICA project [25], implemented in SL for exploring the utility of the emerging VR and VWs technologies for scientific and scholarly work, shows that VW has great potential for:

- Improving scientific collaboration and communication

- Offer a new approach to numerical simulations

- Offer immersive multi-dimensional data visualizations

- Educational and public outreach

In this thesis we will be focusing on the educational use of VWs with focus on the learning aspect.

3.4.1 Second Life

SL is the best known VW. SL is an immersive and interactive three dimensional VW [34]. The content of the world is user-based, meaning that users can interact and change with the world itself by adding simple objects called "prims" or upload models to the VW. The flexibility of these features, combined with SLs inbuilt avatar navigation feature, provides opportunities to create tailored areas that can represent complex phenomena like the human navigation system. These tailored areas have the possibility to be manipulated, making it possible to customize the areas for the users needs.

3.4.2 VWs as a learning environment

Many of the VWs offer several educational opportunities. Users of these worlds can learn by exploring, interacting and reflecting on their experiences inside the world[15]. Here are two studies that indicates that 3D visualizations and virtual worlds can improve learning outcome significantly[26] [5].

3.5   Head Mounted Display

A head mounted display is a wearable device that projects a virtual 3D environment within the glasses, and simultaneously blocks the vision of the real world. With the launch of the Oclulus Rift, HMDs are coming more available and more affordable for the general public than it was previously.

The use of HMDs in a medical context is already present. In a study, six patients with transurethral resection of bladder tumor (TURB) wore HMDs to follow the operation of the tumor in real-time [49]. As a result, the HMD helped to increase the patients understanding of their state of the disease. Another study shows that the use of HMDs for glaucoma patient can make doctors potentially diagnose these patients for balance problems [47].

HMDs have the potential of increased authenticity and immersion [64]. This thesis will be using HMDs to see to improve the immersion of the visualizations.

Figure 15: Oculus Rift DK1

4   Requirements and implementation

This chapter is divided into three part. The first part covers the requirements design process and the actual requirements. The next part covers he implementation of these requirements in SL. The third part contains the unimplemented requirements.

4.1   Requirements Design

This section provides an overview over the requirements design process. It includes the actual requirements and the reasoning behind them. The requirements design process have mainly been influenced by four factors: continuation of requirements from the SP, feedback from SME, feedback from users and elements from the related work. The last three factors have influenced the design of requirements to be a continuous process.

Below is a brief review on the learning goals defined in section 1.3. The requirements defined in the next section are all influenced by these goals.

LG1: Give the user a basic understanding of how the human navigation system is structured anatomically in the brain.

LG2: Give the user a basic understanding of how grid and place cells works in relation to human spatial navigation.

4.1.1   Requirements

This section contains the main set of requirements needed to introduce the user to the human navigation system, using a visualisation and simulation approach to the subject. All the requirements are designed to give the users the best conditions to achieve the learning goals.

Table 1 contains the main set of requirements. An explanation of all the column headers are listed below:

Req: The requirement number.

Description: Description of the requirement.

SP: The requirement is an continuation of a requirement from the SP.

USE: The requirement is influenced by user feedback.

SME: The requirement is influenced by SME feedback.

Related work: The requirement is influenced by some elements from the related work.

SubReq: The requirement contain sub-requirements.

LG: The requirement is based on one or more learning goal.

Req	Description	SP	USE	SME	Related work	SubReq	LG
R1	The project should contain a 3D visualization of the human navigation system (brain model)	✓			Brain Tour	Table 2	LG1
R1.1	It should contain at least three layers of the brain components		✓	✓			LG1
R1.2	The users should be guided through the brain		✓		Testis Tour	Table 3	LG1
R2	The project should contain a simulation of grid/place cells activity	✓			A-Mazing Race	Table 4	LG2
R3	R1 and R2 should be immersive						LG1, LG2
R4	R1 and R2 should be engaging						LG1, LG2
R5	R1 and R2 should be realistic	✓	✓	✓			LG1, LG2
R6	The project should contain a guided tour through the Virtual Campus				Testis Tour		LG2
R6.1	The tour should simulate grid/-place cells activity				A-Mazing Race		LG2
R7	The project should contain a short introduction video of the human navigation system subject.		✓				LG1, LG2
R8	Information of what is going to happen should be presented to the user as the first thing they see.		✓				LG1, LG2

Table 1: Main requirements

The main requirement for giving the user a basic understanding of how the human navigation system is structured anatomically is:

"The project should contain a 3D visualization of the human navigation system (brain model)"

This requirement is a continuation of the same requirement from the SP. The

requirement and its sub-requirements are inspired by the interactive brain model presented in 3D Brain project .
The requirement has also some related requirements for maximizing the potential of the achieving the learning goal. R3, R4 and R5 states that the visualization should be "immersive, engaging and realistic".
The immersive part of the brain model, R3, is supported by R1.2, "The users should be guided through the brain", and its sub-requirements. R1.2 is partially based on the feedback from users at the SP, who stated that it was hard to navigate through the brain on their own, using SL. R1.2 is also inspired by the guided tour through the male reproductive system in the Testis Tour. R5, "R1 (the brain model) should be realistic", is also a requirement that have been continued from the SP. Feedback from both users and SME stated that the brain model implemented in the SP where to inaccurate and lacked structural depth. The last one is the basis for R1.1, "It should contain at least three layers of the brain components".

The main requirement for giving the user a basic understanding of how the human navigation system works in relation to human spatial navigation is:

"The project should contain a simulation of grid/place cells activity"

This requirement is a continuation of the same requirement from the SP. The requirement and its sub-requirements are partially inspired by the A-Mazing Race game from the related work. The R3, R4 and R5 requirements related to this requirement are covered in the sub-requirements in Table 4, and will be presented in a later section.

In addition to the two main requirements presented above, there are some main additional requirements related to the learning goals of this thesis that are not directly related to the requirements above.

"The project should contain a guided tour through the Virtual Campus"

This requirement is an addition to the LG2 learning goal. It is influenced by the guided tour in Testis Tour . Like R2, the guided tour should simulate grid and place cell activity, a requirement covered in R6.1.

"The project should contain a short introduction video of the human navigation system subject

This requirement is based on some of the user feedback gathered during the evaluation stages of this thesis. The users stated that if they got introduced to the human navigation system subject before exploring the implementation of R1 and R2, they would understand more of the implementation.

"Information of what is going to happen should be presented to the

user as the first thing they see"

During the evaluation of the SP, the users stated that a short overview of what is going to happen should be presented to the users to reduce the possible insecurities new users may have when using new technologies, which may prevent an understanding of the implementation.

4.1.2   Brain model requirements

This section contains a reasoning for the brain model requirements, presented in Table 2.

Req	Description	SP	USE	SME	Related work
BM1	It should contain the outer shell of the brain(celebral cortex)				3D Brain
BM2	It should contain limbic system				3D Brain
BM2.1	It should highlight the entorhinal cortex and the hippocampus within the limbic system	✓			
BM3	It should contain grid/place cells within the entorhinal cortex and the hippocampus		✓	✓	
BM3.1	The cells should include a animation to indicate cell activity				Testis Tour
BM4	It should be anatomical correct	✓	✓	✓	
BM5	It should be rotatable				3D Brain
BM6	It should be manipulable				Cranial Nerve Skywalk
BM6.1	It should be possible to make internal component invisible				Cranial Nerve Skywalk
BM6.2	It should be possible to make internal component visible				Cranial Nerve Skywalk

Table 2: Brain model requirements

The first three requirements of this section, BM1, BM2 and BM3, are all related to the R1.1 requirement. BM1 and BM2 are both inspired by the 3D Brain from the related work. The possibility to navigate yourself from the outer shell of the brain to the cell level view via relevant internal brain components, are the the reasoning for defining these requirements.

BM3 is based on feedback from users and SME from the SP, claiming that the

cell level should be a part of the brain model to increase the understanding of where grid and place cells are located within the brain.
BM3.1 is inspired by the Testis Tour, who showed an animation of sperm cells moving around in the flagella. The thought behind this requirement is that an animation can help the user understand that a cell can be active or not.

BM4 is a continuation of the same requirement from the SP. It is related to R5 and it was pointed out in the feedback of both users and SME in the SP that the brain model was to inaccurate to give users an understanding of the anatomic structures in the human navigation system.

BM5 and BM6 are both related to R3, the "immersiveness" of the brain model. BM5 are inspired from the arrow-panel in the 3D Brain application . BM6 is inspired from the several stages in the Cranial Nerve Skywalk from related work, where internal components is manipulated to highlight and set focus on different cranial nerves. BM5 and BM6 are defined to show different views of the brain model.

4.1.3   Guided brain tour requirements

This section contains a reasoning for the guided brain tour requirements, presented in Table 3.

Req	Description	SP	USE	SME	Related work
GBT1	The guided tour should include a SL vehicle as a guide.				Testis Tour
GBT1.1	It should be able to communicate with the brain model.				Testis Tour
GBT1.2	It should be able to manipulate the brain model.				Testis Tour
GBT1.3	It should be movable.				Testis Tour
GBT2	The guided tour should should be adapted to use in combination with HMDs.				
GBT2.1	It should require minimal user input.		✓		
GBT3	The guided tour should give the user textual information during the tour.				3D Brain
GBT3.1	The information given should explain what the user are currently seeing in the brain model.				3D Brain
GBT3.2	The information given should be short.				
GBT3.3	The information given should be understandable.				
GBT3.4	The information given should be adapted to HMD use.		✓		
GBT3.4.1	The textual information should be large.		✓		
GBT3.4.2	The information given should be close to the user.		✓		

Table 3: Guided brain tour requirements

GBT1 is inspired of the guided tour in the Testis Tour . In the Testis tour, a sperm cell takes you on a tour through the male reproductive system. GBT1, GBT1.1, GBT1.2 and GBT1.3 states that this guided tour should be guided by a movable SL vehicle, and the guide should be able to communicate and manipulate the brain model.

GBT2 states that "the tour should be adapted to use in combination with HMDs". A sub-requirement, GB2.1, is based on the user feedback from the SP. When a user are wearing a HMD, the user can not see the keyboard or the mouse. Therefore it is logical that the guided tour should require minimal user input.

GBT3 and GBT3.1 is inspired by the informative panel of the 3D Brian fro the related work. In the 3D Brain, when the user navigated through the brain and its components, an informative panel to the left of the brain gave the user useful information about what can be seen in the brain model. GBT3.2, GBT3.3, GBT3.4 states that this information should be: "short, understandable and adapted to HMD use".
The last requirement is based on user feedback from the SP, where small font size and navigation in combination with use of HMDs made it hard to read the information in the SP. GBT3.4.1 and GBT 3.4.2 is defined as a consequence of this.

4.1.4   Simulation of cell activity requirements

This section contains a reasoning for the simulation of cell activity requirements, presented in Table 4.

Req	Description	SP	USE	SME	Related work	SubReq
S1	The simulation should contain a separate simulation of place cell activity	✓			A-Mazing Race	
S2	The simulation should contain a separate simulation of both place and grid cell activity simultaneously	✓				
S3	S1 and S2 should use a HUD to map cell activity to a static 2D representation of the spatial simulation space .	✓			A-Mazing Race	Table 5
S3.1	S1 and S2 should use the same HUD					
S3.2	The simulation should include a tutorial of how to activate a HUD.	✓	✓		Virtual Halluci-nations	Table 6
S4	S1 and S2 should each have a separate cubical in SL for the different simulations.			✓		
S4.1	Objects in each cubical should be placed near the center.			✓		
S5	Information about each simulation should be presented to the user.					
S5.1	The information should be short.					
S5.2	The information should be understandable.					

Table 4: Simulation of cell activity requirements

S1 is inspired of the A-Mazing Race game. In the game, the simulation of place cells helps the rat finding the key to receive the cheese by showing the direction of the key. In this thesis, the activity of place cells should only by mapped to 2D representation of the spatial simulation space by using a HUD.

S2 is defined to show the user how place and grid cells cells are active in a spatial space simultaneously, by mapping the cells activity to a 2D representation of the spatial simulation space, with use of a HUD.

Both the S1 and S2 are related to the R5 requirement, "the simulation should be immersive", because they have both a 2D and a 3D perspective of spatial simulation space.

S4 and its sub requirement S4.1 is based on the expert feedback from the specialization project, stating that each object should be placed near the center for preventing misunderstandings about the type of cell presented.

4.1.5 HUD requirements

Req	Description	SP	USE	SME	Related work
H1	The HUD should be able to indicate cell activity related to the 3D environment the avatar is navigating in.	✓			A-Mazing Race
H2	The HUD should represent the 3D cubical with a 2D map.	✓			A-Mazing Race
H3	The HUD should be updated dependent on the avatars position	✓			Virtual Hallucinations
H4	The HUD should be able to make internal object linked with the HUD invisible	✓			
H5	The HUD should be able to make internal object linked with the HUD visible	✓			
H6	The HUD should give the users information of the status of the current simulation				
H7	The HUD should give the users an explanation of what the internal objects in the HUD represents.		✓	✓	A-Mazing Race

Table 5: HUD requirements

H1 and H2 is inspired from the HUD in A'Mazing Race, showing the human perceptions of the different grid, place and border cell firing signals.

H3 is inspired from the HUD in Virtual Hallucinations, where the virtual voices in HUD is partly dependant of the avatars local position inside the virtual world.

H7 is inspired by the HUD in the A'mazing Race, where there was an graphical explanation of what the different activation of different cell types meant.

4.1.6   HUD tutorial requirements

Req	Description	SP	USE	SME	Related work
HT1	The HUD-tutorial contain information about how to active an HUD.	✓			Virtual Halluci-nations
HT1.1	The information should be short.				
HT1.2	The information should be understandable.		✓		

Table 6: HUD tutorial requirements

HT1 is inspired from the lack of HUD-tutorial in Virtual Hallucinations. This lack of tutorial made me as user unsure on what to do to activate the HUD.

HT1.2 is based on user feedback from the user evaluation at specialization project, stating that the information provided on how to activate the HUD was not understandable.

4.2   Implementation in SL

This section provides the implementation of the requirements defined in the previous section. In the first subsection, a basic overview of the implementation will be presented. In the next subsections, the implementation of the actual requirements will be presented.

4.2.1   Basic overview

The implementation of the human navigation system made in SL is called "Human navigation center" (HNC), and it includes three sequential stages: an introduction stage, a guided brain tour stage and a simulation of cell activity stage.

Figure 16 shows an overview of the different stages related to their virtual position in SL, shown from above. The entrance of the HNC is at the bottom of the figure. The introduction area is colored in red, the guided brain tour area is colored in green, while the simulation of cell activity area is colored in yellow. The change of the stages are clearly marked in the HNC with yellow posters. Yellow arrows are used along the HNC to guide the users from one stage to the next stage.

Figure 16: A basic overview of the different stages in the HNC

4.2.2   The introduction stage

This stage was added to give the user an introduction to the human navigation system topic. This stage consist mainly on a object with link to an introduction video on Youtube[17]. The introduction video is a barely three minute long film by Massive Rhino, made in cooperation with the Kavli Institute for Systems Neuroscience at NTNU.

The video gives an insight into how the grid cells were discovered by the Moser researchers. It also gives an short explanation of how the grid and place cells works and how this discovery can lead to breakthrough research on mental diseases, like the Alzheimer's disease.

This film was selected because it was short, succinct and it gave useful insight in their research approaches, that are not covered in the rest of the HNC. The latter one includes that the research is done on rats, the use of electrodes to pick up the rats cell signals and the laboratory work done in processing the cell signals. Another reason for selecting this, is to bring the rest of the HNC more relatable to the Mosers research that got them the Nobel Prize [8].

4.2.3   The guided brain tour stage

This subsection includes components that are crucial for the conducting of the guided brain tour. It includes the brain model, the SL guide and the communication line between them.

Brain model

The brain model in SL is based on three different models found on the Internet. The models represents the different layers of the brain model: the outer shell, the limbic system and the cell level. They were all edited in Blender[1], an open-source 3D graphics software program that is used in development of 3D models and animations, before putting them together in SL to form the complete brain model.

Work done in Blender

The outer shell of the brain model is based on a 3D model of the whole brain[3]. This model was edited by removing all the internal components inside of the outer shell. The outer shell or "celebral cortex" was then imported to SL. Figure 17 shows the original model to the left, and the edited model to the right.
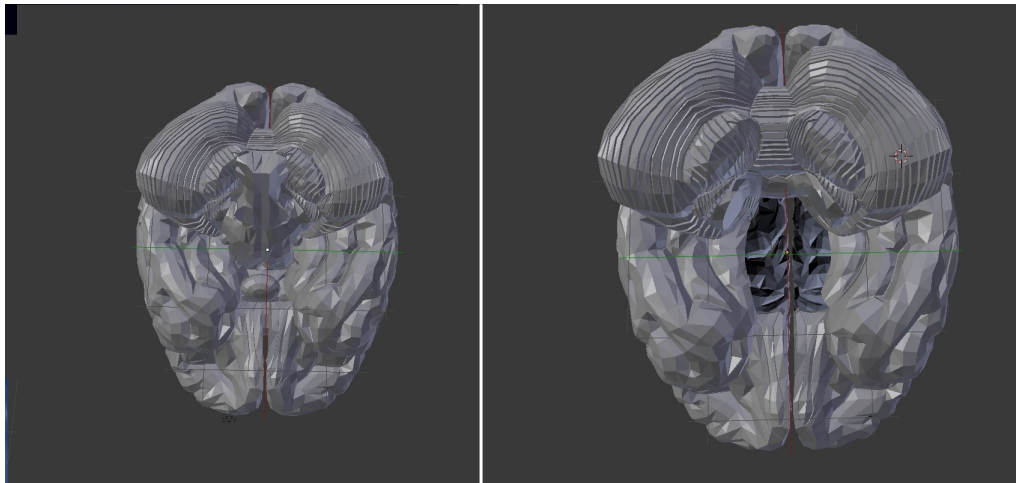
Figure 17: Work on the outer shell of the brain in Blender

The model of the limbic system is based on a model who claims to be based on a MRI scan of the limbic system of a human brain[63]. This model was edited by removing components that was not a part of the limbic system. Figure 18 shows the original model of the limbic system to the left and the edited version of it to the right.
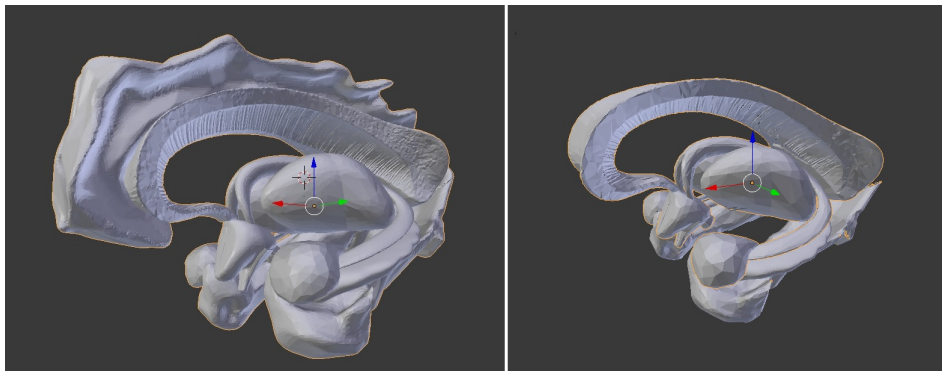
Figure 18: Removal of components in Blender

The hippocampus was segmented from the rest of the limbic model by using the Blenders "Select linked" function. Figure 19 shows the segmentation of the hippocampus to the right from the limbic system to the left.
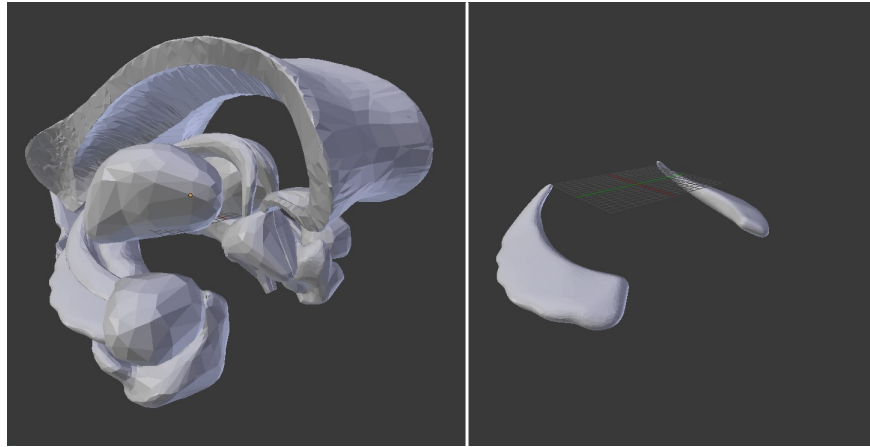
Figure 19: Segmentation of the Hippocampus

The entorhinal cortex was segmented from a brain component called parahippocampal guri, located below the hippocampus. The parahippocampal guri was first segmented from the limbic system using the "Selected linked" function in Blender. The segmentation of the entorhinal cortex was then done with the "Lasso tool" function in Blender. The segmentation of the entorhinal cortex from the parahippocampal guri can be seen in Figure 20.
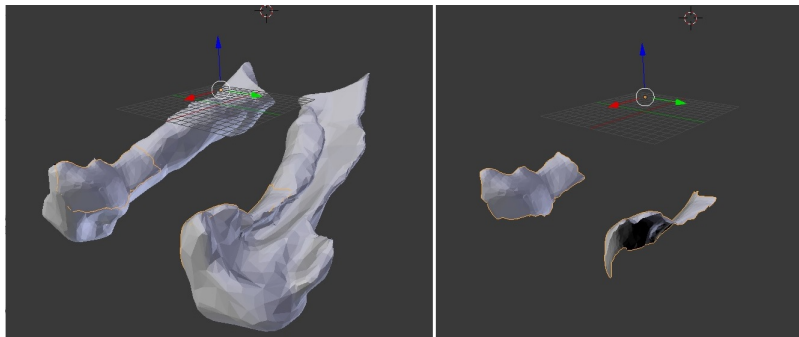
Figure 20: Segmentation of the entorhinal cortex in Blender

The model of the limbic system, including seperate internal components as entorhinal cortex and hippocampus, were then imported to SL. Figure 21 shows the limbic system model after the editing done in Blender.
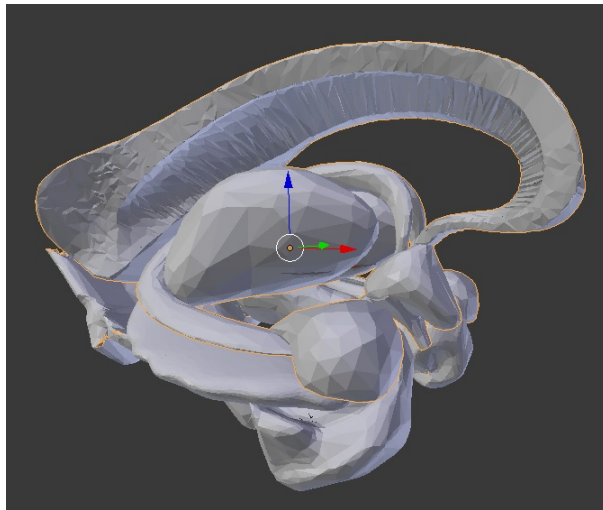
Figure 21: The limbic system model in Blender

4.2.3.1   Cell model   The cell level in the brain model is based on a model of a neuron cell[6]. This model was edited by reducing the thickness of the neuron stem and also reduce the size of the neural axon. This was done to create a more realistic model of the grid and place cells. Figure 22 shows the original cell model to the left and the edited cell model to the right.
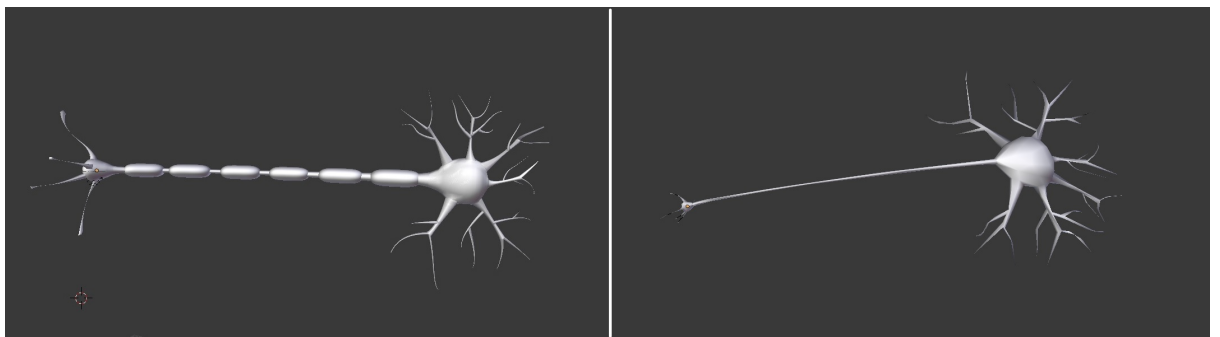
Figure 22: Cell model editing in Blender

Importing to SL
All the models presented above where also edited by reducing the total number of vertices in each model to approximately a tenth of the original number of vertices. This was done with the Blenders "Decimate" tool.

This was done because of the Land Impact (LI) rule in SL. The rule is designed to make a score of how detailed each model is. Each island inside SL has a total capacity of the sum of the LI from all the models it contains. This score i shown to the builders on this island as a total number of available LI remaining. Since the NTNUs island contains many and detailed models from other student projects, the total available LI was low. This led to the reducing of the vertices in the models developed in Blender. Some details from the models may have been lost in this process.

The three models presented above were then imported and put together to one brain model in SL. Guidance from SME helped to position the limbic system model into the outer shell model. Figure 23 shows this placement in the final model.
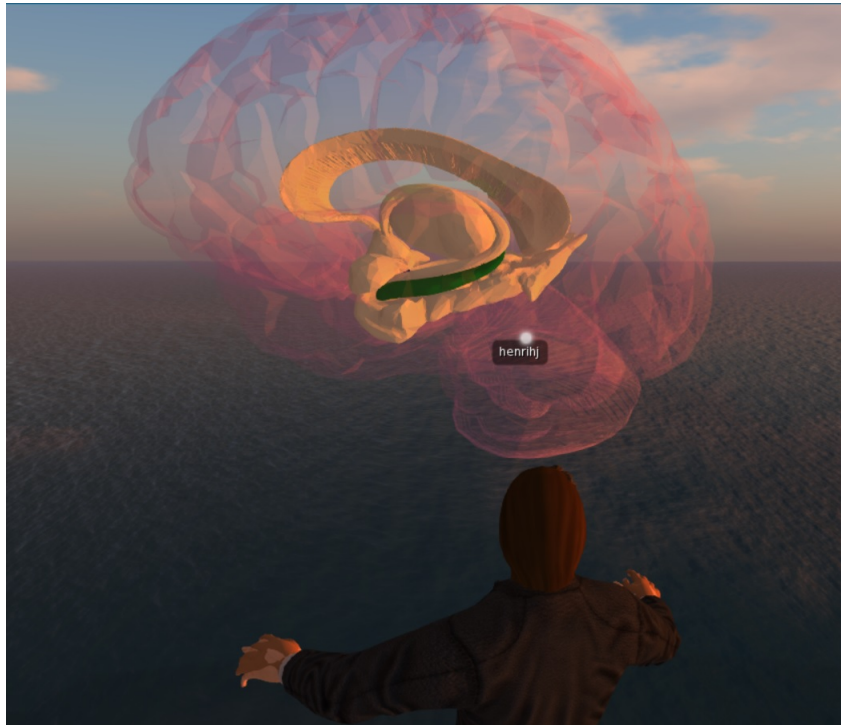
Figure 23: The limbic system

The neuron cell model was duplicated and placed inside the entorhinal cortex and hippocampus components to form a network of grid and place cells. Figure 24 shows the final brain models representation of a network of gridcells in the entorhinal cortex in SL. All these objects in SL were linked together to a form a brain model.
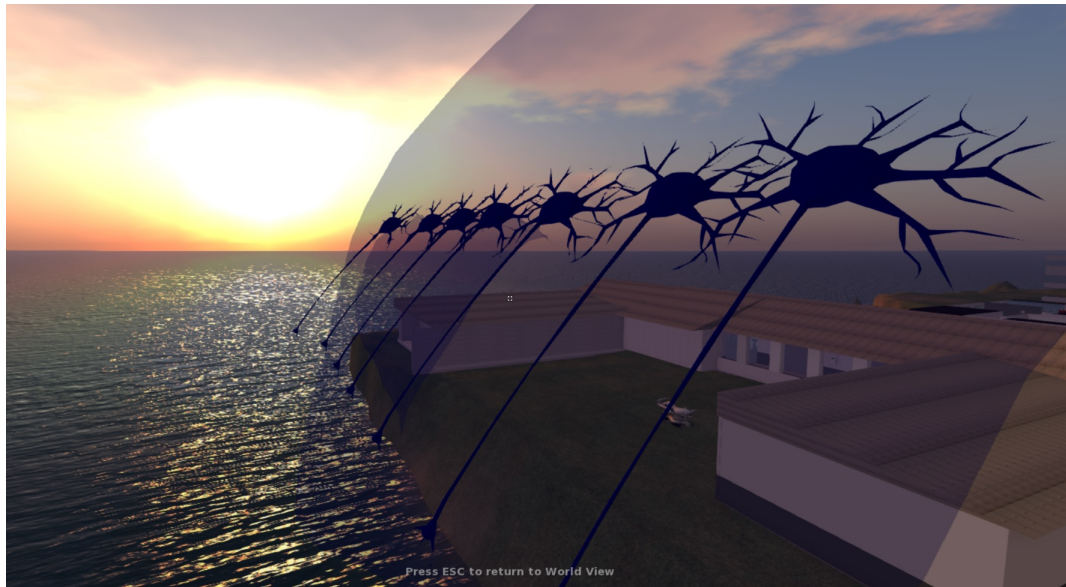
Figure 24: Grid cells in the entorhinal cortex

This brain model were also added some functions, as rotation of the whole model and make internal components visible and invisible. In addition, a combination of changing color and a timer event where made to show simple animations. Below is a list of useful commands used to give the brain model these functions:

llSetRot Sets the rotation of the object.

llSetColor Sets the color of the object.

llSetTimerEvent(x) Sets an event to occur every x seconds

llSetAlpha(x) x should be between 0 and 1. 0 represents invisible and 1 represents visible

llMessageLinked sends a message to all or some linked objects.

link_message listens on channel for a message from a linked object

4.2.3.2 The guide The guide vehicle made in SL consist of two main components: the guide framework and the blackboard.
The guide framework contains the platform where the user can be seated and static objects that connects the platform to the blackboard. This can be seen in Figure 25. All the components of the guide consists of basic SL objects.

35

The blackboard sub-component of the guide, contains fifteen different textures or slides that are related to different aspects of the brain model.

The guide has been given some functions to be able to conduct the brain tour. The most important function is the ability to change its position. This is meaningless unless an avatar is currently seated on the guide, so it also has a function to check if an avatar is currently seated. The guide has also a function for sending messages both to the blackboard sub-component, but also to the brain model via a communication channel. Under is a list of useful commands that have been used to give the brain model these functions:

llSetRegionPos Sets the position of the object based on coordinates.

llShout Communication approach with large range

changed The object properties has been changed

llAvatarOnSitTarget returns true or false if an avatar is seated on the object

llMessageLinked sends a message to all or some linked objects.

llSetTexture Sets the texture of the object

Figure 25: The SL guide vehicle

Communication between the guide and the brain model
After the user have right clicked on the SL guide and selected "brainTour",
the SL guide enables conduction of the brain tour. The progress in the brain
tour is dependant of the user to click on the blackboard to continue the tour.
The difference stages in the tour is made by communication between the guide
and the brain model via a communication channel. Figure 26 shows the

communication between the guide and the brain model. The guide is in charge
of the communication between these components. It initiates contact with the
brain model with instructions, after a click on the the guide or the blackboard.
The click also sends a linked message from the guide to the blackboard to
change the blackboards texture. The message is also sent via the
communication channel to the brain model. The brain model then computes
the manipulation of the model based on the message received. The brain
model then sends further instructions to its sub-components.
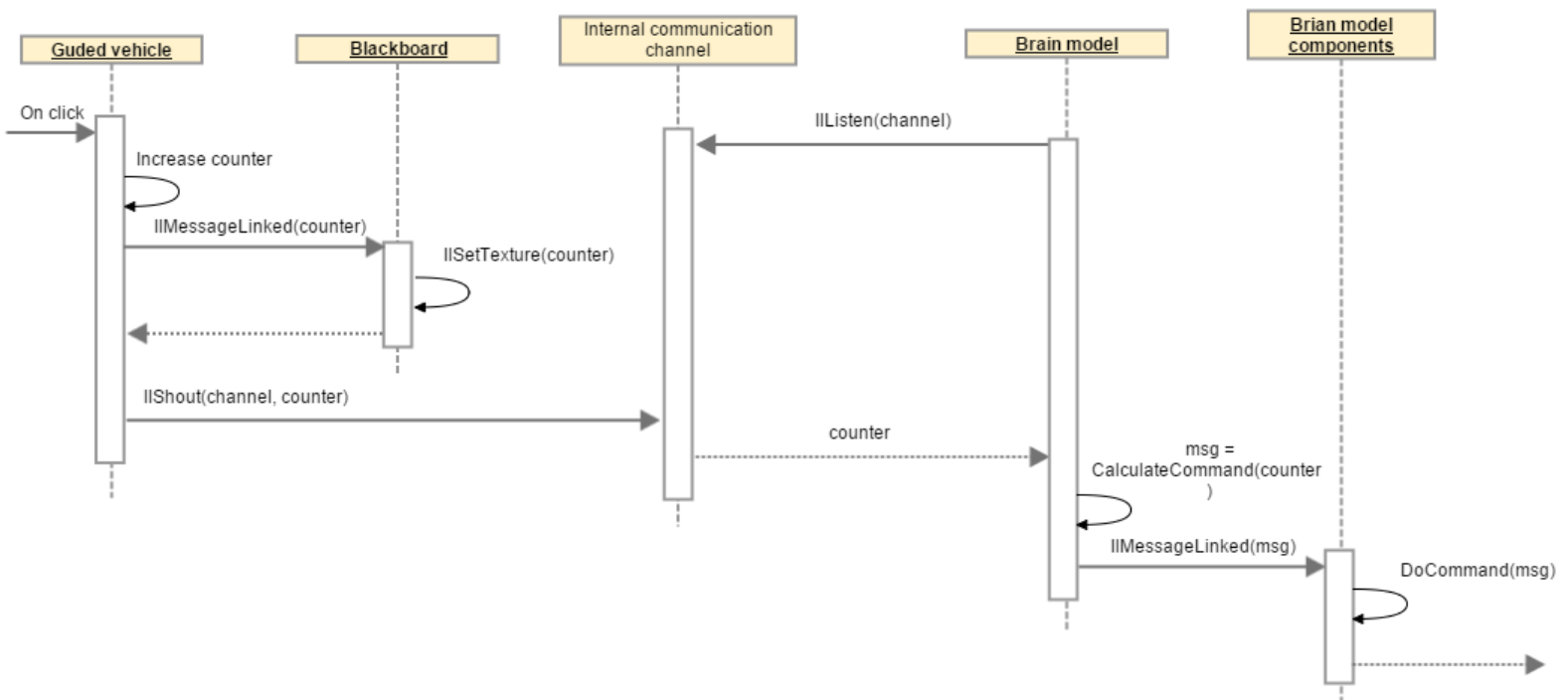
Figure 26: Communication between the guided tour components

Below is pseudocode for the components in the guided brain tour stage presented. The full script can be found in appendix D.

Data: counter
while *someone is seated state* **do**
    if *clicked* **then**
        increase counter;
        send message(counter);
    end
end
while *not seated state* **do**
    reset counter;
    send message(counter);
end

Algorithm 1: Guide script

while *in listen mode* **do**
    if *message received* **then**
        change texture(message);
    end
end

Algorithm 2: Blackboard script

while *in listen mode* **do**
    if *message received* **then**
        forward message;
    end
end

Algorithm 3: Brain model script

while *in listen mode* **do**
    if *message received* **then**
        if *message is for me* **then**
            do some functions(message);
        end
    end
end

Algorithm 4: Brain model components script

The conducting of the guided brain tour

The guided brain tour consist of fifteen sequentially stages, starting from the outer layers of the brain to the cell level of the brain. To go to the next stage in the tour, the user have to click on the blackboard to go from one stage to another.

The tour starts with the user right clicking the guide and selects "BrainTour". The SL guide then changes its region position so it is located in front of the brain. Since the user is seated at the guide, the user also changes position. Under is all the stages of the tour described.

Stage 1, start stage

Figure 27 shows the start stage of the tour. The user sees the outer shell of the brain model. The blackboard gives the user some information on how to get the browser into HMD-mode and in first person view.
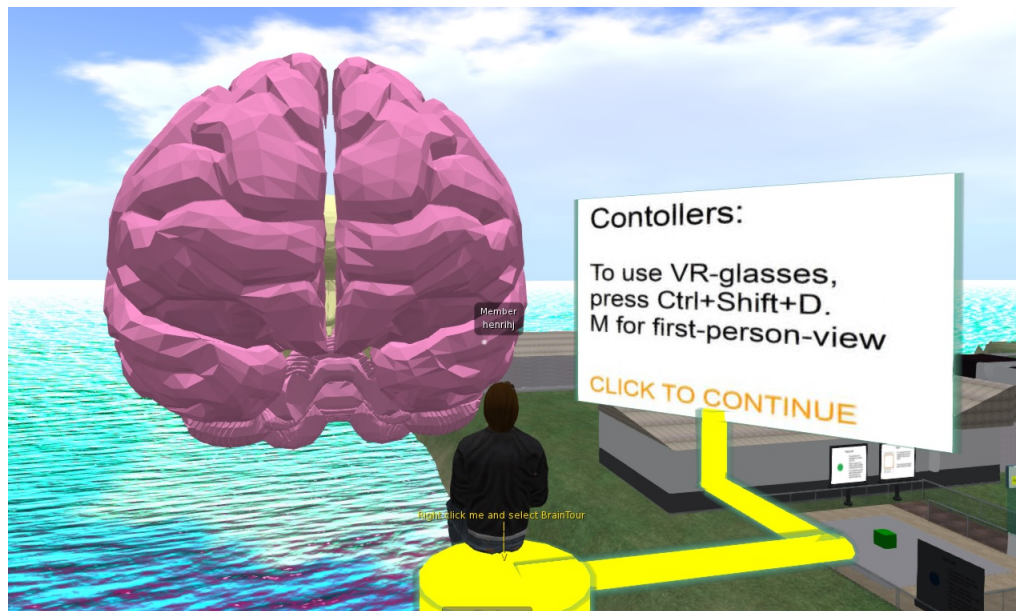
Figure 27: Stage 1: Start stage for the tour

Stage 2, human navigation system

The next stage in the tour is focused on the limbic system of the brain. Figure 28 shows the blurred version of the outer layers of the brain and the limbic system with some of its sub-components. The blackboard gives the user short introduction to the human navigation system: "that it records and storing spatial information about the environment".
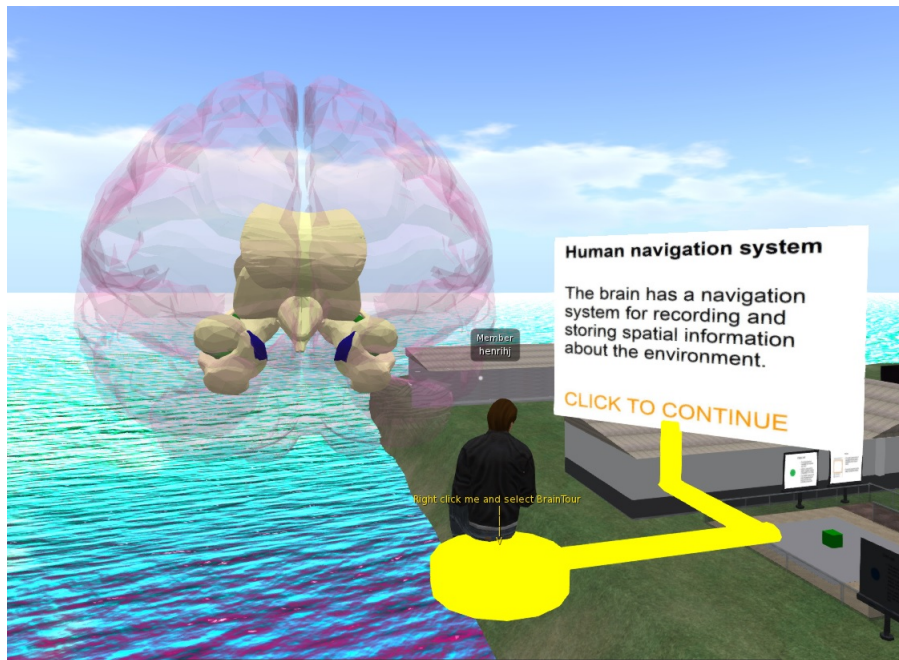
Figure 28: Stage 2: Outer layers of the brain and the limbic system

Stage 3 and 4, rotation of the brain model.
The next stage is the same as the pervious, but the brain is now rotating. It gives the user a 360 degrees view of the limbic system model. Figure 29 shows the rotation of the brain model. By clicking once more on the blackboard, the rotation stops and the brain model goes back to its original rotation degree.
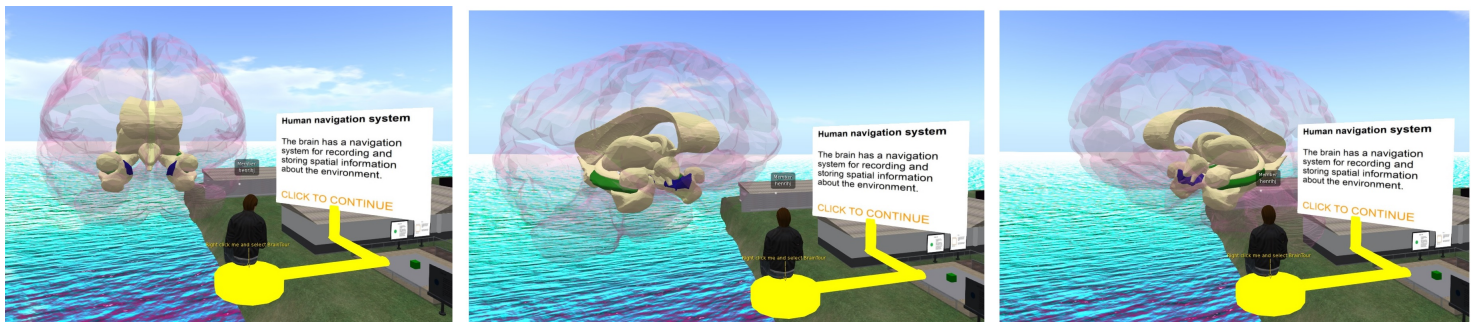
Figure 29: Stage 3: Rotating brain showing the limbic system

Stage 5, closer lookup and information about the limbic system
At this stage, the guide takes the user closer to the brain model and the outer layers of the brain gets invisible. The blackboard gives the user some information about the limbic system and human navigation system.

Figure 30: Stage 5: Limbic system and the human navigation system

Stage 6, main components in the human navigation system
At this stage, the upper part of the limbic system gets blurred out and the brain starts to rotate. The rotation gives the user a better perspective of the limbic system. The hippocampus and entorhinal cortex are presented at the blackboard and colored with green and blue in the brain model.
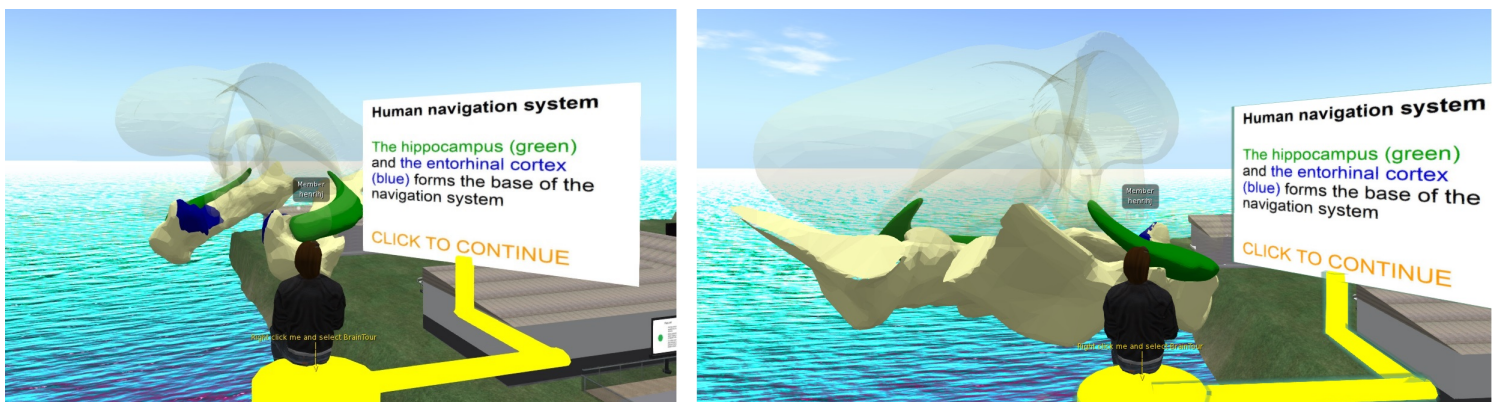
Figure 31: Stage 6: system

Stage 7, hippocampus and place cells.
At this stage, the brain model stops rotating and the upper part of the limbic system is invisible. The blackboard introduces the user to the place cells, located inside the hippocampus.

Figure 32: Stage 7: Hippocampus

Stage 8, entorhinal cortex and grid cells
The lower part of the limbic system, excluding the hippocampus and entorhinal cortex, gets blurred out.The blackboard introduces the grid cells, located inside the entorhinal cortex.

Figure 33: Stage 8: Entorhinal

Stage 9 and 10, rotation of entorhinal cortex and hippocampus
Stage 9: The model, including the hippocampus and the entorhinal cortex, starts to rotate. It gives the user a close lookup on the hippocampus and the entorhinal cortex without the disturbance of other components.
stage 10: stops the rotation.
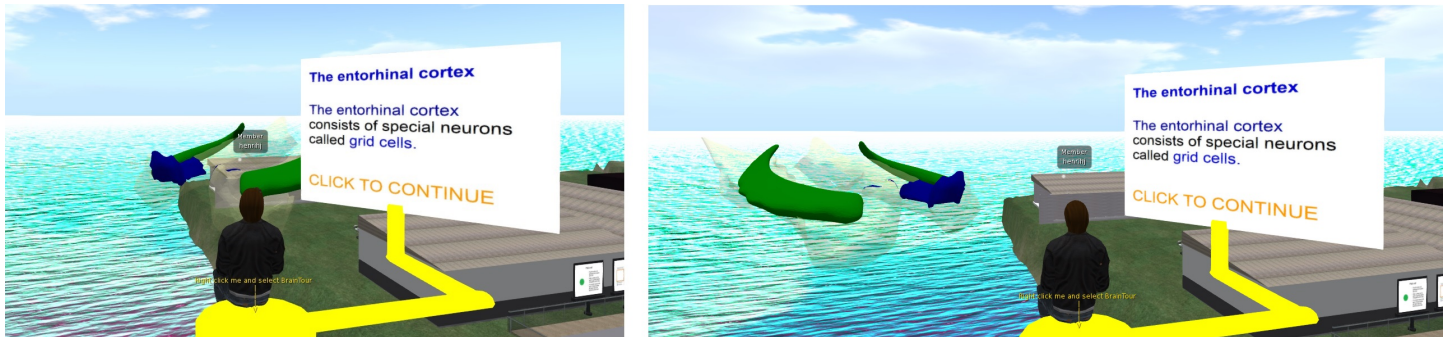
Figure 34: Stage 9: system

Stage 11, place cells inside the hippocampus
The guide take the user closer to the hippocampus. Inside the hippocampus, several place cells are present. The blackboard gives the user an explanation of how place cells work.
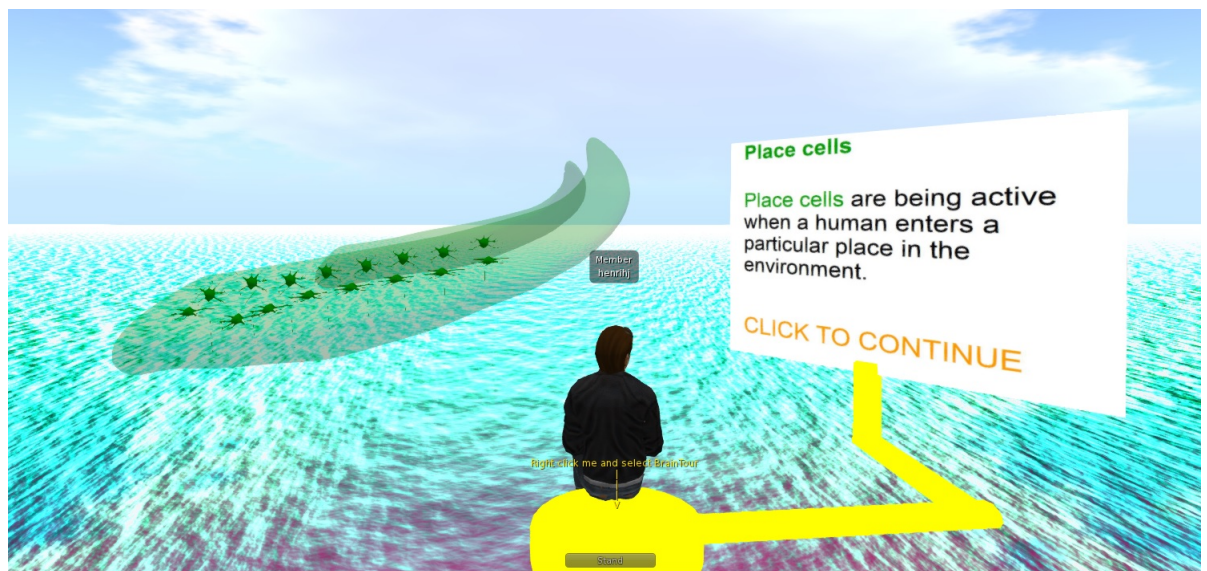
Figure 35: Stage 11: place cells

Stage 12, activation of place cells

One of the place cells in the hippocampus starts to blink. This indicates that the cell is active. This is shown in the Figure below.
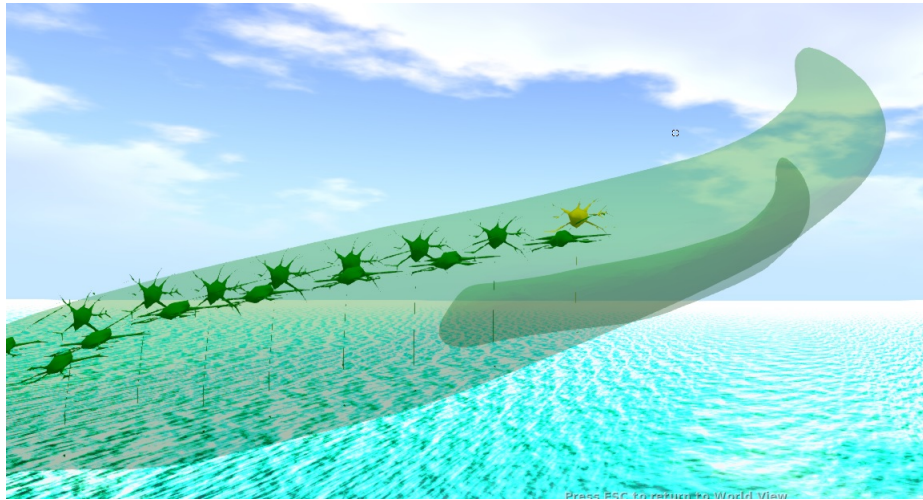
Figure 36: Stage 12: active place cell

Stage 13, grid cells

The guide take the user closer to the entorhinal cortex. Inside the entorhinal cortexx, several grid cells are present. The blackboard gives the user an explanation of how grid cells work.
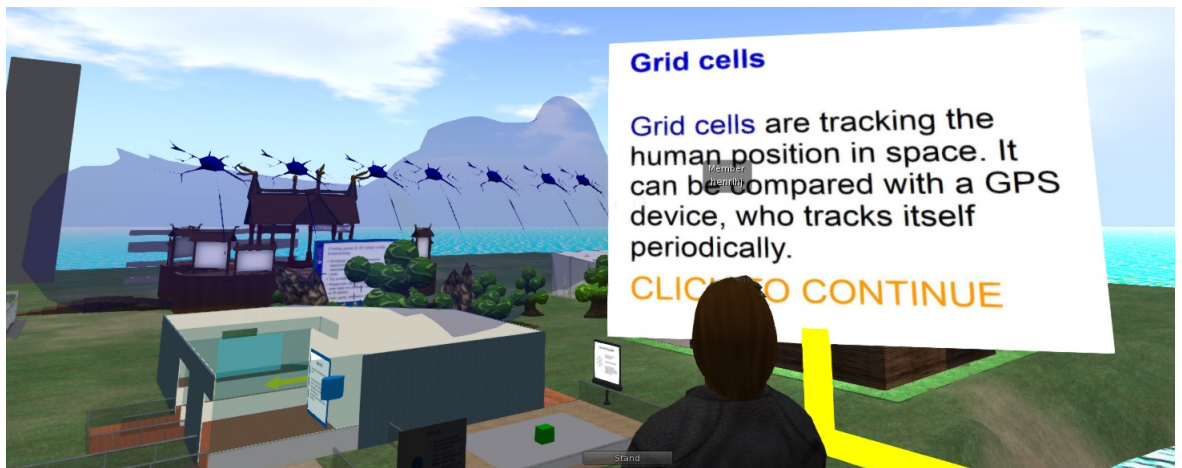
Figure 37: Stage 13: grid cell

Stage 14, activation of grid cells
One of the grid cells in the hippocampus starts to blink. This indicates that the cell is active. This is shown in the Figure below.
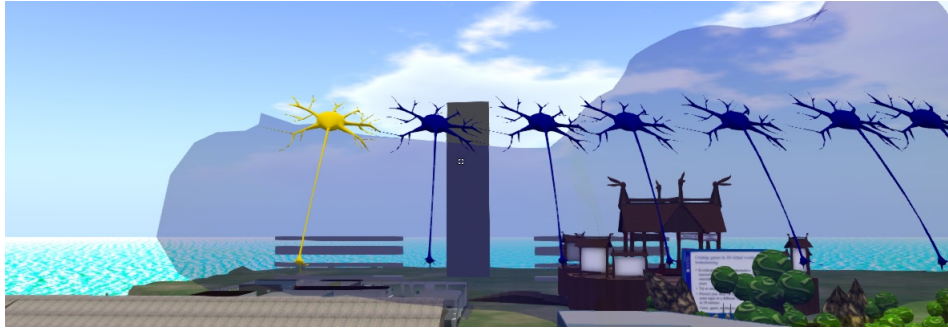
Figure 38: Stage 14: active grid cell

Stage 15 and 16, ending of the tour tour ending
The brain model returns to its original state. The blackboards thanks the user for the tour.
Stage 16. the user is returned to the HNC.
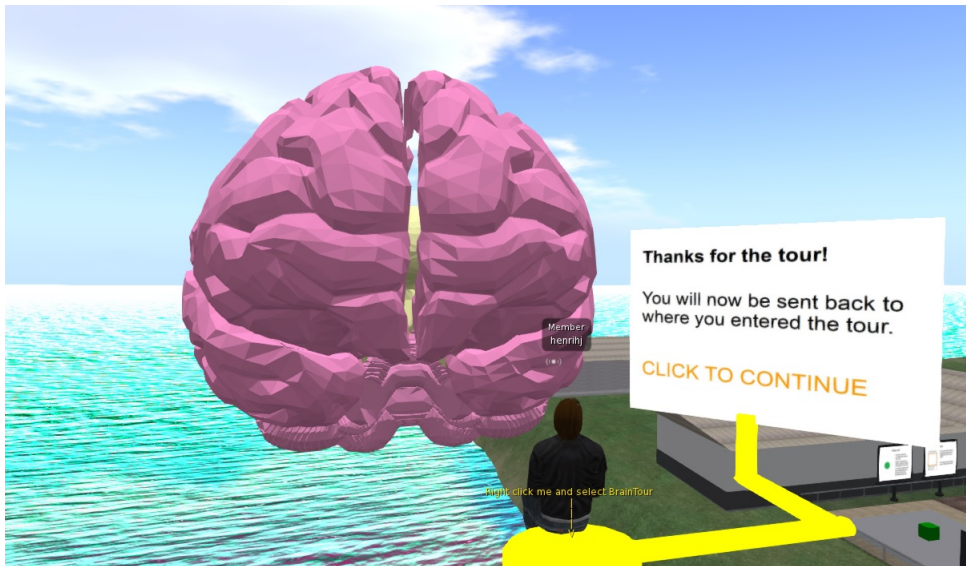
Figure 39: Stage 15: ending of the tour

4.2.4   Simulation of cell activity stage

This subsection includes components that are crucial for the conducting of the simulation of cell activity. It includes the structure of the simulation, the HUD, the HUD sub-components and the HUD activation tutorial.

4.2.4.1   Structure of the simulation   The simulation consists of three different states, where only one state is active at all times. The states are:

- No simulation

- Simulation of place cell activity

- Simulation of grid and place cell activity

Figure 40 shows the the states and transitions between each state. In the transition between states, the previous simulation is reset.
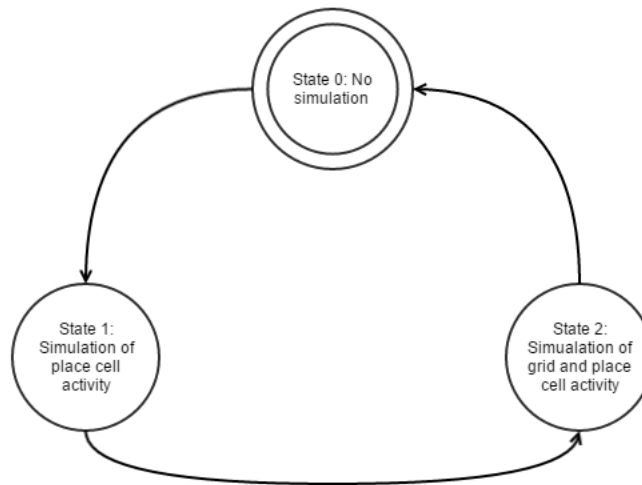
Figure 40: Project processfdfd

Figure 41 shows the different states, dependant on the users position in the HNC.
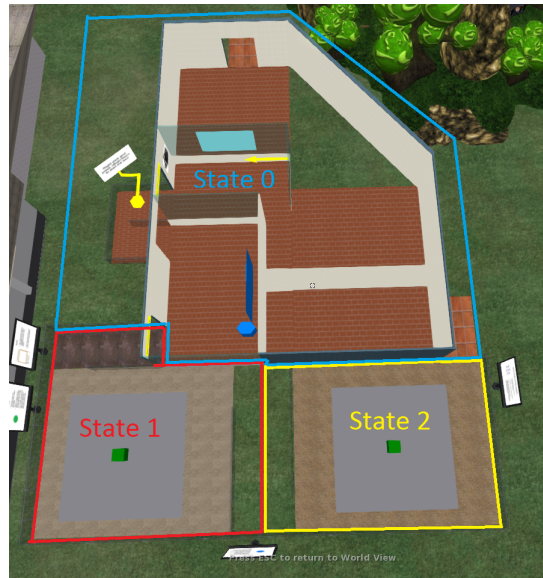
Figure 41: Simulation state dependant of avatar position

State 0, no simulation
The default state, state 0, is a state were no simulation is currently active. This state includes the introduction stage and the guided brain tour stage of the HNC.

State 1, simulation of cell activity
If the avatar is inside the cubical marked with state 1, the user is conducting a place cell simulation.

State 2, simulation of grid and place cell activity
If the avatar is inside the cubical marked with state 2, the user are conducting a simulating of both place and grid cell.

HUD
The HUD is an object that can be statical attached to the users screen. That means, even if the user are changing the view with rotating the avatar, the HUD will still remain at the same position on the screen.

The purpose of the HUD in this case is to get a 2D representation of the grey plane inside the cubicals, located in both state 1 area and state 2 area. This representation will then be mapped with cell activity data from the simulations in state 1 and state 2.

The HUD was created by creating simple objects with the SL inbuilt "Create tool" and link these objects together in SL. All the components were

customized before the linking was done, so they could react unique on commands from the HUD.

This was done because I did not find a way of moving the internal sub-component of the HUD in SL. The only thing i wqs able to make them do was to make them visible or invisible. Figure 42 shows the final HUD. An explanation of the different HUD sub-components is given below.
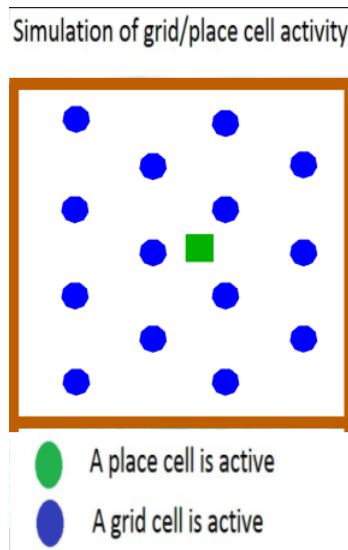
Figure 42: HUD

Behavior of the HUD
The HUD checks mainly two things in each iteration, the change of state and if the current position should be marked with an brain activity object at the HUD.

If the HUD have changed state, then all the subcomponents have to be reset to their default value for a new simulation. If the current state is 0, then all the subcomponents in the HUD and the HUD itself should be set to invisble. If the current state is not 0, then only the HUD frame should be present. This can be seen in Figure 43.

Simulation of place cell activity

A place cell is active

A grid cell is active
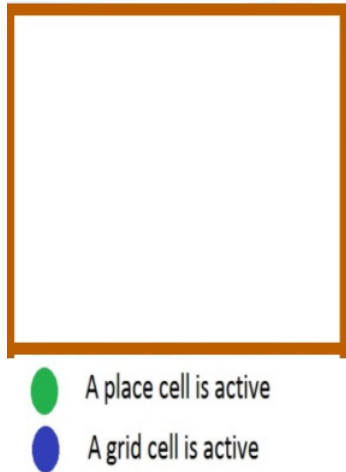
Figure 43: HUD frame with no cell activity registered

The conditions that determine if a position should be marked with an cell activity is based on two types of cells activity: grid and place cells activity.

For the check of the place cell activity, the only thing needed to be checked is weather the avatar is close to the green box or not.

The checking of grid cell activity consist of checking the position with some hardcoded coordinates, based on a hexagonal grid cell pattern. If the position of the avatar matches one of these coordinate conditions, a message to the related subcomponent is sent through a linked message.

Under is a pseudocode for the HUD. The full code an be found in appendix D.

```
previousState;
while true do
    position = getPosition();
    state = checkCurrentState(position);
    if state != previousState then
        reset subcomponents;
        if state == 0 then
            make all subcomponents invisible;
            make myself invisible;
        else
            send stage to header;
        end
    else
        if check for brain activity(position) then
            send message(position);
        end
    end
    previousState = state;
end
```

HUD header

The HUD header is an object that contains two textures, one for each of the simulation stages. When the HUD are sending a linked message about the change of a state, this object either changes texture or makes itself invisible. A pseudocode for the header is presented below. The full script can be found in appendix D.

```
if new message received then
    if I was the receiver(message) then
        if message == state0 then
            make myself visible;
        else
            change texture(message);
        end
    end
end
```

Brain activity objects

Before the brain activity objects were linked together with the rest of the HUD, the scripts in each of the objects were customized to make the ID of each object unique. Figure 44 shows the identification process of the objects.

First, all the object got assigned a letter for what color the object has. Then, the next number represents their coloumn number. The last number represents their row number. So the blue marker at the lower left corner would have ID "b06".
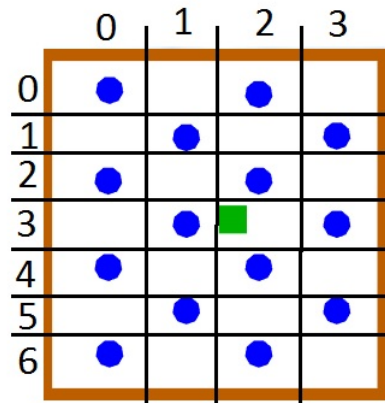
Figure 44: Identificatin of brain activity objects

When the HUD sends a message, each of sub-components check if the message is equal to reset. If true, then all sub-components get invisible.

Then all the objects check if they are the receiver, based on the message sent. If that is true for an object, this object makes itself visible. A pseudocode for this is presented below.

if *new message received* **then**
    if *message == reset* **then**
        | make myself invisible;
    end
    if *I am the receiver(message)* **then**
        | make myself visible;
    end
end

HUD-tutorial

The HUD-tutorial includes a text based set of instructions on how to activate the HUD for any avatar.
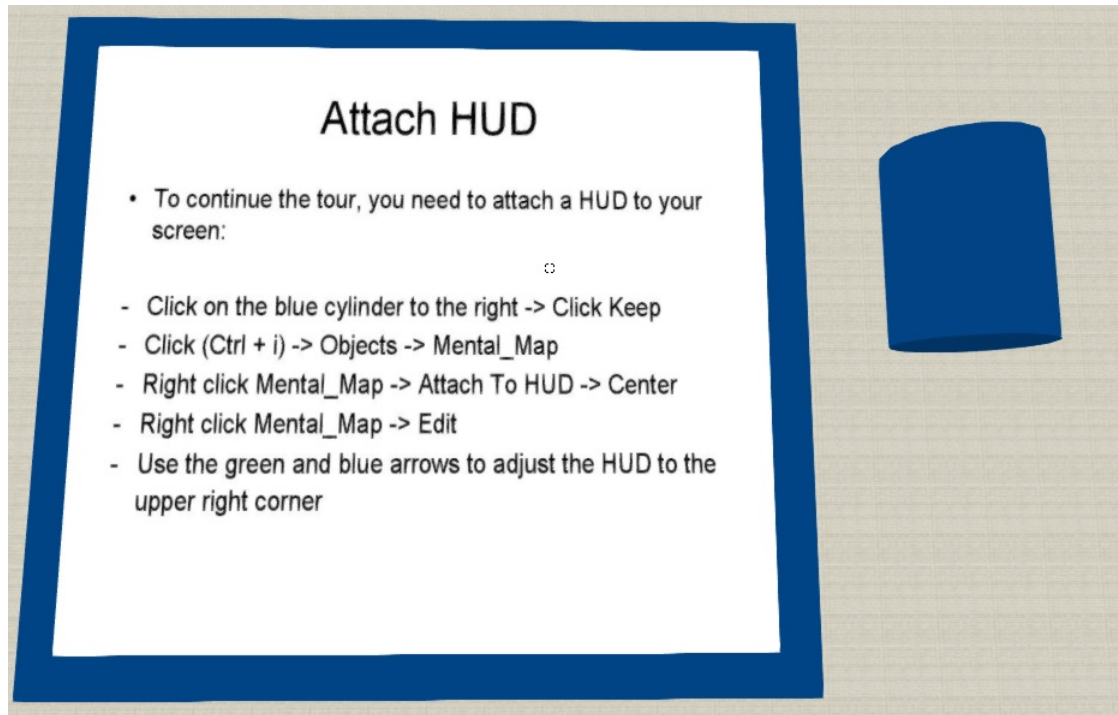
Figure 45: HUD-tutorial

The conducting of the place cell simulation

The simulation of place cell activity is taking place in the grey plane in the first cubical. When the avatar moves close to the green box inside the cubical, a green marker appears at the HUD, indicating place cell activity at this location.

Figure 46: Simulation of place cell activity

The conducting of the grid and place cell simulation

The simulation of grid and place cell activity is taking place in the grey plane in the second cubical. In addition to the place cell activity marker at the HUD when navigating close to the green box, blue markers appear at the HUD with even distance to each of its blue marker neighbours. This indicates grid cell activity. After navigating through the whole plane, the markers of grid cell activity form an hexagonal pattern.
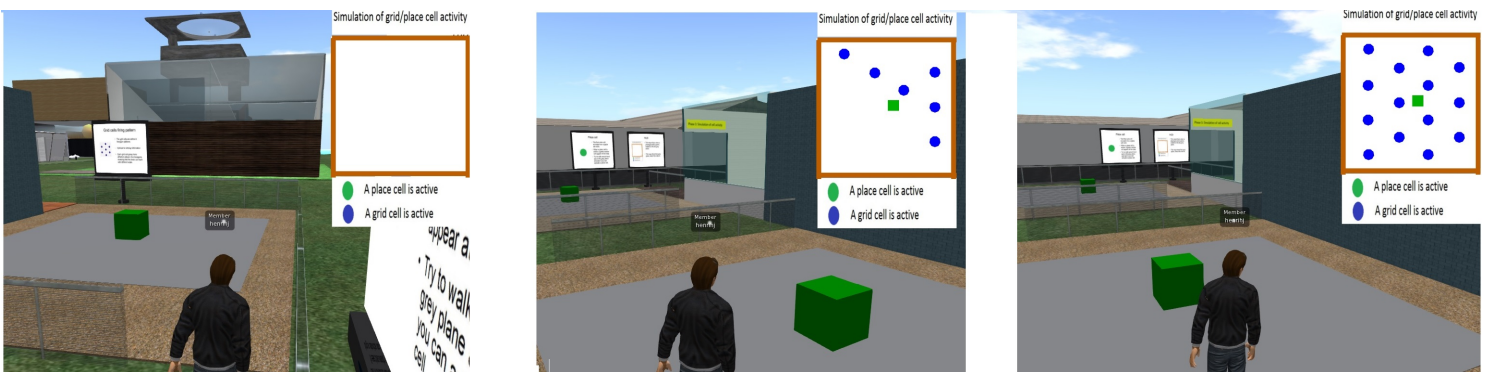
Figure 47: Simulation of grid and place cell activity

4.3   Unimplemented requirements

Due to problems with the LSL-coding of the SL vehicle guide, the GBT1.3, "The guide should be movable", was not fully implemented. The intention with the requirement, was that it could have the possibility to "dive" into the different parts of the model down to cell level. This unimplemented requirement may therefore reduce the immenseness of the guided brain model stage. This should therefore be considered to implement in the future.

Another unimplemented requirement was the R6 requirement, "the project should contain the guided through the virtual campus". This was not implemented with the same reasoning as above and time constraints.

5   Evaluation

The evaluation of this thesis was split into a general public part and a expert part. The evaluation was done to see if the HNC was suitable for giving the general public an understanding of the human navigation system.

The general public evaluation was slit into two parts, a quantitative evaluation and a qualitative evaluation. The quantitative part of the evaluation consisted of a tour through the HNC, followed up by a short questionnaire. The qualitative part consisted of a tour through an extended version of the HNC, followed up by an interview.

The expert evaluation was based on previous tours through the HNC by the SME, screenshots of the HNC and an interview.

In this evaluation, the Second Life Project OculusRift viewer[2] was used to conduct the tour through the HNC.

5.1   General Public Evaluation

The general public evaluation were split into parts. The first one forms the basis of the quantitative research method in this thesis, while the second iteration forms the qualitative research method in the thesis.

5.1.1   Quantitative evaluation

The quantitative part of this evaluation was conducted by holding stands and recruiting people at the science center, "Vitensenteret", and the local tourist office, "Visit Trondheim". This process was conducted on both the 2nd of May and the 9th of May.

Participants
The quantitative part of the evaluation recruited a total of 21 participants, who also were willing to conduct the questionnaire afterwards. The participants were fairly evenly distributed between the science center and the tourist office.
At the science center, 14 kids aged from 6-12 also conducted the tour through the HNC. Because they did not understand the questionnaire and the relation to the human navigation system, a digital smiley survey was developed to see if the kids liked the tour through the HNC or not.

Procedure
The participants were logged into SL, using my own SL account, and placed in front of the HNC entrance. At that moment of time, the participants did not wear the HMDs. The participants were told orally that they should explore the HNC and conduct the guided brain and the simulation of cell activity.

The participants then navigated themselves to the guided brain tour. Some of

the participants then needed help to get the SL browser into HMD mode to prepare the guided tour with the HMD glasses. Figure 48 shows a participants wearing the HMD glasses.

Figure 48: A participant with HMD glasses

After the participants assembled the HMDs, almost all of them needed help to find the mouse for clicking on the blackboard to continue the trip.

After the guided tour through the brain, four participants did not want to continue the tour in the HNC to the simulation of cell activity stage. The reasoning behind this was that some of them felt dizzy after using the HMDs and some because of time issues. Figure 49 shows a participant in the conducting of the guided brain tour in SL.

Figure 49: A participants in the conducting of the guided brain tour

The participants did not try to activate the HUD from the HUD-tutorial. This was not done to not confuse them with technical issues, when observing that they already have full focus on trying to understanding the human navigation system topic.

The ones that continued the HNC tour to the simulation of cell activity stage, took of the HMDs. The HUD popped automatically up with no further information of why. This explanation and the explanation of the HUDs sub-components were given orally to the participants.
During the evaluation, it was noted that especially older people had problems with basic navigation in SL, done by using the arrows keys on the keyboard. Figure 50 shows a participant in the conducting the simulation of place cell activity.

Figure 50: A participants in the conducting of the simulation of place cell activity

After the tour through the HNC, the participants filled out a questionnaire, found in appendix A. This questionnaire has several questions related to the learning potential of the HNC. The results of this questionnaire can be found in the next chapter.

5.1.2   Qualitative evaluation

For qualitative part of the general public evaluation, the participants were asked to complete the tour through the HNC. After the tour, an interview based on the interview guide in appendix B was conducted. This interview was taped by using a recording device for further use.

Participants
The participants in this evaluation were four male and two females with no or low previous knowledge of the human navigation system and SL. All the participants were students from either NTNU or HiST. They were all recruited as volunteers.

Procedure
The evaluation started with the participants got an introduction to the human navigation system by the introduction video from the introduction stage of the HNC. This was done jointly for all the participants by using a projector for saving some time.

The participants then, one by one, got logged in to the SL server and placed in front of the entrance at the HNC. They were then asked to complete the tour through the HNC.
Since they already have seen the introduction video, the introduction stage of the HNC was skipped.

The participants then navigated themselves to the guided brain tour stage. During the guided tour, they pointed out that a status of how far they have come in the guided tour should be present. Especially when using the HMDs. Figure 51 shows a participant wearing a HMD.

Figure 51: Participant wearing a HMD

In this evaluation, the participants were asked to try to activate the HUD by using the tutorial. The actual activation of the HUD went well, but the participants pointed out that the HUD were invisible immediately after activation. That made them insecure if the activation have gone well or not. The participants then continued their tour through the HNC with the simulation of cell activity stage.

After the tour through the HNC, all the participants were gathered to conduct a joint interview. This interview were based on the interview guide presented in appendix B. The results of this interview can be found in the next chapter.

5.2   Expert Evaluation

The evaluation with SME was done before the evaluation of with the general public, so some of the feedback from this evaluation have been used to improve the implementation between those evaluations.
It was used to verify the realism of the models and to verify the human navigation system related concepts presented in the HNC.

Participants
The participants in this evaluation were SME at the Kavli Institute for Systems Neuroscience. The SME have been consulted through the information adviser, Hege Jørgensen Tunstad, from the same institute. She is especially suitable for evaluate the HNC, since she already have tried to explain the human navigation system topic to the general public through the development of the A-Mazing race game[60].
At the day of evaluation, two other SME were also present.

Procedure
The evaluation consisted of a tour through the brain and simulation of cell activity. The brain tour was focused on the visual appearance of anatomic components in the brain, the correctness of these in form of anatomic form and placement and possible improvements. The focus on the simulation of cell activity was whether the simulation gave an insight into the cell firing patters, whether its components represented this in a good way and possible improvements.

At the evaluation date, the SL guide in the guided tour through brain was not yet fully implemented, so the SME were not able to conduct the guided brain tour. The SL guide was replaced by using SL navigation and the SL "fly function". The functionality of the brain model was still coded, so all the brain model elements from the guided brain tour were evaluated.

During the evaluation, feedback from the SME was given on the fly as the tour through the HNC continued. This was recorded by a recoding device.

Do to time constrains and much activity at the Kavli Institute for Systems Neuroscience, a final evaluation tour through the HNC was not conducted after the general public evaluation.

The changes made after this evaluation were presented to the SME as a series of screenshots of changes since the first evaluation, along with some questions related to the learning potential of the HNC and correctness of the models. These questions can be seen in appendix C

6   Results

6.1   Results from quantitative part of the general public evaluation

The questionnaire from the first the general public evaluation was answered by 21 participants. Below are figures that shows the result from this questionnaire. The main focus of the evaluation was related to general experience with the HNC, the use of HMD devices and HNC and potential learning.

Participant background
Of the participants that filled out the questionnaire, 12 out of 21 were males and 9 of 21 were females. 62% of the participants were in the age range from 18-40 years. 29% of the participants were between between 40 and 60 years old. 5% of the participants were in aged between 0-18 years old. The age range from 60 and above were also represented with 5% of the participants. Most of the participants did not have much previous knowledge about the human navigation system. 80% answered none or low about this knowledge, while 20% of the participants answered moderate or high on this question.

Figure 52: Gender?

Age

0-18	1	4.8 %
18-40	13	61.9 %
40-60	6	28.6 %
60+	1	4.8 %

Figure 53: Age?

Previously knowledge about the human navigation system?

None	7	33.3 %
Low	10	47.6 %
Moderate	2	9.5 %
High	2	9.5 %
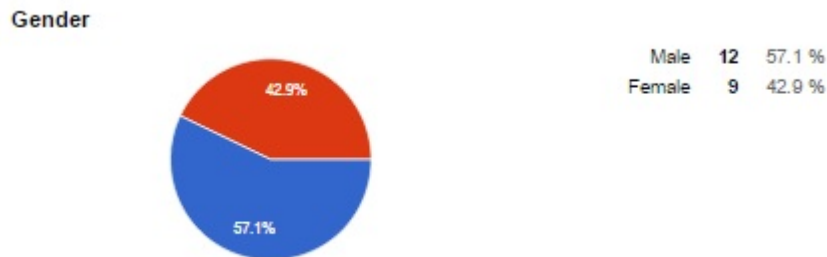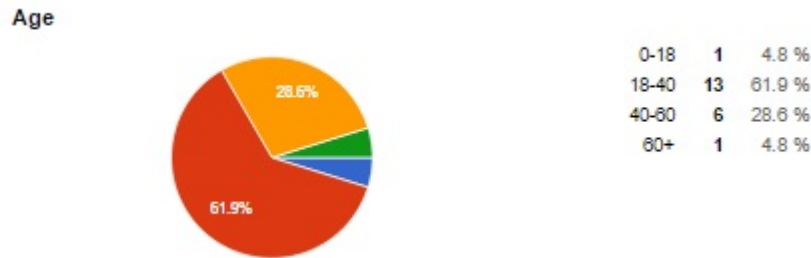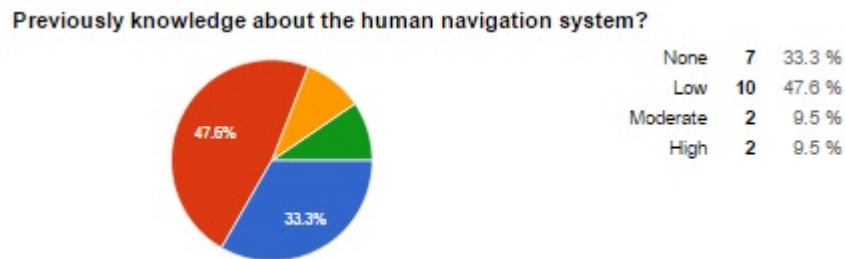
Figure 54: Previous knowledge of the human navigation system?

General experience of the HNC

On the claim that the visualization was interesting, the majority of the participants with 71% answered "strongly agree". The rest of the participants answered "agree" on this claim. This indicates that the implementation of the HNC is interesting to the general public.

Figure 56 shows the distribution on the question of which visualization approach the participants preferred. The results shows a slight slope in the distribution towards the guided brain tour compared to the simulation of cell activity. In this result, the fact that four of the participants did not conduct the simulation of cell activity must the taken into account, because it may have affected the result.

Figure 57 shows the result of the smiley survey for the kids that were not able to conduct the questionnaire. From the figure, 64% answered that they liked the HNC, by selecting one of the "smiling" smileys. 21% were undecided about this, while 14% did not like the HNC.

Strongly Disagree	0	0 %
Disagree	0	0 %
Undecided	0	0 %
Agree	6	28.6 %
Strongly agree	15	71.4 %
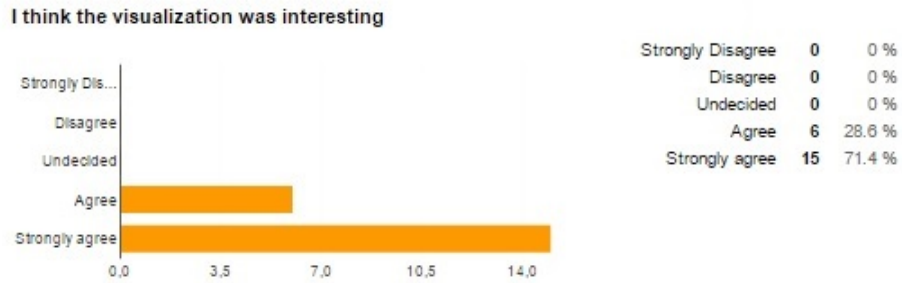
Figure 55: I think the visualization was interesting

Tour through the brain	12	57.1 %
Simulation of place / grid cell activity	9	42.9 %
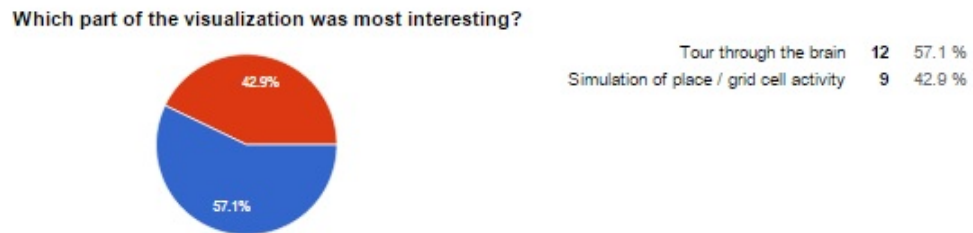
Figure 56: Which part of the visualization was most interesting?
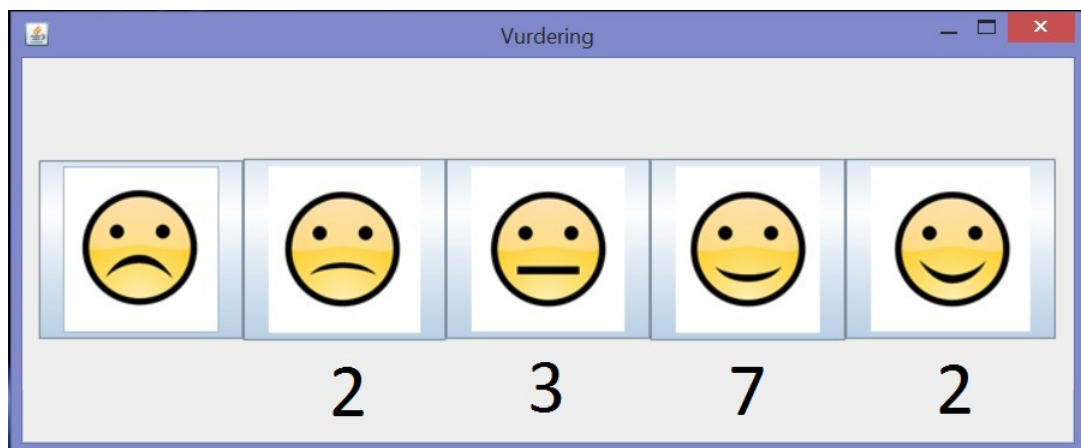
Figure 57: Smiley survey for kids

HNC and potential learning of the human navigation system
On the claim that the visualization gave the participants an understanding is structured anatomically, 86% of the participants answered "agree" or "strongly agree". 5% were undecided on this claim, while 10% did not think that the HNC provided them with an understanding of the human navigation system.

On the claims that the HNC gave the users understanding of how grid and place cells work, the distribution of the results were evenly between the two claims. 72% answered agree on the claim related to the place cells. Here, 19% were undecided, while 10% answered "disagree". In the claim related to the grid cells, 67% answered "agree" or "strongly agree". 24% of the participants were undecided, while 10% of the participants disagreed with this claim.

The visualization give me an understanding of how the human navigation system is build up

Strongly Disagree	0	0 %
Disagree	2	9.5 %
Undecided	1	4.8 %
Agree	13	61.9 %
Strongly agree	5	23.8 %
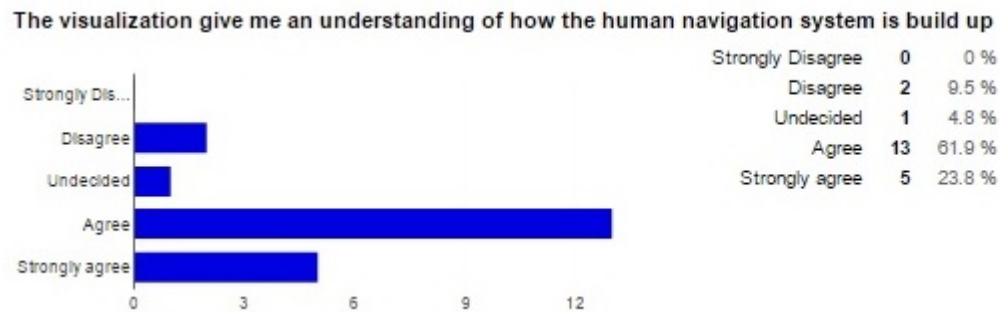
Figure 58: The visualization give me an understanding of how the human navigation system is build up

I understand how place cells work

Strongly Disagree	0	0 %
Disagree	2	9.5 %
Undecided	4	19 %
Agree	9	42.9 %
Strongly agree	6	28.6 %
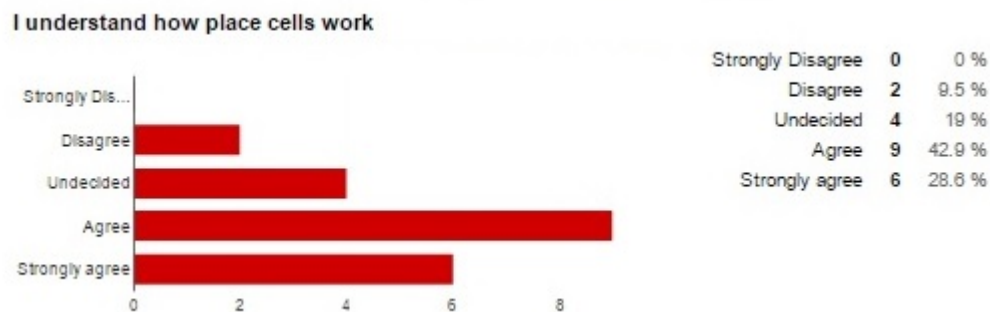
Figure 59: I understand how place cells work

I understand how grid cells work

Strongly Disagree	0	0 %
Disagree	2	9.5 %
Undecided	5	23.8 %
Agree	10	47.6 %
Strongly agree	4	19 %
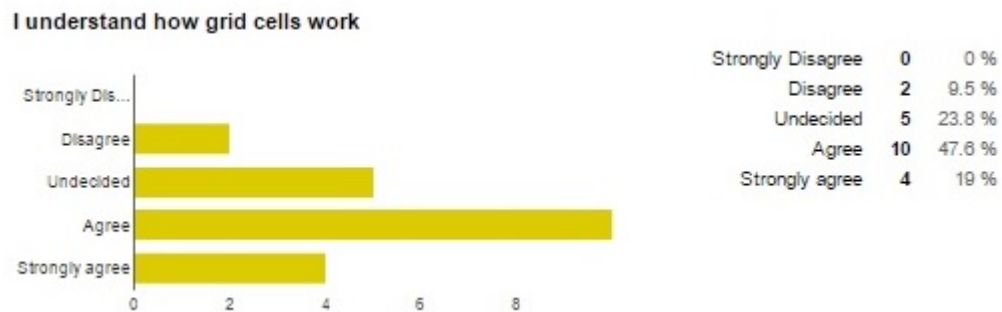
Figure 60: I understand how grid cells work

The use of the HMDs
Of the 21 participants, 86% of them answered "agree" or "strongly agree" on the claim that the HMD provided presence and involvement in the virtual environment. The remaining 14% of the participants answered "undecided" on this claim.

The participants were unevenly distributed in their answers on the claim that they felt physical discomfort using the HMDs. 38% of the participants answered "disagree" or "strongly disagree" on this claim, 29% answered "undecided" on the claim, while 33% answered "agree" or "strongly agree" on this claim.

I felt presence and involvement in the virtual environment by using the VR-goggles

Strongly Disagree	0	0 %
Disagree	0	0 %
Undecided	3	14.3 %
Agree	13	61.9 %
Strongly agree	5	23.8 %
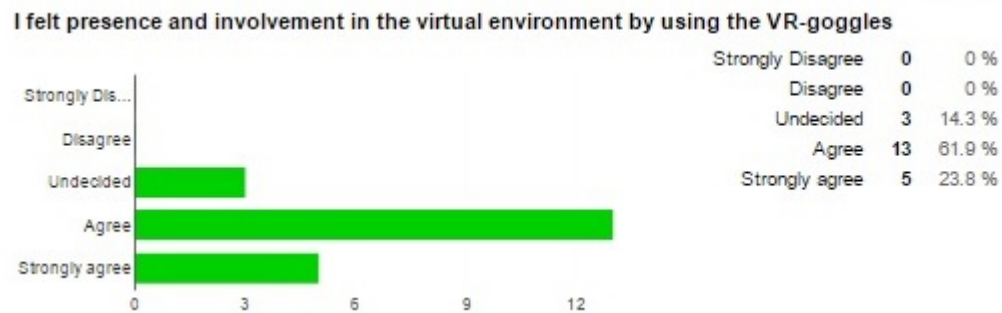
Figure 61: I felt presence and involvement in the virtual environment by using the VR-goggles
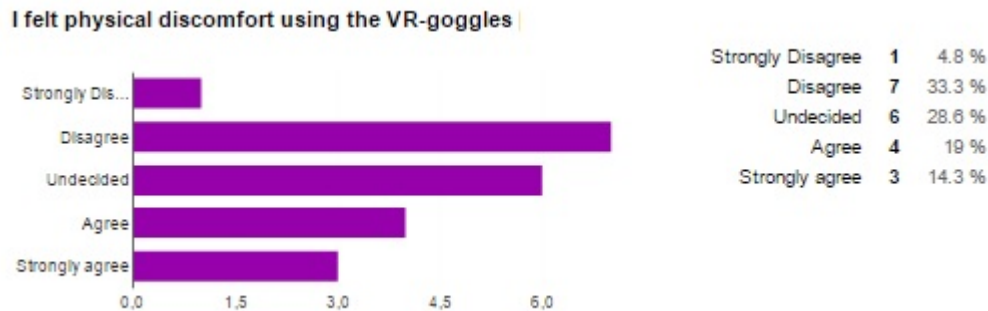
Figure 62: I felt physical discomfort using the VR-goggles

6.1.1   Comparison of quantity results

This section conducts a comparison between the results gathered in the master thesis to the results gathered in the specialization project. Most of the questions in the questionnaire were transferred from the specialization project to the master thesis, to enable comparison of data results. The following section is a comparison of the data gathered.

The weighted score is computed by multiplying the percentage of the distribution with the score representation for the answer alternative for each answer alternative. The weighted score is finally computed by summing all these sub-scores [59].

Answer alternative	Score
Strongly agree	5
Agree	4
Undecided	3
Disagree	2
Strongly disagree	1

Table 7: Answer alternative and score representation

General
Table 8 shows a relative unchanged distribution in the answers to the question of which part of the HNC the participants in the different evaluations thought was most interesting.

	Specialization project	Master thesis
Guided tour through the brain	50%	57%
Simulation of cell activity	50%	43%

Table 8: Which part of the HNC was most interesting?

Table 9 shows the distribution in the answers about the claim that the visualization was interesting. The clear improvement in the weighted score indicates that the participants of the master thesis evaluation thought the visualization was more interesting then the participants of the specialization project evaluation.

Topic:	Specialization project	Master thesis
Strongly agree	24%	71%
Agree	41%	29%
Undecided	29%	0%
Disagree	6%	0%
Strongly disagree	0%	0%
Weighted score	**3.83**	**4.71**

Table 9: I think the visualization was interesting

HNC and potential learning of the human navigation system
Table 10 shows the distribution of the answers to the claim that the HNC gave the participants an understanding of how the human navigation system is structured anatomically. The slight increase of weighted score from the evaluation of the specialization project to the master thesis indicates that the HNC implemented in the master thesis gives a better understanding of the anatomic structure of the human navigation system, compared to the early version of the HNC in the specialization project.

	Specialization project	Master thesis
Strongly agree	18%	24%
Agree	35%	62%
Undecided	35%	5%
Disagree	12%	10%
Strongly disagree	0%	0%
Weighted score	**3.59**	**4.03**

Table 10: The visualization gave me an understanding of how the human navigation system is build up

Table 11 shows the distribution of the answers to the claim that the HNC gave the participants an understanding of how the grid cells inside the human navigation system works. The slight increase of weighted score from the evaluation of the specialization project to the master thesis indicates that the HNC implemented in the master thesis gives a better understanding of grid cell works, compared to the early version of the HNC in the specialization project.

Topic:	Specialization project	Master thesis
Strongly agree	12%	29%
Agree	53%	43%
Undecided	24%	19%
Disagree	6%	9%
Strongly disagree	0%	0%
Weighted score	**3.56**	**3.92**

Table 11: I understand how grid cells work (place cells was not asked about in the specialization project)

The use of the HMD
Table 12 shows the distribution of the answers to the claim that the HMD did provide presence and involvement in the virtual environment. The slight increase of weighted score from the evaluation of the specialization project to the master thesis indicates that the participants at the master thesis evaluation was more agree on this claim then the participants at the specialization project evaluation.

Topic:	Specialization project	Master thesis
Strongly agree	24%	14%
Agree	24%	62%
Undecided	41%	24%
Disagree	12%	0%
Strongly disagree	0%	0%
Weighted score	**3.63**	**4.10**

Table 12: I felt the presence and involvement in the virtual environment by using VR-goggles

Table 13 shows the distribution of the answers to the claim that the participants felt physical discomfort using the HMDs. The slight increase of weighted score from the evaluation of the specialization project to the master thesis indicates that the participants at the master thesis evaluation felt slightly more discomfort then the participants at the specialisation project evaluation.

Topic:	Specialization project	Master thesis
Strongly agree	12%	14%
Agree	24%	19%
Undecided	24%	29%
Disagree	18%	33%
Strongly disagree	18%	5%
Weighted score	**2.82**	**3.04**

Table 13: I felt physical discomfort when using the VR-goggles

6.2   Results from qualitative part of the general public evaluation

This results are based on an interview with six studentes, aged from 22-26, with no or low previous knowledge about the human navigation system. Below is a summary of the results conducted during the interview. The interview guide can be found in appendix C.

6.2.1   General experience with the HNC

The participants thought that the HNC was interesting. They thought that the tour through the HNC was more fun than motivating. The human navigation system is a complex and narrowly subject. Therefore, a basic understanding of the human navigation system is more than enough for the general public. They thought that few would actually be motivated for further use.

The students thought that the HNC explained the difference between grid and place cells in a good way. It provided a good basis to understand the basis of the human navigation system. They also thought it was fun to get a basic insight into the research field that got the Mosers the Nobel Prize.

The students were also engaged by the interactive parts of both the guided brain tour and the simulation of cell activity.

The structure of the HNC
The students liked the implementation of the introduction stage, which formed "a basis for further understanding and learning of the human navigation system topic" one participant stated. They also pointed out that the structure of the HNC comparable to a school-lesson, where they first have a passive learning session and then an active learning session.

Guided brain tour stage vs simulation of cell activity stage
The students thought that the different visualizing methods were both helpful in their own way. The guided brain tour stage was easier to understand, straight forward and the standard way of of conducting a passive learning method. On the other hand, the simulation of cell activity was existing and a new way of learning for many of them. The active learning gave them more practice knowledge of how the cells worked. Both the visualizations approaches were understandable to them.

6.2.2   The introduction stage

The introduction video in the introduction stage gave the students prior knowledge to the human navigation system subject. This prior knowledge was

useful to understand the visualizations at later stages in the HNC. If they have not seen the video, the students thought that they would use more time figuring out what the visualization was trying to explain then they did.

6.2.3   The guided brain tour stage

The students thought that the brain tour was understandable. According to them, it consisted of short and simple information which was easy to the user to understand, altough the professional terminology as the hippocampus and entorhinal cortex was hard to process.

The students thought that it was a good solution to let the user decide when to go to the next stage of the simulation, by clicking on the blackboard. In that way, the users were able to stop the simulation on a stage that was interesting or had to understand.

They also thought that the mix of a static brain and a rotating brain was a good way of seeing the brain model from multiple views. The rotating brain helped in their perception of the speciousness of the brain components. It was simultaneously disturbing the user when trying to read information from the blackboard.

The technical solution in the guided brain tour, where the user shifts point of view between the blackboard and the brain model, gave one of the participants pain in the neck. By using HMDs, she forgot to rotate her body and did only rotate her head. This led to pain in her neck after the tour.

The blackboard gave the user useful information. Although the information was short and concise, the users did not feel that it should be extended. The amount of information was suitable for the general public.

For further improvements in this section, the user missed a status on the blackboard, stating the current status of the brain tour. How long they have come and how long they have left.

The brain components in the brain model should also have arrows with description text over them, showing the user which components the blackboard relates to.

One participant stated that the visualization does not provide any information of how this cell information is stored and is being sent through components in the brain. She said that this information is vital for understanding the rest of the system.

The use of HMDs
According to the participants, the use of the HMDs gave the users a immersive and exciting experience. The combination with the rotating brain model and the use of HMDs gave the users a different 3D perspective of the brain model

than they would have gotten without the HMDs, they stated.

The students also stated that the danger in using this technology is that it can take away the focus from the visualizations and the human navigation system.

6.2.4   Simulation of cell activity stage

The simulation of cell activity stage gave mixed feedback from the students. Two of out of six students stated that they did not know what was going on, and they navigated round and round inside the cubicles just seeing some dots popping up on the map. The other four students thought that the simulation of cell activity was understandable.

The students who understood the visualization stated that the sensitivity of the activation of the cells should be reduced. According to them, because of the sensitivity, the user did not get successful feedback based on their navigation inside the planes in the cubicles. The activation of the grid cell seemed almost at random for some of the participants.

HUD
The students thought that the HUD itself was intuitive and easy to understand.
Problems related to the HUD were related to the activation of the HUD. The inventory menu covered most of the HUD-tutorial and users were insecure whether they could close the inventory menu or not.

6.2.5   3D visualizations, HNC and learning

The participants thought in general that 3D visualization could be used in a very high degree for learning about complex science phenomenons. One of the big advantages of using 3D visualizations that the users stated, was that it can bring new views and new methods of learning this phenomenons.

One statement from one of the participant was that the VR gives the possibility to adapt the visualization and its details to multiple audiences, by having different difficulty levels. All the participants thought that 3D visualizations belong to the future.

HNC and the human navigation system
According to the partcipants, the tour through the HNC gave them a basic understanding of the human navigation system. The participants thought initially that the human navigation system was a big and challenging to learn, but the visualization approaches in the HNC made it easier to understand. They would prefer this way of learning about the human navigation system compared to the standard learning by reading in a book.

The simulation of cell activity stage related to the understanding of

how cells in the human navigation system works
The participants stated that the simulation of cell activity stage gave them an understanding of how this system works in real life. They also stated that this understanding would be hard to get through standard reading in a book.

One of the participants stated that he thought that the grid cells firing were related to objects we see and senses in real life. This simulation gave him a new perspective on how these grid cells worked.

The guided brain tour stage related to understanding of the how the human navigation system is structured anatomically
The participants stated that the guided brain tour gave them a basic understanding of the relevant components belonging to the human navigation system inside the brain. One of the participant stated that he had an idea of how this system worked, but the guided tour give an understanding of where in the brain this system is located.

6.2.6   HNC, the relation to real life and possible improvements

The participants stated that it was easy to relate the navigation done in SL to navigation done in the real world. They also stated that the transfer from the place cell firing at SL objects to place cells firing at buildings in the real world was not so intuitive. One of the participants stated that the virtual campus in SL could be used in the simulation for a better representation of real life objects.

The participants were then informed of the unimplemented "guided tour through the virtual campus" requirement, with help of a SL vehicle like in the guided brain tour.
The participants liked the idea, but they would like to explore the virtual campus with simulation of cell activity by themselves. They would also have liked to choose between a place or grid cell simulation, by clicking on a menu option on the HUD.
The participants agreed upon that the next stage of the HNC is to explain the human use of the cells and why we have them. A participant suggested that a future visualization could be how we as humans are using these cells in our daily life.

6.3   Results from expert evaluation

The evaluation from the expert is divided in two. The first iteration contains the main expert evaluation, where an early version of the HNC were evaluated. The second iteration includes final expert evaluation with answers based on the questions in appendix C.

The statements in the sections below are all made by SME.

6.3.1 First evaluation

The first sections below is related to components of the brain model. All the statements are from the SME.

The limbic system model
The placement of the limbic system inside the brain is too far forward and too high, compared to the rest of the brain. The limbic system should also be reduced with approximately 1/10 in size. The mountain formed sub-component at the top of the limbic system model is not a part of the limbic system. This part should be removed.

Hippocampus and entorhinal cortex components
The hippocampus and the entorhinal cortex are correct placed relative to each other, and their shape are roughly correct. Entorhinal cortex is placed in the front and below the hippocampus, which is correct.

Cell model
The cell model is simple and stylized. For a more realistic model, the axon should be reduce so the axon is thinner then the dendrites. The axon terminal should be reduced in size. One axon terminal is so small that is can create a connection with a single dendrite on another cell. In this example, the axon terminal appears to be comparable to the soma in size, which is wrong.
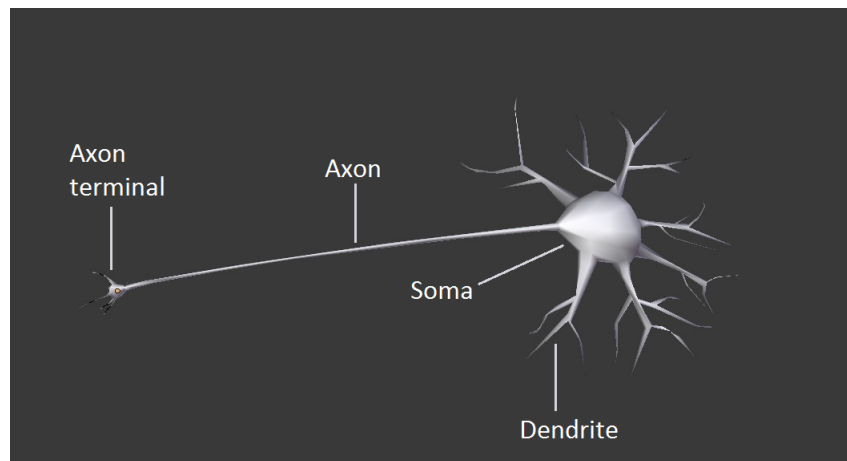
Figure 63: Explanation of cell components

The network of cells
This is a quite simplified model of the network of cells in the human brain. In real life, millions of cells are connected to each other. They are layered

crisscrossing. In real life, the different cells also have different shapes and sizes. In this model it can appear that the cells are connected with one-to-one connections. This is wrong.

Cells in entorhinal cortex
These cells typical have their soma placed close together and their axons are angled in a certain direction. This is especially prominent for the cells in entorhinal cortex.

Animation of cells
The animation of a flashing cell maybe indicate activity, but does not say anything about the signals that are sent from one cell to another cell. One way to show this is to start a signal from the soma, being transferred to the axon and out to another cell. Then the signal can split and activate multiple cells.

The next sections focuses on on the simulation of cell activity stage.

Simulation of cell activity
The simulation should show the user where it has gone, not just the places where cells are active. The simulation should also show the places the user have gone with no registered cell activity. In that way, it will be easier for the user to understand how this system works. The combination of this also gives a more correct picture of how this works.

HUD
The HUD should include more spots where the grid cell is active. The size of these spots should also be reduced. The square pattern in the background of the HUD should be removed, because it confuses the user in seeing the hexagonal grid cell firing pattern as the user evokes through the simulation.

The sections is related to other improvements of the HNC.

Guided tour through the virtual campus
The SME were informed of the unimplemented "guided tour through the virtual campus" requirement.
The SME thought that the general public want to explore and use the interactive possibilities that the SL provides, instead of being guided around in the virtual campus. They also stated that since the campus already have objects that are easy relatable to the real life, this can be exploited in the simulation of cell activity.

Animation of cell firing and transfer of signals
One possibility that were mentioned be the SME was the possibility to animate how signals between cells are being transferred. The soma of a cell gathers

signals from the dendrits. If the sum of the signals reaches a certain amount, the signal is sent trough the axon to the axon terminal. From there, the signals are transferred trough certain connections to other cells, called synapses.

6.3.2   Final evaluation

The SME states that in the HNC, there have been done simplifications in the brain models that may not be anatomic correct. She states that these simplifications have been done considering the audience, the general public.

The appearance of the cells in the model are more complex then shown in the brain model, but they, and the simulation of the cell activity, are suitable for giving the general public an introduction to the structures of the human navigation system and how the cells inside this system work.

For field experts, the HNC will have little to none value, because of its simplification caused by targeting the general public. For this model to be useful to field experts, it have to answer or elucidate concrete research topics.

7   Discussion

This chapter start with describing the objectives and main findings. Then interpretation of the results and research questions and limitations are being discussed. At last, possible improvements and a recommendation of how to create educational 3D visualizations are presented.

7.1   Objectives

In this thesis, a representation of the human navigation system, called Human Navigation Center, have been implemented using SL. This implementation has been made considering explaining the human navigation system to the general public. The Human Navigation Center includes a guided tour through a brain model and a simulation of how the cells inside the human navigation system works.

7.2   Main findings

The results from the evaluations shows that the implementation is able to give the general public an understanding of how the human navigation system is structured anatomically and how the cells inside this system works in relation to spatial navigation in an environment.

7.3   Interpretation of the results

The two subsections below discusses the results in relation to the implementation, the requirements, the literature and related work.

7.3.1   The implementation is able to give the general public an understanding of how the human navigation system is structured anatomically

This result indicates that the brain tour stage of the implementation were able to provide the general public with useful information about the components of the human navigation system within the brain.
Since the specialization project, this stage have been extended with a more detailed brain model, based on the feedback from the students and experts who stated that it should contain more details and show more anatomic depth to make it more interesting.
This led to a creation of a more detailed model of the limbic system with neuron cells placed inside it.

Results from Table 9 show that the students thought that the improved version in the master thesis was more interesting than the one in the specialization project, so the defining of the R1.1 requirements and the brain model sub requirements proved to be an success.

Another important part of this visualization was the introduction of the guided vehicle, based on the feedback from students in the SP claiming that navigation inside the brain model was difficult.

Results from the qualitative part of general public evaluation showed that the students did not have any navigational issues and thought that the static guide and the rotating brain model provided a good solution for seeing the brain from multiple views.
On another side, if the impemented guide is compared to the guide in the Testis Tour from the related work, my subjective opinion is that the guide from the Testis Tour provides more immersiveness because of its ability to actually move and "dive" into the models components, instead of just change its position.
This can be direct related to the immersion section from the literature, stating that multiple views can contribute to a better understanding of the current topic.

The use of HMDs was also done with an intent to increase the immersiveness of this stage. Results from both the qualitative and the quantitative part of the evaluation showed that the use of HMDs increased the presence in the virtual environment, which again affected the immersion in a good way.
All these factors are affecting the fulfillment of the immersive R3 requirement, in relation to the visualization.

7.3.2 The implementation is able to give the general public an understanding of how the cells inside this system works in relation to spatial navigation in an environment.

This result indicates that the simulation of cell activity stage of the implementation were able to provide the general public with useful information about human navigation and firing of these cells.

Results from the qualitative evaluation from the general public showed that two of six persons did not understand what the purpose of this stage was. Nevertheless, results from the same evaluation shows that the main component of this stage, the static 2D representation of the 3D virtual environment (HUD), was very easy to understand how worked for the same participants. How is this contrast in results possible? Two of the students did not understand what they were doing, but at the same time they did understood how the HUD worked.

The answer to this can be given by the definition of learning method used in this simulation. "Active learning requires students to do meaningful learning activities and think about what they are doing at the same time"[52]. By the definition of active learning, it do not help if the learning activity is meaningful if the users do not think of what they are doing at the same time.

This can explain how some of the students felt that they understood the HUD and how it worked, but not the simulation of how cells in the human navigation worked. To do so, the users have to relate their own movements in the virtual space to the action happening at the HUD. So the active learning approach can be more intuitive for some than others. Therefore, the explanation maybe should have been better in the front of this stage. This could ensure that users that do not relate this so intuitively could have understood more.

The HUD was directly inspired by the HUD in the A'Mazing Game from the related work section. The HUD from the latter one also showed cell activity from the human navigation system, but was more focused on the human perception of space, distances and direction than of the actual cell firing itself. Therefore it is hard to compare the two HUDs, since they surve different purposes.

7.3.3   The role of the introduction video

This subsection provides reasoning for how the introduction video affected the achieved leaning goals.

The introduction video was introduced based on feedback from the first evaluation of the general public evaluation. Results from the qualitative evaluations show that the introduction video gave the participants prior knowledge to the human navigation system, useful to understand the later stages. So by introducing the users to this video, the learning outcomes of the other two visualizations increased. This is also supported by an article, stating that "prior knowledge related to the format or content of a visualization interface can significantly affect perception and comprehension"[29].

The findings means that the implementation has been created successfully, considering the learning potential it has to persons from the general public without prior knowledge about a complex and narrowly research area as the human navigation system.

Below is some of the results discussed in relation to the implementation, the requirements, the related work and some of the theory.

7.4   Retrospective on research questions

A retrospective on the research questions is given below:

RQ1: What are the requirements needed for creating 3D visualizations of the human navigation system?

RQ2: What visualisation approaches are most efficient and preferable for understanding the human navigation system among general public?

The following two subsections will be explore his the results of this thesis can be used to answer these research questions.

7.4.1   What are the requirements needed for creating 3D visualizations of the human navigation system

The results of this thesis is based on the requirements design process that is affected mainly by four factors: continuation of already successful requirements, new requirements based on related work and relevant literature, feedback from users and feedback from experts.

The first two factors have been used for gaining knowledge about the human navigation system subject. This knowledge have been used to design reasonable requirements for the implementations. These implementation of these requirements have then been tested by both users and experts through the specialization and the master thesis.

This feedback from the users have helped to reevaluate and design requirements to be more suitable for the general publics use. The feedback from the experts provides validity to the components requirements design and to make them more realistic.

So this combination of feedback have been crucial for the requirements needed for this creating 3D visualizations of the human navigation system. The feedback from users formed basis for understandable requirements, while feedback from experts formed requirements that were based on realism of models and concepts.

7.4.2   What visualisation approaches are most efficient and preferable for understanding the human navigation system among general public

The results from both the quantitative part of the general public evaluation shows that there is no preferred visualization approach which the participants preferred. This is also supported from the qualitative part of the general public evaluation, were the participants stated that "the visualizations are both useful in their own ways".

That also shows that the participants have understood that they do not try to visualize the same concept. The guided tour through the brain is trying to visualise how the brain looks like, while the simulation of cell activity are trying to explain how the different cells work.

Simultaneously is it interesting to see how this difference in learning method do not give any huge impact of the selection of which visualization approach people preferred. Results from the qualitative part of the general public evaluation showed that the preferred method of learning was pretty evenly

distributed among the participants.

Since the results from the evaluations did provide an answer to this research question, it can be concluded that a combination of these two is preferred.

7.5   Limitations

The section below describes some of the limitations in this thesis.

The results in this study is based on the participants own subjective assessments of if they have achieved learning or not. Their actual learning outcome should have been tested instead of making an own assumption based on their learning outcome.

Another factor that can affect the results achieved is the sample size and age distribution of the quantitative part of the general public evaluation. The age group from 18-40 was overrepresented in the evaluation, compared to other age groups. This combined with the total number of 21 participants in the quantitative part of the general public evaluation may have led to inaccurate data findings.

The findings of this thesis is also based on the weighted sum method. This method is simple and efficient to use, but the need for declare a number score for each of the answer options may provide weakness to the result. This is because of the subjective assessment the designer of the weighted sum method have to make? How can he say that "strongly agree" is worth five times as much as the "strongly disagree", and how can he defend that the increment between each of the answer alternatives is or is not constant.

The models of the brain components gives an overview over the human navigation system, but is not realistic models. Results from the final expert evaluation shows that these models are stylized and simplified models, used as a tool for better understanding of the anatomic structure aimed towards the general public.

The research on the human navigation system is constantly evolving by gaining more knowledge on the field. It is divided on both the internal components forming the limbic system[44] and which visual form grid and place cells have. The latter one is based on the expert feedback, stating that researchers are divided on whether grid and place cells are stallets cells or pyramid cells. This uncertainty about the content of the human navigation system may form other theories about the human navigation system, which may lead to a rejection of current theories that this thesis is build up upon.

7.6   Improvements

This section provides some proposals for improvements of the implementation.

For further tests of the implementation, the Oculus Rift DK2 should be considered to be used instead of the Oculus Rift DK1. Since some of the participants in the different evaluations stated that they did feel physical discomfort by using the HMD, the DK2 version should be testet for this use. The DK2 version has over double the amount of pixels compared to DK1 and should also resolve latensy issues related to head movements in the DK1 version[30].

The technical solution for giving users feedback with help the blackboard should be reevaluated. This solution combined with the use of the HMD now leads to many head movements, which also led to neck pain for one of the participants from the qualitative part of the general public evaluation. The blackboard should also show the current status of the guided brain tour, for giving the user information of how long it is left.

The guided vehicle should be added the movable requirement defined in section ???. This should be done because of the immersion aspect by "diving" into the brain components.

The simulation should use more of the already existing virtual environment at the NTNU Virtual Campus in SL. By adding this feature, the simulation hopefuly gets more relatable to how the brain works in the real life. Results from the qualitative part of the general public evaluation showed that it was no so relatable in this implementation of the human navigation system.

The simulation should also be able to show he user where he has gone with none cell activity. By showing both where cells are active and not active, the simulation would be more understandable for the general public, the SME stated. The number of cells firing in the simulation should also be increased. The sensitivity for a cell to fire should also be reduced, because it will make the implementation more intuitive and easy to use.

7.7 Recommendations for educational 3D visualizations for the general public

The list below is a set of recommendations for creating educational 3D visualizations for the general public, based on the experiences and lessons learned throughout this project.

- Give the users a general introduction to the subject.

- Explain to the user what is going to happen.

- Show the user the current status of the progress in the visualization.

- Let the user be in control of the progress in the visualization.

- When needed, simplify models to increase understanding.

- Constant evaluate understandability versus realism of the visualization.

- Use manipulation to focus on sub-components

- Provide multiple views to increase immersion.

- If suitable, use Head Mounted Displays to increase immersion and presence in the virtual environment.

8   Conclusion and future work

This chapter describes the conclusions from this thesis, the contributions for thesis and recommendations for future work

8.1   Conclusions

This thesis explored the possibility to use different visualization approaches in combination with virtual reality to create an understanding of the human navigation system for the general public.

To do so, a 3D visualization of the brain components inside the human navigation system was created along a simulation of how these cells works in relation to spatial navigation.

These different visualization approaches were researches further, to see which one was the most preferable. The results indicated that a combination of this two is preferable for understanding of the human navigation system.

Results from the evaluations conducted showed that both visualization approaches brought understanding to the human navigation system. These results was based on participants own subjective assessment of their learning outcome. Therefore, additional testing are needed to control the objectives achieved.

Based on the experiences and lessons learned in this project, a list of recommendations to create educational 3D visualization for the general public was created. This list can be found in chapter??.

8.2   Contributions

- Successfully created a visualization that was able to give the general public an understanding of how the human navigation system is structured anatomically.

- Successfully created a simulation that was able to give the general public an understanding of how the cells inside the human navigation system works in relation to human spatial navigation.

- Created a nine point recommendation of how to create educational 3D visualizations for the general public.

8.3   Future work

During this thesis, feedback from evaluations led to new possible research areas, that can contribute for the understanding of the human navigation system. Two of these areas are listed below.

- How can 3d visualizations and VR be used to give the general public an understanding of how the cells in the human navigation system communicate and store spatial information?

- How can 3d visualizations and VR be used to give the general public an understanding of how we are using the human navigation system in our daily life and what benefits that gives us?

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A   Questionnaire

Survey

Gender

○ Male

○ Female

Previously knowledge about the human navigation system?

○ None

○ Low

○ Moderate

○ High

Age

○ 0-18

○ 18-40

○ 40-60

○ 60+

Which part of the visualization was most interesting?

○ Tour through the brain

○ Simulation of place / grid cell activity

The navigation system

Take into account the claims under

	Strongly Disagree	Disagree	Undecided	Agree	Strongly agree
The visualization give me an understanding of how the human navigation system is build up	○	○	○	○	○
I think the visualization was interesting	○	○	○	○	○
I understand how place cells work	○	○	○	○	○
I understand how grid cells work	○	○	○	○	○
I felt presence and involvement in the virtual environment by using the VR-goggles	○	○	○	○	○
I felt physical discomfort using the VR-googles	○	○	○	○	○

Any improvements:

B Interview Guide

This appendix includes the interview guide that formed the interview that participants from the qualitative part of the general public evaluation conducted.

Background

- Previous knowledge about the human navigation system?

- Previous experience with 3D games?

- Previous knowledge with Second Life?

General[7]

- Was the tour fun?

- Was the tour motivate?

- Was the tour interesting?

- How was the information given during the tour? Were you unsure at any point?

- What did you like best, the trip through the brain or the simulation of cell activity? Why?

- Did you feel that both the trip through the brain or the simulation of cell activity where understandable?

- To what extent do you think 3D visualizations can be used to increase understanding of complex science phenomenon, like human navigation system (in general)?

Learning

- How did this tour contribute to your understanding of the human navigation system (in general)?

- How did the guided tour through the brain contribute to your understanding of how the human navigation system is structured anatomically?

- How did the simulation of cell activity contribute to your understanding of how grid and place cells work?

Navigation

---

[7]here, "tour" is used as a term on both the visualization and the simulation

- How was it to navigate in the SL?

- Did you have any problems related to the navigation of the avatar?

- How was it to go round and round in the last simulation of cell activity?

- What did you like best, navigate and exploring yourself or be passive and guided around?

HMD

- How was the experience of using Oculus Rift?

- What did you like by using these glasses?

- What did you not like by using these glasses?

- How did the use of glasses affect your sense of space?

- In what way would you say that the glasses impacted the learning effect?

- Did you feel discomfort when wearing the glasses?

Intruduction video

- Did you feel that the introduction video was necessary to understand the rest of the trip?

- Was there any part of the introduction video that you missed in the rest of the trip?

- Do you believe this video could have been dropped and you had understood as much afterwards?

Guided tour through the brain

- Was the guided tour understandable?

- Was it okay to be taken on a guided tour of the brain, or would you like to explore it yourself?

- In what way gave the guided tour you information about how the human navigation system is structured?

- Did you feel that the brain looked realistic?

- Do you prefer a static or rotating brain? Why?

- How was it to shifting views from looking and clicking on the blackboard to look at the brain, with HMD glasses on?

- Did the blackboard provide any usefull information?

- Should the information have been more extensive?

- Should brain model contained more detailed animations such as firing pattern of place and grid cells?

- What are you left with after the guided brain tour?

Simulation of cell activity

- Was the simulation understandable?

- Did the blackboard by the fences give you enough information? Did you use them?

- Could gameplay elements have been used to make the simulation more motivating (Like fastest time and a total count).

- How could the simulation been done differently (for example coloured tiles in the floor)?

- Was it understandable that only the grey plane was part of the simulation area, and not the areas around the fences?

- Should the simulation contained other types of cells, like border cells or head direction cells?

- How intuitively is it that this cell activity simulated in VR also is the same in the human brain when a person moves around in the real world?

- How easy is it to relate walking around in a VW with walking around in real life?

HUD

- How did the activation of the HUD go?

- Did the tutorial contain enough information?

- Should there have been screenshots of how to active the HUD?

- Did you understand how the HUD worked?

- Can the HUD be made more intuitively?

- Was it something you did not understand related to the HUD?

Guided tour through the Virtual Campus

- How would you like to enhanced the simulation with with a trip around the virtual campus and not just in cubicles (the cell activity is still part of this simulation)?

- Would it then be easier to relate it to the real world?

- Would you eventually like to be guided through the virtual campus or explore it yourself?

In conclusion

- Do you have any suggestions for improvements?

- Do you have some other comments?

C   Interview with expert

This appedix includes the questions that were sent to the expert by mail. Attached to the same mail were screenshots of the changed made since the first evaluation.

Brain model

- Is the location of the limbic system correct in relation to the rest of the brain?

- Does the limbic system look realistic?

- How is the placement of the hippocampus and the entorhinal cortex in relation to other components in the limbic system?

- Does the hippocampus and the entorhinal cortex look realistic?

- Does the grid and place cells look realistic?

- Can the model, along with the guided tour, give the general public an basic understanding of how the human navigation system is structured anatomically?

- Which parts of the model can be improved?

- What changes are required for this model to be used by expert users as researchers?

Simulation of cell activity

- Does the HUD provide a good picture of how grid cells and place cells works in relation to the room the avatar navigates in?

- Is the placement of the green box ok?

- Is the firing pattern of the grid cell correct?

- Can this simulation give the general public an introduction to how grid cells and place cells works?

- Which other types of cells can be relevant to include?

- What can be improved?

D   Scripts

This appendix contains the scripts of the components created in Second Life. The
first two sections include components that are needed to conduct the guided brain
tour stage. The last section includes components that are needed to conduct the
simulation of cell activity stage.

D.1   SL guide script

```
integer teller = 0;
integer grounded = 1;
default
{
    state_entry()
    {
            llSetText("Right click me and select BrainTour \n|\n|\n|\nV", <1.000, 0.863
    }

     touch_start(integer total_number)
    {
        if(teller == 0 && grounded == 0){
            llMessageLinked(-1, 0, "Slide3", "");
        }
        if (teller > 0 && teller < 16 && grounded == 0){
            if (teller== 13){
                rotation arc = llEuler2Rot(<0.0, 0.0, 180.0> * DEG_TO_RAD);
                llSetRot(arc);
                integer hasMoved = llSetRegionPos(<130.0, 19.0, 40>);
                llMessageLinked(-1, 0, "Slide12", "");
            }
            else if (teller == 14){
                teller = 0;
                llMessageLinked(-1, 0, "reset", "");
                integer hasMoved = llSetRegionPos(<103.0, 68.0, 27>);
                grounded = 1;

            }else if(teller == 12){
                llMessageLinked(-1, 0, "Slide11", "");
            }else if(teller == 10){
                llMessageLinked(-1, 0, "Slide9", "");
            }
            else if(teller == 5){
                llMessageLinked(-1, 0, "Slide6", "");

            } else if(teller == 3){
                integer hasMoved = llSetRegionPos(<120.0, 19.0, 40>);
                 llMessageLinked(-1, 0, "Slide4", "");
            }
             else if(teller == 4){
                llMessageLinked(-1, 0, "Slide5", "");
```

97

```
            } else if(teller == 6){
                llMessageLinked(-1, 0, "Slide7", "");
            }
            else if(teller == 9){
                integer hasMoved = llSetRegionPos(<97.0, 26.0, 38>);
                rotation arc = llEuler2Rot(<0.0, 0.0, 270.0> * DEG_TO_RAD);
                llSetRot(arc);
                llMessageLinked(-1, 0, "Slide8", "");
            }else if(teller == 11){
                integer hasMoved = llSetRegionPos(<100.8, 18.0, 37.2>);
                rotation arc = llEuler2Rot(<0.0, 0.0, 90.0> * DEG_TO_RAD);
                llSetRot(arc);
            llMessageLinked(-1, 0, "Slide10", "");
            }
        }

        if(grounded == 0){
            teller ++;
            llShout(1361,(string) teller);
        }
    //integer hasMoved = llSetRegionPos(<103.0, 68.0, 27>);

    }
    changed(integer change)
    {
        key av = llAvatarOnSitTarget();
        if (av ) // evaluated as true if key is valid and not NULL_KEY
        {
            integer hasMoved = llSetRegionPos(<130.0, 20.0, 40>);
            grounded = 0;
        llMessageLinked(-1, 0, "Slide2", "");
     //llSetVehicleVectorParam(VEHICLE_LINEAR_MOTOR_DIRECTION, <0.5, 0, 2.0>);
        }else{
    rotation arc = llEuler2Rot(<0.0, 0.0, 180.0> * DEG_TO_RAD);
        llSetRot(arc);
            integer hasMoved = llSetRegionPos(<103.0, 68.0, 27>);
            teller = 0;
            grounded = 1;
        //llMessageLinked(-1, 0, "Invis", "");
        }
    }
}
```

D.1.1   Blackboard script

```
default
{
    state_entry()
    {
        llSetTexture("Slide1", ALL_SIDES);
```

```
    }

    link_message(integer sender_num, integer num, string msg, key id)
    {
        if (msg == "reset"){
            llSetTexture("Slide1", ALL_SIDES);
        }
        else {
            llSetTexture(msg, ALL_SIDES);
        }

    }
}
```

D.2   Brain model

```
integer teller;
integer ON;
vector gPos;
default
{
    state_entry()
    {
        llSetRot(ZERO_ROTATION);
        llListen(1361, "",NULL_KEY, "");
    }

    listen(integer channel, string name, key id, string message)
    {
        if (message == "1"){
            llMessageLinked(-1, 0, "BrainFayde", "");
        }
        else if (message == "2"){
            llTargetOmega(<0,0.0,.06>,TWO_PI,1.0);
            rotation oneZ = llEuler2Rot(<0,0,1> * DEG_TO_RAD);
            llSetRot(oneZ);
        }
        else if (message == "3"){
            llTargetOmega(<0,0,0>,TWO_PI,1.0);
            llSetRot(ZERO_ROTATION);
        }
        else if (message == "4"){
            llMessageLinked(-1, 0, "BrainInvis", "");
        }
        else if (message == "5"){

            llMessageLinked(-1, 0, "LimbicFayde", "");
            llTargetOmega(<0,0.0,.06>,TWO_PI,1.0);
            rotation oneZ = llEuler2Rot(<0,0,1> * DEG_TO_RAD);
            llSetRot(oneZ);
```

99

```
        }
        else if (message == "6"){
            llTargetOmega(<0,0,0>,TWO_PI,1.0);
            llSetRot(ZERO_ROTATION);
            llMessageLinked(-1, 0, "LimbicInvis", "");
        }
        else if (message == "7"){
            llMessageLinked(-1, 0, "ParaFayde", "");
        }
        else if (message == "8"){
            llTargetOmega(<0,0.0,.06>,TWO_PI,1.0);
            rotation oneZ = llEuler2Rot(<0,0,1> * DEG_TO_RAD);
            llSetRot(oneZ);
        }
        else if (message == "9"){
            llTargetOmega(<0,0,0>,TWO_PI,1.0);
            llSetRot(ZERO_ROTATION);
        }
        else if (message == "10"){
            llMessageLinked(-1, 0, "ParaInvis", "");
            llMessageLinked(-1, 0, "HippoFayde", "");
            llMessageLinked(-1, 0, "EntorInvis", "");
            llMessageLinked(-1, 0, "NeuronHippoShow", "");
        }
        else if (message == "11"){
            llMessageLinked(-1, 0, "NeuronHippoSpike", "");
        }
        else if (message == "12"){
            llMessageLinked(-1, 0, "NeuronHippoInvis", "");
            llMessageLinked(-1, 0, "NeuronEntorShow", "");
            llMessageLinked(-1, 0, "EntorFayde", "");
            llMessageLinked(-1, 0, "HippoInvis", "");
        }
        else if (message == "13"){
            llMessageLinked(-1, 0, "NeuronEntorSpike", "");
        }
        else if (message == "14"){
            llMessageLinked(-1, 0, "NeuronEntorInvis", "");
            llMessageLinked(-1, 0, "BrainShow", "");
            llMessageLinked(-1, 0, "LimbicShow", "");
            llMessageLinked(-1, 0, "HippoShow", "");
            llMessageLinked(-1, 0, "EntorShow", "");
            llMessageLinked(-1, 0, "ParaShow", "");

        }

    }

link_message(integer sender_num, integer num, string msg, key id)
    {
```

100

```
        if (msg == "BrainInvis"){
            llSetAlpha(0, ALL_SIDES);
        }
        else if (msg == "BrainShow"){
            llSetAlpha(1.0, ALL_SIDES);
        }
        else if (msg == "BrainFayde"){
            llSetAlpha(0.2, ALL_SIDES);
        }


    }
}
```

D.2.1   Brian component script

```
default
{
 link_message(integer sender_num, integer num, string msg, key id)
    {
        if (msg == "ParaInvis"){
            llSetAlpha(0, ALL_SIDES);
        }
        else if (msg == "ParaShow"){
            llSetAlpha(1.0, ALL_SIDES);
        }
        else if (msg == "ParaFayde"){
            llSetAlpha(0.3, ALL_SIDES);
        }


    }
}
```

D.3   HUD script

```
float x;
float y;
float z;
float gap = 0.1;
integer stage;

grid(){
    if (x> 117 && x < 118.2 && y<53.8 && y > 52.6){
                    // llMessageLinked(LINK_ALL_CHILDREN, 0, "g01;1", llDetectedKey(0));
            }else if (x> 123.6 && x < 125.0 && y<53.8 && y > 51.6){
                if (y> 52.6){
                    //llMessageLinked(LINK_ALL_CHILDREN, 0, "g00;1", llDetectedKey(0));
                }else{
                    llMessageLinked(LINK_ALL_CHILDREN, 0, "b00;1", llDetectedKey(0));
                }
            }if (x> 121.1 && x < 122.1 && y<52.6 && y > 51.6){
```

```
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b02;1", llDetectedKey(0));
                     }else if(x> 118.3 && x < 119.3 && y<52.6 && y > 51.6){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b04;1", llDetectedKey(0));
                     }else if(x> 117.6 && x < 118.6 && y<52.6 && y > 51.6){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b06;1", llDetectedKey(0));
                     }else if(x> 121.1 && x < 122.1 && y<49.8 && y > 48.8){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b22;1", llDetectedKey(0));
                     }else if(x> 118.3 && x < 119.3 && y<49.8 && y > 48.8){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b24;1", llDetectedKey(0));
                     }else if(x> 117.6 && x < 118.6 && y<49.8 && y > 48.8){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b26;1", llDetectedKey(0));
                     }else if(x> 123.3 && x < 124.3 && y<49.8 && y > 48.8){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b20;1", llDetectedKey(0));
                     }else if(x> 122.3 && x < 123.2 && y<51.1 && y > 50.1){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b11;1", llDetectedKey(0));
                     }else if(x> 120.5 && x < 121.5 && y<51.1 && y > 50.1){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b13;1", llDetectedKey(0));
                     }else if(x> 118.4 && x < 119.4 && y<51.1 && y > 50.1){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b15;1", llDetectedKey(0));
                     }else if(x> 122.3 && x < 123.2 && y<48.2 && y > 47.2){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b31;1", llDetectedKey(0));
                     }else if(x> 120.5 && x < 121.5 && y<48.2 && y > 47.2){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b33;1", llDetectedKey(0));
                     }else if(x> 118.4 && x < 119.4 && y<48.2 && y > 47.2){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "b35;1", llDetectedKey(0));
                     }else  if(x> 119.5 && x < 122.5 && y>48.5 && y < 51.5){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "g23;1", llDetectedKey(0));
                     }
}

place(){
     if(x> 101.5 && x < 104.5 && y>48.5 && y < 51.5){
                                        llMessageLinked(LINK_ALL_CHILDREN, 0, "g23;1", llDetectedKey(0));
                     }
}


default
{
     state_entry()
     {
          llSetTimerEvent(gap);
          llSetAlpha(1.0, ALL_SIDES);
          llMessageLinked(LINK_ALL_CHILDREN, 0, "reset", llDetectedKey(0));
          //llMessageLinked(LINK_ALL_CHILDREN, 0, "reset", llDetectedKey(0));
     }


     timer(){
```

```
vector position = llGetPos ();
 x = position.x;
 y = position.y;
 z = position.z;
 if(z < 28){
     if(stage == 1){
         place ();
     }else if(stage == 2){
         grid ();
     }
 }
 if(stage == 0 && x < 105 && y > 55.7 && y < 58.7){
     llSetAlpha(1.0, ALL_SIDES);
         stage = 1;

         llMessageLinked(LINK_ALL_CHILDREN, 0, "reset", llDetectedKey(0));
         llMessageLinked(LINK_ALL_CHILDREN, 0, "place", llDetectedKey(0));

 }else if(stage == 1 &&  x > 112.8){
     llSetAlpha(1.0, ALL_SIDES);
     stage = 2;
     llMessageLinked(LINK_ALL_CHILDREN, 0, "reset", llDetectedKey(0));
     llMessageLinked(LINK_ALL_CHILDREN, 0, "grid", llDetectedKey(0));
 }else if(stage == 2 && y > 55.7){
     llSetAlpha(0.0, ALL_SIDES);
         stage = 0;
         llMessageLinked(LINK_ALL_CHILDREN, 0, "reset", llDetectedKey(0));
 }

         //llMessageLinked(LINK_ALL_CHILDREN, 0, "reset", llDetectedKey(0));

     //      stage = 0;
    //llSay(0, "Stage0");
         //llMessageLinked(LINK_ALL_CHILDREN, 0, "reset", llDetectedKey(0));

 }
}
```

D.3.1   HUD-header scpript

```
default
{
   link_message(integer source, integer num, string str, key id)
    {

         if(str == "reset"){
             llSetAlpha(0.0, ALL_SIDES);
         }else if (str == "place"){
             llSetAlpha(1.0, ALL_SIDES);
             llSetTexture("s1", ALL_SIDES);
```

```
        }else if (str == "grid"){
            llSetAlpha(1.0, ALL_SIDES);
            llSetTexture("s2", ALL_SIDES);

        }
    }
}
```

D.3.2   HUD-component script

```
default
{
    link_message(integer source, integer num, string str, key id)
    {

        if(str == "reset"){
            llSetAlpha(0.0, ALL_SIDES);
        }else if (str == "b35;1"){
            llSetAlpha(1.0, ALL_SIDES);  ;
        }
    }
}
```