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ART AND TECHNOLOGY PERSPECTIVES ON BRAIN ATLASES

Thesis for the degree of Philosophiae Doctor

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Science and Technology

Preface

This thesis is submitted to the Norwegian University of Science and Technology (NTNU) for partial fulfilment of the requirements for the degree of philosophiae doctor (Ph.D). This doctoral work has been hosted and funded by the Centre of Quantifiable Quality of Service in Comunication Systems, Centre of Excellence (Q2S) at the Faculty of Information Technology, Mathematics and Electrical Engineering. Q2S is funded by the Norwegian Research Council, NTNU and Uninett. The doctoral work has been also funded by the Picturing the Brain project which is funded by the Norwegian Research Council and held at the Department of Art and Media Studies at the Faculty of Humanities. The thesis been supervised by three professors, Professor Andrew Perkis as the main supervisor, and Professor Aud Sissel Hoel as co-supervisor. In addition to the conducted research, the doctorate education consists of compulsory courses that correspond to a volume of 30 ECTS-credits and a year of duty work. The courses where taken from the period of fall 2010 to spring 2012.

The research has greatly benefited from the very fruitful seven month research visit at the Ishikawa Oku Laboratory at the University of Tokyo in spring 2013, having the opportunity to work with Asst. Prof. Alvaro Cassinelli together with the guest researcher Philippe Pinel.

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Abstract

The research presented in this thesis explores an approach to neuroimaging which concerns the use of Brain Atlases and Neuronavigation techniques. The main focus has been to perform investigations regarding the methods, validity and scope of current visualisations of the brain. Although it is presented at the faculty of Information Technology, Mathematics and Electrical Engineering, this thesis does not focus on a technical research. The thesis does not aim at refining, advancing nor improving the state of the art of neuroimaging technologies but, instead, rethink the methods in order to find unexplored points of view which could ultimately impact and question current neuroimaging practices. Therefore, this thesis has both technical and reflective objectives, and it delivers its materials through practice based research.

The hypothesis thesis is pursued with the following research questions:

RQ1: Can an interactive installation provoke the reflection on the current scope of brain atlases and neuronavigation?

RQ2: Can neurosciences benefit from an interactive installation provoking the reflection on the scope of brain atlases?

Each of the research questions has been approached with a contribution (C1 and C2) which consequently produced a number of scientific publications, art exhibitions, with their correspondent art catalogues, documentation and press articles, and also software implementations which are open to the public domain. In our research we explore uses of vision technologies to mediate neuronavigation as well as series of prototypes conceiving tools to support neuroscience cooperation. Following are the descriptions of the mentioned contributions:

C1: A-me

The first contribution of the thesis focuses on how visualisation and navigation technologies used in the surgical environment can have diverging social, cultural, and ethical implications when used in the exhibition space. The aim of this study is to analyse the state

of the art of the current visualization and neuronavigation techniques and to develop an alternative device to insert current discussion on Brain Atlases (usually lead by the scientific community) into the creative arena. To do that, an interactive augmented reality installation was developed, which resembles the current instrumentation used in the surgical field. The research has moved towards the assessment of the quality of the system through the evaluation of perceived aesthetics and functionality. The proposed perceptual apparatus results in a design of a novel human-computer interface for neuronavigation. The complete system has been exhibited at several art venues having a great impact on visitor's perception of the current neurosurgical technologies shredding light into the topics and challenges that concern brain visualization and its limitations.

C2: Braincloud

The second contribution has been enabled as a consequence to the previous experiences and technologies developed during the first contribution. A-me paved the way for a research on tools to support neuroscience through brain atlases. BrainCloud aims at the definition of a new tool that maps neuroscientists social activities onto a virtual human brain. The application allows to publish, find and collect notes that other researchers have placed on specific areas in the brain. By selecting certain areas of interest the researcher will be updated on a daily basis about the activity of other researchers. BrainCloud is a prototype which has been developed in order to convey a study which gives an overview on the functionalities required as well as general neuroscientists expectations on the tool for the near future.

Contents

List of Thesis Contributions

Papers:

[A] J. Puig, A. Perkis, F. Lindseth, and T. Ebrahimi, "Towards an Efficient Methodology for Evaluation of Quality of Experience in Augmented Reality" Proceedings of Quality of Multimedia Experience (QoMEX). IEEE, May 2012. (ISBN: 978–1–4673–0724–6)

[B] J. Puig, A. Perkis, A. S. Hoel, and A. Cassinelli, "A-me: augmented memories" SA '13: SIGGRAPH Asia 2013 Art Gallery. ACM, Nov. 2013. (ISBN: 978–1–4503–2628–5)

[C] J. Puig, A. Perkis, P. Pinel, A. Cassinelli, and M. Ishikawa, "The neuroscience social network project" SIGGRAPH Asia 2013 Posters No. 20. ACM, Nov. 2013. (ISBN: 978–1–4503–2634–6)

[D] J. Puig, A. Cassinelli, P. Pinel, A. Carusi and A.S. Hoel, "Brain Art-Science: Explorations through A-me and BrainCloud" submitted to Leonardo, Journal of Arts, Sciences and Technology.

Exhibitions:

[A] J. Puig. A-me: Augmented Memories. [Artistic or museum related presentation] Meta.Morpf; Trondheim, Norway. September 27 – October 28, 2012.

[B] J. Puig. A-me: Augmented Memories. [Artistic or museum related presentation] STRP; Eindhoven, Netherlands. March 1st – 10th, 2013.

[C] J. Puig. A-me: Augmented Memories. [Artistic or museum related presentation] Babel Gallery; Trondheim, Norway. September 1st – 7th, 2014.

[D] J. Puig, C. Gutierrez, M. Canet, A. Perkis. LummoBlocks. [Artistic or museum-related presentation] Glow 2012; Eindhoven, The Netherlands. November 10th - 17th 2012.

[E] J. Puig. A, Franco. Onirical Reflections. [Artistic or museum related presentation] SP_Urban; Sao Paulo, Brazil. November 4th – 28th, 2013.

[F] J. Puig. A, Franco. Onirical Reflections. [Artistic or museum related presentation] VIA festival; Mons – Maubeuge, France. March 14th – 24th 2013.

[G] J. Puig. A, Franco. Onirical Reflections. [Artistic or museum related presentation] EXIT festival; Paris / Créteil, France. April 4th – 14th, 2013.

[H] J. Puig. A, Franco. Onirical Reflections. [Artistic or museum related presentation] Gare St Sauveur; Lille, France. May 2nd – September 7th, 2013.

Software:

[A] A-me (Project Software)

[B] OfxVRPN (OpenFrameworks Addon)

[C] BrainCloud (Project Software)

[D] OfxPoint (OpenFrameworks Addon)

[E] OfxVolume (OpenFrameworks Addon)

Press and Catalogues:

[A] A-me: Augmented memories. Meta.morf 2012: A Matter of Feeling. TEKS Publishing (ISBN 9788299821131)

[B] A-me: Augmented memories. STRP catalogue [Artistic or museum related presentation].

[C] A-me has been featured at We-Make-Money-Not-Art.

[D] A-me has been featured at the STRP website.

[E] Onirical Reflections has been featured at The Creators Project.

Presentations:

[A] Presentation at "The Vital Body, Sensuous Body-symposium" at Örenäs Castle, arranged by the Division of Art History and Visual Studies at Lund University, Sweden.

[B] Presentation at Ishikawa Watanabe Laboratory at the University of Tokyo.

Video Documentation:

[A] A-me: http://vimeo.com/wasawi/a-me.

[B] BrainCloud: http://vimeo.com/wasawi/BrainCloud.

Chapter 1

Introduction

This research has been carried out within the Picturing the Brain project, which primary objective is "to deepen our understanding of the epistemological roles neuroimaging technologies play, as images and as visual tools, in the conduct and communication of medicine and science." [1] The goals of the project have influenced the objectives of this thesis, which have been directed to understand, experiment, criticise, assess and evaluate current uses of Brain Atlases. This constraint has offered a valuable opportunity to enter the field of brain sciences from multiple perspectives ranging from the scientific (physiological, psychological, technological, etc.) and the humanistic (epistemological, aesthetic, etc.). And this important feature has gifted this research with a holistic perspective of Brain Atlases, making use of a highly interdisciplinary teams, resources and developments resulting on exciting discussions and outcomes.

At the same time, the research has been initiated at the Centre of Quantifiable Quality of Service in Communication Systems, Centre of Excellence (Q2S). The centre, mainly focused on technical research, has had an interest on studying principles, methods and technical solutions and assess their performances by means of scientific experimentation. Specially looking at the perceived quality of media technology (streamed image, speech/music and video, network traffic, information security, etc.). To this effect, the initial interest of this research has been to look at the perceived quality of the neuronavigation technologies

involved during pre-operative planning.

The research started with field explorations in order to gain understanding of the topics related to brain science including neuronavigation and neuroscience. Where the researchers at the SINTEF Department of Medical Technology gave an excellent introduction which included an observation of the process, methods and technologies involved in a surgical operation. Without those explorations it would have been unfeasible to land on the field of neuronavigation and consequently impossible to undertake a fruitful research.

After the first contact with the neurosurgical field we proceeded to investigate the technologies involved in neuronavigation practices. At first, we looked at the tools involving Augmented Reality (AR) and tracking technologies and proposed a method to assess their quality by quantitative metrics. Later on we developed an entire system resembling a surgical neuronavigation setup to understand its core elements and basic functionalities. From that research, we created an artistic interactive installation called A-me: Augmented Memories. The installation provokes a reflection on the challenges of localization aspects of functional maps in brain atlases. Through the use of the example of memory storage and retrieval, the visitor is able to locate stories on a virtual brain using a neuronavigation surgical system.

Once the developments, exhibitions and evaluations of A-me where completed we had a number of technologies ready for experimentation. At that point we started cooperating with neuroscientists with the basic goal of creating a prototype of an innovative tool to support neuroscience. The research was carried out at the at the Ishikawa Oku Laboratory at the University of Tokyo in spring 2013 with the helpful cooperation of Asst. Prof. Alvaro Cassinelli and the guest researcher Philippe Pinel. We then developed a number of prototypes which were constantly reshaped and redesigned. At first, we expected to develop and evaluate a visualization, but later on, because of the novelty of our proposal, we realised that achieving a fully functional visualization was only possible if we could establish a requirement specification in order to trace proper directions for our designs. The project concluded with several assessment and design iterations of a prototype, pointing at a very promising

future deployment which could greatly improve the current landscape of the technologies supporting neuroscience. The project is called BrainCloud, its code has been opened to the public domain and hopefully the project will keep growing in the near future.

1.1 Background

The interdisciplinarity of this thesis

It is important to highlight that the development of this thesis has been profoundly interdisciplinary. In fact, it required a substantial base knowledge in brain sciences, both in Neuronavigation and in Neuroscience. In this research, Neuronavigation has been approached from the field of Media Technology (MT), Quality of Experience (QoE) and Signal Processing with an Interactive Augmented Reality (AR) Neuronavigation tool called A-me. And the research on Neuroscience, which is probably one of the most multidisciplinary fields including Psychology, Biology, Chemistry, Physics, Statistics, Genetics, and so on, has been approached with the development of an application called BrainCloud, which will be described later on. The project has required experts on Neuroscience to help design proper implementations for the research. To that end, this research has tried to include as many points of view as needed in order to achieve a sufficient and valid practices. For example, technical disciplines like Software Design, Software Architecture, Visualization and Interaction have been crucial because the success of the tool depends on its quality. Also Human Factors (HF), User Experience (UX) and Computer Supported Cooperative Work (CSCW) are areas of research highly important to assess the quality of the tool and its suitability for a target group.

In order to follow the course of this manuscript we will introduce the different topics of this thesis with the following sections.

- ArtScience Research of the Brain: An introduction to the interactions between artistic and scientific research and their intersections on brain science.

- Brain Atlases and Neuronavigation Technologies: A brief introduction to the concepts

concerning neuroscience brain mapping and neuronavigation and the state of the art of their technologies.

1.1.1 ArtScience Research on the Brain

Science, art and technology have been deeply correlated throughout the history of humankind. In fact, we could track down their interactions until the ancient greek philosophers. When Aristotle described in The Nicomachean Ethics (350 BC) the meanings of the three types of knowledge: Episteme, Phronesis and Techné. The first one, Episteme, could be translated as a theoretical "to know", or "to know why". We could now relate it to scientific knowledge (universal, invariable, context-independent…). Phronesis was the wisdom necessary for the deliberation about values with referent to praxis, that is what we call today "ethics". But, Techné, in simplified terms, concerns the art and craft of making. The term would be used as the technical "know how" and now could embrace both "art" and "technology". Therefore, Techné is not only concerned with what is made, but "how" and "why" it is made. This holistic view of a research practice is what this dissertation has been pursuing. Not only trying to improve technologies but reflecting on their actual "raison d'etre". This thesis has followed a practice-based research. The materials of the thesis are not only textual but also in the form of applications and devices which have been constructed with an substantial amount of time and effort. It is for that reason that the contribution has to be considered not only by value of its verbal dissertation but also by the contributions made to the scientific community in the form of art exhibitions, code opened to the public domain and technical designs and device developments materialised to achieve proof of concepts.

Media art

Throughout the history of contemporary art, critical thinking and scientific research there have been numerous examples of holistic explorations to explain different aspects of nature. Intersections between art, science and technology, and research practices at the limits of the technical and the theoretical. Without the intention to give a historical perspective, we must

mention the efforts of the latest art pioneers which have brought scientific and technological explorations closer to the art world. Renown artists like Cory Arcangel, Roy Ascott, Jodi, Myron Krueger, Ryoji Ikeda, Lynn Hershman, Perry Hoberman, Rafael Lozano-Hemmer, John Maeda, Manfred Mohr, Carsten Nicolai, Jeffrey Shaw or Stelarc amongst many others, they all share an interest for the blending of the fields of art, science and technology in their explorations. This disposition towards knowledge has been described with the term of ArtScience. As the editor of Leonardo Journal Root-Berntsein describes it, ArtScience is "A new way to explore culture, society and human experience that integrates synesthetic experience with analytical exploration. It is knowing, analysing, experiencing and feeling simultaneously." [2].

ArtScience approaches on the Brain

During the last decades several artists and researchers have approached neuroscience with aesthetic or experimental purposes. A great number of them are described at the Leonardo Journal [3] which focuses on the intersections of art, science and technology. One of the references to our research has been the project Mindscape [4], an artwork in the form of an audiovisual installation which visualises complex brain activity, attempting to bridge the distance between scientific imagery and artistic representations. In this project, the artist Sol Sneltvedt and the neuroscientist Michael O'Shea collaborate to create a visualization of the human thought. Another artist who has influenced our research is Andrew Carnie, who has undertaken several projects centred around memory, the brain, and neuroscience – primarily in the form of time-based installations, involving 35 mm slide projections using dissolve systems or video projections. A prominent example among these works is Magic Forest (2002), which is an installation consisting on a series of projections presenting colourful tree-like neurons displayed on voile screens. Finally, it is important to mention the work of Jillian Scott who has worked at the intersection of art and neuroscience in several occasions. She is the author of The Electric Retina [5], a sculpture symbolising a part of the retina; Somabook a media sculpture that explores interpretations from a dancer with data about the growth of neural circuits; and Dermaland, a media sculpture that explores our perception of the

physical environment. She is also the curator of the Neuromedia [6] at the Kulturama Science Museum Zurich, an exhibition exposing how scientists investigate perception and behaviour at the molecular, cellular and systems level, demonstrating how media art can help to demystify these complexities for diverse audiences. Other recent examples of art-science explorations on neuroscience are the exhibition Mind Gap by Robert Wilson, at the Norwegian Technical Museum; the exhibition [7] Brains: The Mind as Matter by Marius Kwint, at the Wellcome Collection in London; and the Art of Neuroscience exhibit at Society for Neuroscience annual meeting in Washington, DC. These exhibitions examined the neurosciences from diverse viewpoints – artistic, historical, and scientific – pursuing reflection, documentation, or open interpretation depending on the curator's focus.

In the Picturing the Brain project we have integrated research and creative activities. During our explorations we have had the opportunity to pursue scientific and technological, as well as artistic aims in close collaboration with science, technology and humanities researchers. Our multidisciplinary approach has enabled research in neuroscience and neuronavigation from diverse perspectives, resulting in a synergy that has enriched both ways, scientists through art practices, and artist through scientific knowledge. Both projects, A-me: Augmented Memories and BrainCloud, explore the role of localization and neuronavigation in neuroscience. In order to understand the centrality of brain science in our research we summarize below the key concepts that have driven our explorations.

1.1.2   Brain Atlases and Neuronavigation Technologies

Currently being one of the hot topics of scientific research (within the European Union's 7th Framework Programme 2 billion euros were awarded to brain research), the brain is it still considered the container of the most intriguing unexplained phenomena. Brain research has profoundly changed its methods in the current globalised era. Nowadays researchers are rapidly aware of new advancements around the world. New tools are constantly being developed to provide such rapid interconnected research arena. Software systems, networks, programs and databases across multiple locations are active with the goal of facilitating distributed, multi-institutional, multidisciplinary information sharing and collaborative activities. One of the biggest initiatives, the Neuroscience Information Framework (NIF) [8] in cooperation with the Human Brain Project [9] and the Human Connectome Project [10] have been set up to exploit possible research directions on brain science. This new landscape has produced a number of tools and services for neuroscientists, trying to define all possible cartographies of the brain at very different levels. The types of information to display can be very distinct, from anatomical (High Definition Fibre Tractography, Diffusion Imaging, Magnetic Resonance Imaging(MRI), Magnetic Resonance Angiography, Microscopy) to functional (Functional MRI, Magnetoencephalography (MEG), Functional Connectivity MRI (connectomics)) or genetic (Gene Expression Mapping) etc. And this complexity has given raise to an interest for better tools to map the information on the human brain. In this research we have focused on the matters related to brain mapping which are Brain Atlases and Neuronavigation.

Neuronavigation and AR

Neuronavigation accommodates multi modal perception on interaction. Seeing, using, holding, touching or pointing are parts of the exercise needed to understand a hidden tissue, its position, morphology, orientation and so on. Technologies try to facilitate this action by presenting radiographic data at the surgeon's demand. These technologies must use the highest visual quality possible at the highest response time in an easy and intuitive inter-

action paradigm to allow fast and precise performances. The visual representation of the radiographic data, its image quality (resolution, brightness, registration delay, to name only a few) the virtual labels and signs used to indicate functionalities or different parts of the navigated body, the ease of use of the physical tools, their dimensions and their mechanical properties and functionalities; all these are aspects that conform the overall quality of the Visualization system.

Within the scope of Neuronavigation we have investigated the potential for using 3D technologies in surgery, including the use of simulators as training tools for surgeons or as tools in preoperative planning. Augmented Reality (AR) has been under the research agenda of computer scientists now for a long time [11], [12], [13], [14]. And the uses of AR for the surgical applications have also been intensively investigated [15], [16] [17], [18], [19]. Or aim has been to develop tools assessing the surgeon's experience in a qualitative way and to develop models and simulations for further improving the visualizations. This involves developing a methodology for subjective testing (described in paper A) and comparison of training systems as compared to real surgery. In undertaking this task, the project further develops existing platforms for quality assessment in the convergence of information technology, digital communication and entertainment, extracting the general nature of these solutions and applying them to surgery.

Brain Atlases

The Talairach Atlas [20] was the first standardized coordinate system for neurosurgery. It has allowed the comparison of brain locations across multiple studies. Nowadays it is still being used although other atlases like the ones purposed by the Montreal Neurological Institute (MNI305, MNI Colin27 or MNI ICBM152) are more commonly used. The main differences are that Talairach is an old coordinate system based on a single post-mortem dissected brain and MNI templates are more up to date systems which use an averaged brain from several users or averaged scans from a single user. Using a single coordinate system result in a number of challenges because of individuals morphological differences. Additionally, the human

brain is in constant development and that creates more difficulties for scientists to define a standard system. This challenge has been at the very centre of our research where both C1: A-me and C2: BrainCloud are dealing with this constraint. In both cases Brain Atlases have been used to visualise functional areas. The delimitation of the areas is never standardised with consensus. In fact the brain regions like the Broadman Areas [21] are usually used as diffuse landmarks to guide the location of brain activity. In A-me this conflict has been used to present a question to the visitors. The question was how to locate a memory in the cortical structure. In the case of BrainCloud, where the project aims at a scientific uses of Brain Atlases the topic of localisation has been dealt with Visualization technologies to allow scientists the location of brain related information.

Visualization

The term Visualization has been used in many disciplines and from several different points of view. Some refer to it as an "interdisciplinary study" which sits in the middle of different fields such as Computer Science used as "scientific visualization" or in Information Technology as "Information Visualization", where other disciplines like Computer Graphics, Graphic or Industrial Design or Science and Technology Studies use the term "visualization" in a similar manner, most of the times to display data, information or knowledge in a visual way. We have gone through the general visualization literature with [22] [23] [24] [25] [26]. Also we have learned from the tools and techniques used in neuroscience visualization from [27] [8] [28] [29] [30]. From this resources we have created a vision and afterwards developed a visualization tool that allows neuroscientists the navigation of a brain atlas with several levels of information. The atlas allows the use of social networks strategies to share information mapped on a human brain atlas.

1.2 Methodology

This section defines the methods used to conduct the research for this thesis. The research has been conducted though **practice-based research**. We describe below the meaning of this term, and we explain how practice-based research is applied to a doctoral dissertation. The implementation of this type of investigation is described for each contribution (C1 and C2). In the implementation stage we explain what methods we have used to design and implement our developments and we also explain the methods used for the analyses of our developments.

Practice-based Research

This thesis has been conducted with practice-based research. Practice-based research is defined as "[...] an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice." [31] In this thesis contributions to knowledge are demonstrated with creative outcomes in the form of an interactive installation (C1), an application (C2) their respective publications, exhibitions and software modules. Contributions are described in scientific papers, however the complete understanding of the totality of the contribution of this thesis is obtained by the inclusion of the non textual creative outcomes. These outcomes are described with the following documentation of the implementations of the research process. To demonstrate the validity of the thesis we have provided the following materials:

- 1. Research questions (RQ1 and RQ2):

  We have defined two research questions that are addressed in the body of this thesis. The research also defines the motivation and the objectives of the investigations to highlight the relevance of this contribution. The next section "Dissertation Discussions" (in page 21) addresses the research questions and their resolution with the thesis contributions.

- 2. Context:

In the "Background" section (in page 3) we have defined the context in which this research has been conducted. Including the definition of the key concepts, the researchers and scientific fields that conform the scope of this thesis. We have mentioned the project that has initiated this research and the consequent interdisciplinary nature of it.

- 3. Methods:

In this section we specify the methods employed in this research which explain how we have pursued our investigations to answer the research questions. This section gives details on the research process for both contributions (C1 and C2). Additionally it explains the methods employed to analyse their results through quantitative and qualitative assessment methods.

1.2.1 Research process for Contribution 1

The Contribution 1 addresses the first research question:

RQ1: Can an interactive installation provoke the reflection on the current scope of brain atlases and neuronavigation?

This contribution has provoked the reflection on the current scope of brain atlases and neuronavigation by creating and exhibiting and interactive installation called A-me. In order to create this interactive installation we have followed a method to accomplish the technical requirements that our research question states. Our interactive installation resembles the neuronavigation tools that neurosurgeons employ during pre-operative planning. By exhibiting this device and allowing the visitors of the exhibition to interact with it we have opened up a public discussion on the concept of localization in brain atlases.

The method employed to design and implement A-me is based in the Spiral Model of the Software Process [32]. This model allows the researcher to implement a prototype by revising a process learning from a previous outcome. This means that technical developments, their outcomes, and their constraints will lead the forthcoming research, resulting on a cycle where the conclusions and results of the technological prototypes build are constantly reviewed and improved. This type of research is necessary when the subject of study, in this case, the design of the interactive installation, is wide and depending of infinite variables, for example: different kinds of graphical symbols or different interaction paradigms or different hardware configurations. These variables can be technical configurations or aesthetic differences, and these variables might affect the overall perceived quality of the device.

We used a simplified version of this model (figure 1.1) because our development is less complex than the developments used in the original Spiral Model of the Software Process. To achieve the design and implementation of A-me we have employed four phases and three cycles. Each phase is a stage of development for each cycle:
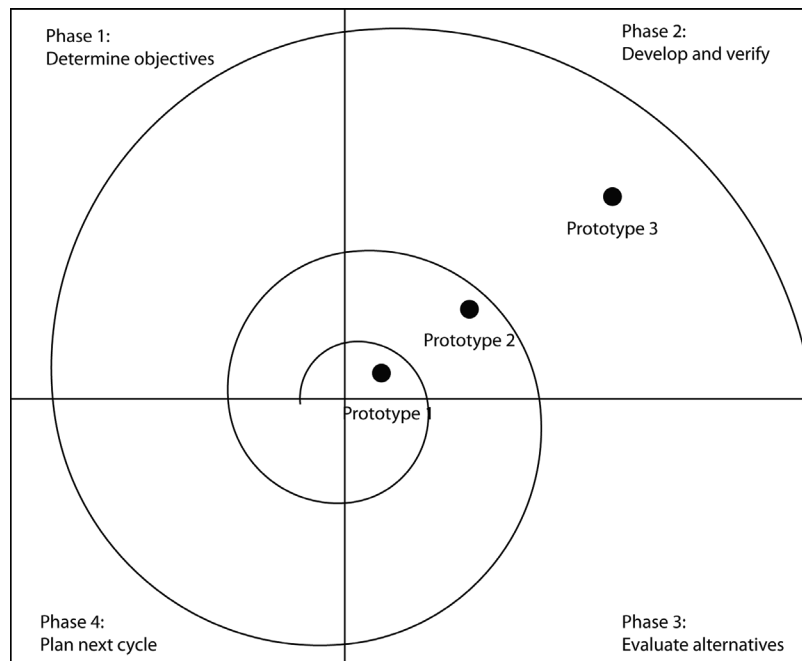
Figure 1.1: The phases of the spiral model.

- **Phase 1. Determine Objectives:** Definition of the objectives to accomplish and the implementations to be carried out. Definition of the prototype for the purposed subject of study.

- **Phase 2. Develop and verify:** Implement the prototype to evaluate a visualization. Running experiments to assess the quality on any of the parameters that conform the visualization. Experiments were conducted in A-me (see Paper A) to assess the quality on AR systems.

- **Phase 3. Evaluate alternatives:** Evaluate the alternative implementations. Identify and resolve risks of the current prototype definition. The resolve risk of the software prototypes developed in this research are evaluated both by the users in various exhibitions, user interaction observations are noted and are used for discussion on regular meetings with interdisciplinary members of the A-me project team.

- **Phase 4. Plan next cycle:** Drawing a conclusion extracted from the experiments and from the process itself. This will be the seed for the forthcoming study and design. Once the first implementations are evaluated new conclusions arise allowing the researcher to improve the previous prototype.

The development of the AR device in A-me is a work in progress that was developed through three cycles. The Spiral Model allowed us to break down the development of the technologies involved in the installation. As paper B explains, the project was composed by a software capable of rendering MRI data using a Volume rendering technique, a system to overlay digital images in the real world and a tracking system to enable interactivity in the system. The implementation of these technologies has been divided in different cycles, allowing us to analyse the system at each stage. The following are the cycles of our research process:

- **Cycle 1: AR with tracked probe**

  The first cycle has the objective of developing a prototype of an AR device displaying three-dimensional (3D) static graphics. No stereoscopy is involved at this stage. Reflections of the display on the glass are used to overlay the real object with the virtual stimuli (fig.1.2). Controlled illumination is used to adjust the similarity between real and virtual stimuli. This setup does not allow interaction of the user and it does not update changes of viewpoint. It is a static visualization.

- **Cycle 2: Interactive 2D AR**

  An additional degree of complexity is added by transforming the previous prototype into an interactive device. The user is able to navigate the virtual content, in this case the MRI dataset, by moving the probe which position and orientation is being registered; this means that moving it physically will automatically update the virtual visualization. This implementation necessitates the use of a tracking system in order to register the position and the orientation of the dummy head accurately (fig.1.3). Additionally the visualization has to allow real time modification of its clipping point, that

is the height at which the MRI scan is cut. This setup presents some limitations: the visualization is correctly registered only at a certain point of view of the user. To solve this constraint the only solution is to add stereoscopy to the device to allow the rendering of different points of view of the rendered MRI scan. The following cycle addresses new requirement.

- **Cycle 3: Interactive stereo 3D AR**

  The final cycle is a prototype presenting the virtual simulation in stereoscopic 3D. This allows the correct registration of volumetric objects on the real world. In order to achieve AR with a stereo pair of images we also need to track the glasses position of the user (fig.1.4). At this point, the user is able to alter his point of view and to manipulate the real object freely while the system updates the virtual overlaid simulation in three dimensions in real-time. This implementation was not used in the exhibitions due to its delicate maintenance.

Method of analysis in C1: Quantitative Assessment Methods

Several methodologies can be applied to measure the qualities of an interactive system. Time or accuracy measurements can be used to determine how long it takes to perform a task or how precisely it can be done. Also rating scales may give feedback from the subject to assess quality. Most of the times the data is statistically processed to obtain trustful conclusions. Interviews can also be used to extract specific information from the visualization experience, and they are a good method to obtain details that rating scales or laboratory experimentation are not able to provide. Perceptual Quality has been widely researched in Audio Engineering, Food Science and others. Quality of Experience (QoE) [33], [34] is the equivalent applied to multimedia technologies. The Augmented Reality device designed for A-me was studied using QoE methodology.
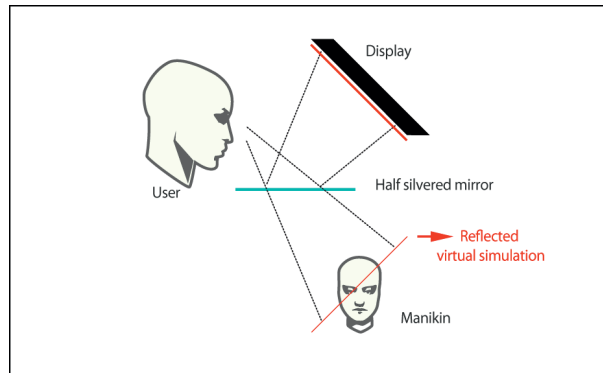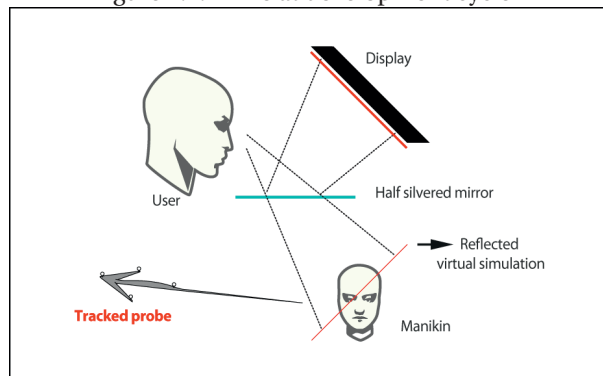
Figure 1.2: A-me at development cycle 1

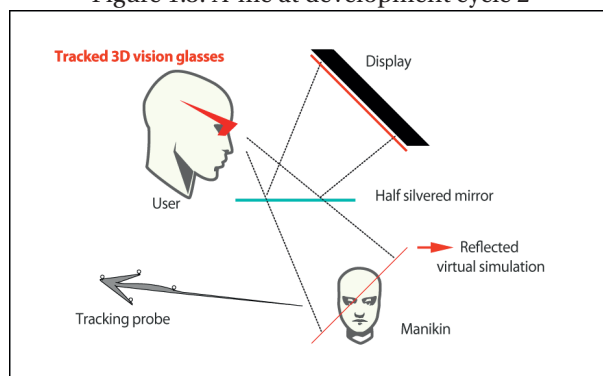Figure 1.3: A-me at development cycle 2

Figure 1.4: A-me at development cycle 3

1.2.2   Research process for Contribution 2

The Contribution 2 addresses the second research question:

RQ2: Can neurosciences benefit from an interactive installation provoking the reflection on the scope of brain atlases?

The interactive installation A-me grew out of a technological development for surgical purposes, and evolved into an art intervention to enable users to interrogate some aspects of the discourse of neuroscience, brain atlases and their use of localization. BrainCloud uses this technological development to contribute to the scientific community in order to enhance the sociability aspects of neuroscience.

BrainCloud is a software with an important component of visualization strategies. In this research process, the design of the project depends directly on the requirements specified by the domain experts, in this case the neuroscientists. Therefore Boehm's Spiral Model was not appropriate in this case. More over, the objectives of the project were not to materialize a device or application but to define the requirements for it. For that reason, we followed Sedlmair's definition of design study:

"A design study is a project in which visualization researchers analyze a specific real-world problem faced by domain experts, design a visualization system that supports solving this problem, validate the design, and reflect about lessons learned in order to refine visualization design guidelines." [35]

Sedlmair defines three types of design research contributions depending on their focus during the design process. The first one is problem characterisation and abstraction, the second is validated visualization design and the last one is reflection. The research in BrainCloud focused on the first category, meaning that its goal is to achieve a shared understanding between visualization researchers and domain experts, in this case, the neuroscientists are the ones establishing the requirements to define the design proposal. This contribution also provides a first approach to the a prototype design initiating discussion about its suitability for its real world application. Consequently Contribution 2 (BrainCloud) focuses on

the processes on prior implementation stages, aiming at describing the visualization problem and abstracting its main features and resulting with a description of the requirements to be implemented in the future.

The research process was achieved from a close cooperation with a neuroscientist that guided the discussions about the requirements for the project. The method used to lead the design of the prototype was inspired by the previous Spiral Method and modified with ideas from Sedlmair's framework. The collaboration for the design of the application consisted in the following design phases:

- **Brainstorming session:**

  Everything started from an informal brainstorming session where the team gathered to propose ideas on the objectives for the project.

- **Research on the state of the art:**

  After initial research we found out that a large number applications in this area have been developed. Furthermore, we detected a lack of tools to support the exchange of information between neuroscientists in a locative manner.

- **First draft of requirements:**

  In this phase a set of requirements were listed to give a first direction to the project. The phase concluded in Paper C, a publication defining the main vision for the project.

- **First Prototype of the application:**

  The first prototype targeted the most basic functionalities such as the ability to store and retrieve comments that researchers place in specific areas in the brain atlas.

- **Second draft of requirements:**

  The first prototype served to visualize the advantages and disadvantages of the direction taken in the design of the project. In this phase modifications were proposed in order to rectify the design.

- **Second Prototype of the application:**

  In this phase the main features that constitute the final prototype of BrainCloud are defined. The features are: To create and maintain and explore a network of researchers with affinity, to create and maintain and explore a brain atlas of messages, notes, or links to references, and to update researchers on current activities depending on the preferred area of interest. Further details on the project are described in Paper D.

Qualitative Assessment Methods

BrainCloud was assessed using qualitative evaluation methods. These methods do not employ quantitative metrics, instead they use verbal assessment by field experts, usually in a deep discussion analysing its qualities. As mentioned, BrainCloud was designed in cooperation with a neuroscientist. More over, our team decided that the best way to evaluate the current prototype would be to present it to other neuroscientists and to discuss about its suitability from many different points of view. We carried out an interview where the application was discussed on its general objectives and through each of its features.

In order to get this input from the evaluation session we decided to guide the topics from a wide and open discussion on its goals and challenges, to a detailed discussion about specific features. The session was video recorded to be able to analyse the conversations having also access to the non-verbal interactions that could appear during the session. The participants were two experienced researchers in neuroscience which were able to discuss the ideas of the project in an open and free setting. Some outcomes of the assessment are reflected in Paper D. Additionally an exhaustive analysis of the interviews is planned to be published in the future in a paper dedicated to the functionality of BrainCloud, however this research is not included in this thesis.

1.3   Summary of Contributions

This section summarizes the contents of the thesis by answering our research questions (RQ1 and RQ2) with our Contributions (C1 and C2) and their respective publications (Paper A, Paper B, Exhibition A, Exhibition B, Exhibition C, Software A, Software B, Paper C, Paper D, Software C, Software D, Software E). Figure 1.5 depicts the structure of the contributions as follows: RQ1 has been addressed with Contribution 1 which refers to the entire project of A-me: Augmented memories. This project has produced two peer-reviewed publications (Papers A and B), three exhibitions (Exhibitions A, B and C) and two software modules (Softwares A and B). RQ2 has been addressed with Contribution 2 and refers to the project BrainCloud. The project has produced two peer-reviewed publications (Papers C and D) and three software modules(Softwares C, D and E). In the following subsections we will briefly describe the contributions C1 and C2 with a short summary of each publication, exhibition and software modules.
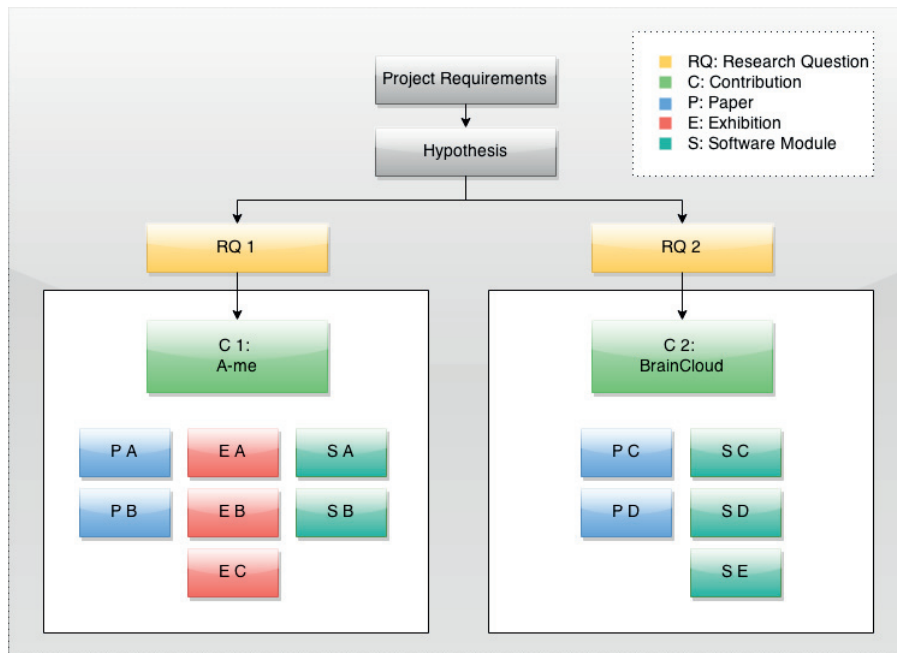

Figure 1.5: Diagram of the thesis materials.

1.3.1 Dissertation Discussions

This section provides an overview of the main contributions of the thesis. We first explain the motivation that initiated the doctoral program, highlighting the relevance of its challenges and the novelty of its results. And finally, we describe the contributions of the thesis by giving answer to our research questions (RQ1 and RQ2) with our contributions (C1 and C2) and their respective materials.

This research has been conducted within the umbrella of the Picturing the Brain project. The project aims at the convergence of multiple fields from the creative, the cultural and the scientific at the intersection of neuroscience and neuroimaging as mediation tools. The main challenge and the main outcome of this thesis has been to connect the variety of its different disciplines through the design and development of media technology relevant to the applications of neuroscience and neuronavigation. To include the creative and cultural aspects of the project, the same technical developments have been applied to cultural applications, provoking the reflection on localization challenges of neuroscience to the visitors of an art exhibition. We go through the contributions of the thesis highlighting the main results for each contribution and explaining and how they contributed to answer the research questions.

C1: Paper A The research presented in this paper gives a broad perspective on the assessment methods available to assess the quality of Augmented Reality (AR) systems. The paper gives an account of the different approaches currently available for quality assessment of AR: ergonomics, usability, human factors, ethnography, subjective quality assessment and psychophysics. Furthermore, the paper presents a methodology balancing quantitative and qualitative assessment methods. The proposed methodology aims at a wider perspective of the quality of a system compared to the common practices, which are usually focused in either quantitative or qualitative analyses. Additionally, the paper presents a proof of concept applying the proposed methodology to compare two distinct presentations of Augmented Reality, one through a computer screen and the other one through a projection. An experiment is defined to gather user data for its quantitative assessment of subjective quality met-

rics. The authors suggest that subjective assessment through ratings and questionnaires can better explain the source of performance rates obtained. This paper has been the first step to approach the topics of quality assessment strategies, quality assessment applied to AR systems, topics that have had an important relevance throughout the research involved in this thesis, and specially they been researched and implemented on the contribution C1 (A-me). Furthermore, in paper D of contribution C2 qualitative assessments are used through the design cycle of the prototype of BrainCloud.

C1: Paper B The interest in the previous paper on quality on AR initiated the research enclosed in this paper. The paper defines an AR installation that resembles the visualisation tools used by surgeons during operation planing. The device served as a support for the interactive installation "A-me: Augmented Memories" exploring the potential of artistic interventions for facilitating dialogues across the art and science domains, in this case across art and neuroscience. This paper is directly linked to the first research question (RQ1) of this thesis:

RQ1: Can an interactive installation provoke the reflection on the current scope of brain atlases and neuronavigation?

A-me was created, and has proven to provoke reflection on current neuroscience interest to localize mental functions, such as memory, in the anatomical brain. The centrality of the installation resides on the location of human memories in the human brain. Provoking reflection to art exhibition visitors through their own interaction and exploration of the system. The creation of A-me highlights the fact that neuroscience is currently mapping brain functions more and more accurately and that there is an urge in the scientific community to refine accuracy of brain atlases. Therefore, A-me directly addresses the research question 1. A-me was exhibited as an art installation at the Meta.morf electronic arts festival in Trondheim in October 2012, and also at the art and technology festival STRP in Eindhoven in March 2013, where it was explored by a large number of visitors. After that, it was exhibited again in the Babel Gallery in Trondheim in September 2014, during the Picturing the Brain closing conference. Additionally, this project produced a number of software modules and

exhibitions which are detailed below. The publications and results related to this project are enclosed as Contribution 1 (C1).

C2: Paper C This paper gives a vision for an application that aims at the support of research in the neurosciences. It proposes an interface designed to provide a direct mapping between neuroscience and the visualization of the anatomical human brain space. This paper is the first step for a definition of a prototype which is further detailed in Paper D. This contribution has defined the scientific challenge that later on BrainCloud will address. The main research focuses towards the improvement of social interactivity amongst neuroscientists. Therefore, this contribution uses the knowledge on AR and brain atlases acquired with previous publications to the rich field of interactivity and data visualization, in this case the data produced by neuroscientists.

C2: Paper D This papers constitutes the most relevant contribution to the thesis. The paper summarises the research done across the doctorate program. The paper gives an overview of the interdisciplinary research conducted across art, technology and neuroscience. It explains how the process in which the interactive installation A-me turns into the scientific project BrainCloud, giving details of the process and the interaction of the team involved in the research. Additionally, the paper gives further insight on the prototype of Braincloud. This paper that directly addresses the research question 2:

RQ2: Can neurosciences benefit from an interactive installation provoking the reflection on the scope of brain atlases?

BrainCloud was created based on the previous experience and lessons learned on the development of the interactive installation A-me. In this regard, BrainCloud and A-me are connected through the technological development around the specific topic of neuroscience localisation, exploring new perceptual tools that expanded the state of the art in navigation and interactivity. While A-me is an AR interactive installation, BrainCloud can be seen as an application aiming to augment sociability among neuroscience researchers. BrainCloud aims to visualize disparate information in an intuitive way to neuroscientists. Therefore, BrainCloud visualizes and facilitates scientists' interactions with each other, and augmenting

sociability through a 3D spatial interface.

1.3.2   Contribution 1

Title: A-me: Augmented Memories

Contribution Description:

The Contribution 1, A-me, consists of an interactive installation that has used a number of technical achievements, including an innovative Augmented Reality display, and a new interface to explore its visual contents. Quality measures have been explored in Paper A. The installation as a whole has been described in Paper B. The installation has been exhibited in three ocasions (Exhibitions A, B and C). And the software created for its implementation has been released to the public in Software Module A and B. The project has been documented and the video has been released to the public in Video Documentation A.

Results:

[Paper A] J. Puig, A. Perkis, F. Lindseth, and T. Ebrahimi, "Towards an Efficient Methodology for Evaluation of Quality of Experience in Augmented Reality" Proc. of Quality of Multimedia Experience (QoMEX). IEEE, May 2012. (ISBN: 978–1–4673–0724–6)

[Paper B] J. Puig, A. Perkis, A. S. Hoel, and A. Cassinelli, "A-me: augmented memories" SA '13: SIGGRAPH Asia 2013 Art Gallery, Nov. 2013. (ISBN: 978–1–4503–2628–5)

[Exhibition A] J. Puig. A-me: Augmented Memories. [Artistic or museum related presentation] STRP; Eindhoven, Netherlands. March 1st – 10th, 2013.

[Exhibition B] J. Puig. A-me: Augmented Memories. [Artistic or museum related presentation] Meta.Morpf; Trondheim, Norway. September 27 – October 28, 2012.

[Exhibition C] J. Puig. A-me: Augmented Memories. [Artistic or museum related presentation] Babel Gallery; Trondheim, Norway. September 1st – 7th, 2014.

[Software module A] A-me

[Software module B] OfxVRPN

[**Video Documentation A**] A-me: http://vimeo.com/wasawi/a-me

1.3.3 Paper A

Title: Towards an efficient methodology for evaluation of Quality Of Experience in Augmented Reality

Authors: Jordi Puig, Andrew Perkis, Frank Lindseth, Touradj Ebrahimi

Abstract:

The goal of this paper is to survey existing quality assessment methodologies for Augmented Reality (AR) visualization and to introduce a methodology for subjective quality assessment. Methodologies to assess the quality of AR systems have existed since these technologies appeared. The existing methodologies typically take an approach from the fields they are used in, such as ergonomics, usability, psychophysics or ethnography. Each field utilizes different methods, looking at different aspects of AR quality such as physical limitations, tracking loss or jitter, perceptual issues or feedback issues, just to name a few. AR systems are complex experiences, involving a mix of user interaction, visual perception, audio, haptic or other types of multimodal interactions as well. This paper focuses on the quality assessment of AR visualization, with a special interest on applications for neuronavigation.

Contribution Statement:

The main contributor of this work is Jordi Puig. The execution and analysis of the experiment were due to Jordi Puig. Andrew Perkis Frank Lindseth and Touradj Ebrahimi contributed to the to the active discussions, experimental methodology, parts of the writing and literature.

1.3.4   Paper B

Title: A-me: Augmented Memories

Authors: Jordi Puig, Andrew Perkis, Aud Sissel Hoel, Alvaro Cassinelli

Published at: SA '13: SIGGRAPH Asia 2013 Art Gallery, Nov. 2013. (ISBN: 978–1–4503–2628–5)

Abstract:

A-me is a fictitious memory-evoking apparatus at the intersection of science, art and technology. The system enables users to experience other people's memories as well as store their own by interacting with a volumetric representation (MR) of a human brain. The user retrieves or stores memories (audio traces) by pointing and clicking at precise voxels locations. Triggered by their exploratory action, a story is slowly revealed and recomposed in the form of whispering voices revealing intimate stories. A-me it's a public receptacle for private memories, thus exploring the possibility of a collective physical brain. The installation introduces an original optical see-through AR setup for neuronavigation capable of overlaying a volume rendered MR scan onto a physical dummy head. Implementing such a system also forced us to address technical questions on quality assessment of AR systems for brain visualization.

Contribution Statement:

The main contributor of this work is Jordi Puig. The execution and exhibition of the art installation were due to Jordi Puig. Alvaro Cassinelli, Aud Sissel Hoel and Andrew Perkis contributed to the to the active discussions, parts of the writing and literature.

1.3.5 Exhibition A

Title: Exhibition at Meta.morf

Location: Sense-It. NTNU. Trondheim, Norway.

Exhibition dates: September 27 – October 28, 2012.

1.3.6   Exhibition B

Title: Exhibition at STRP

Location: STRP. Eindhoven, Netherlands.

Exhibition dates: March 1st – 10th, 2013.

Photographic documentation: Appendix A (page 49).

1.3.7   Exhibition C

Title: Exhibition at Babel Gallery.

Location: Babel Gallery. Trondheim, Norway.

Exhibition dates: September 1st – 7th, 2014.

Photographic documentation: Appendix B (page 61).

1.3.8   Software module A

Title: A-me: Augmented Memories

Code hosted at: https://github.com/wasawi/a-me

Licence: MIT License

Description:

A-me is an augmented reality device that lets the visitor experience stored feelings on a brain. At the intersection of science, art and technology, this project is focusing on the limits between neuroscience and psychology. The matter and the location of human memories has been shown to be linked to the experienced emotions at the time they where stored. The emergence of powerful new radiological measurement techniques (e.g., fMRI, PET, SPECT) combined with experimental techniques from cognitive psychology allows neuroscientists and psychologists to address abstract questions such as how human cognition and emotion are mapped to specific neural substrates.

A-me is an emotional memory recall device. Following the state of the art knowledge on brain atlases to map out the location of human experiences this device allows the reproduction of them by providing visual and auditory feedback.

An Optical See-Through display is used to overlay the virtual information into a phantom head (a medical term for a dummy head). The user will be able to navigate the brain by using a tracked probe in a similar way the neurosurgeons use it in pre-operative planning. While navigating the brain, the user will find active areas in specific parts of the nervous structure. Pointing at them with the probe will trigger an stored emotional experience in the form of a voice coming from the phantom and a visual interpretation of its neural activity.

Dependencies:

```
Openframeworks 0,8
OF addon ofxVRPN
MaxMsp v 4.6
Optitrack software tools
```

Includes:

```
Openframeworks code for visual feedback
Max\Msp code for auditory feedback.
Connection through OSC Port: 7420
Optitrack example scenes
```

Installation:

```
Install MaxMsp v 4.6
Install Openframeworks 0.8
Innstall optitrack Software and use licenced dongle.
Install ofxVRPN
Run a full calibration for the Optitrack scene.
Check VRPN connection to OF
Check OSC to MaxMsp
```

1.3.9 Software module B

Title: ofxVRPN (OF addon)

Code hosted at: https://github.com/wasawi/ofxVRPN

Licence: MIT License and inherited Boost Software License 1.0 (BSL1.0) from VRPN.

Description:

ofxVRPN is an Openframeworks wrapper of the VRPN library. The original version of VRPN (The Virtual Reality Peripheral Network) was placed into the public domain by the copyright owner Russell M. Taylor II at the University of North Carolina at Chapel Hill on May 4th, 1998 [36].

The credits to the VRPN library are for the CISMM project at the University of North Carolina at Chapel Hill, supported by NIH/NCRR and NIH/NIBIB award #2P41EB002025.

VRPN can be found here:

https://github.com/vrpn

Dependencies:

```
Openframeworks 0.8
```

1.3.10   Contribution 2

Title: BrainCloud

Contribution Description:

The Contribution 2, BrainCloud, consists of a neuroscience social network visualization tool. The vision for the application has been described in Paper C. An overview of the scientific co-operation that enabled the creation of the tool as well as details of the application have been detailed in Paper D. The software created for its implementation has been released to the public in Software Module C, D and E. The project has been documented and the video has been released to the public in Video Documentation B.

Results:

[**Paper C**] J. Puig, A. Perkis, P. Pinel, A. Cassinelli, and M. Ishikawa, "The neuroscience social network project" p. 20, 2013. (ISBN: 978–1–4503–2634–6)

[**Paper D**] J. Puig, A. Cassinelli, P. Pinel, A. Carusi and A.S. Hoel, "Brain Art-Science: Explorations through A-me and BrainCloud" submitted to Leonardo, Journal of Arts, Sciences and Technology.

[**Software module C**] BrainCloud (Project Software)

[**Software module D**] OfxPoint (OpenFrameworks Addon)

[**Software module E**] OfxVolume (OpenFrameworks Addon)

[**Video Documentation B**] BrainCloud: http://vimeo.com/wasawi/BrainCloud

1.3.11   Paper C

Abstract:

Recent advances in neuroimaging over the last 15 years leaded to an explosion of knowledge in neuroscience and to the emergence of international projects and consortiums. Integration of existing knowledge as well as efficient communication between scientists are now challenging issues into the understanding of such a complex subject [Yarkoni et al., 2010]. Several Internet based tools are now available to provide databases and meta-analysis of published results (Neurosynth, Braimap, NIF, SumsDB, OpenfMRI…). These projects are aimed to provide access to activation maps and/or peak coordinates associated to semantic descriptors (cerebral mechanism, cognitive tasks, experimental stimuli…). However, these interfaces suffer from a lack of interactivity and do not allow real-time exchange of data and knowledge between authors. Moreover, classical modes of scientific communication (articles, meetings, lectures…) do not allow to create an active and updated view of the field for members of a specific community (large scientific structure, international work group…). In this view, we propose here to develop an interface designed to provide a direct mapping between neuroscientific knowledge and 3D brain anatomical space.

Contribution Statement:

The main contributor of this work is Jordi Puig. The description and interface design of the prototype were due to Jordi Puig. Philippe Pinel, Alvaro Cassinelli, Andrew Perkis, and Masatoshi Ishikawa contributed to the to the active discussions, and parts of the writing and literature.

1.3.12   Paper D

Title: Art-science research across neuroimaging: From A-me to BrainCloud

Authors: Jordi Puig, Aud Sissel Hoel, Annamaria Carusi, Alvaro Cassinelli, Philippe Pinel.

Submitted to: Leonardo. Journal of Arts, Sciences and Technology.

Abstract:

Cognitive neuroscience has become a major player in shaping ideas about the self and about human capacities of behaviour. For this reason, it is crucial that neuroscience should be open to a broad range of perspectives and voices that actively engage in defining research questions and interpretive frameworks. This article reports on two projects that venture across the art-science boundaries, and that experiment with ways of integrating science, technology and society through artistic intervention. Both projects, A-me: Augmented Memories and BrainCloud, explore the central role of localization in neuroscience, or more precisely, the elusive links between cognitive information and brain anatomy.

Contribution Statement: The main contributor of this work is Jordi Puig. The execution of the described projects A-me and BrainCloud were due to Jordi Puig. Alvaro Cassinelli, Philippe Pinel, Annamaria Carusi and Aud Sissel Hoel contributed to the to the conceptualization and planning of the projects, the active discussions, experimental methodology, parts of the writing and literature.

1.3.13 Software module C

Title: BrainCloud

Code hosted at: https://github.com/wasawi/BrainCloud

Licence: MIT License

Description:

BrainCloud is an application to enable visualisation and interaction of the neuroscience community. The main goal of the project is to specify the requirements for the application which addresses the needs of the neuroscience community. The prototype has the ability to store and find comments that other researchers have placed on specific areas in the brain atlas. By selecting certain areas of interest the researcher will be updated on a daily basis about the activity of other researchers. The intention is to keep this application next to the other tools when doing research. It is meant to be a small piece of software to discover and relate to current global related research activities. It serves to connect to researchers and research sources depending on their location in the brain.

Dependencies:

```
Openframeworks 0.8
OF addon ofxPoint
OF addon ofxVolume
```

Includes:

```
ofEasyCam
ofxVolumetrics
ofxSuperlog
ofxUI
ofxCameraSaveLoad
```

```
ofxJSON
ofxXmlSettings
ofxOauth
ofxTwitter
ofxFTGL
ofxRay
```

Installation:

```
Download and compile source code
```

1.3.14 Software module D

Title: ofxPoint (OF addon)

Code hosted at: https://github.com/wasawi/ofxPoint

Licence: MIT License

Description:

An Openframeworks addon to handle 3D coordinates with different C++ types. It is a template for ofVec3f. It follows ofImage and ofPoint pattern.

Dependencies:

```
Openframeworks 0.8
```

1.3.15   Software module E

Title: ofxVolume (OF addon)

Code hosted at: https://github.com/wasawi/ofxVolume

Licence: MIT License

Description:

An Openframeworks addon to load, save, and process 3Dimage data in the CPU. It follows ofImage and ofPixels pattern. This addon is aims to offer the same utilities of ofImage and ofPixels but for 3D images. Contents: Equivalent to: ofxVolume ofImage ofxVoxels ofPixels ofxImageSequence

The rendering is done with ofxVolumetrics[1] which is an addon by Tim Scaffidi.

Dependencies:

```
Openframeworks 0.8
ofxPoint
ofxVolume
ofxVolumetrics
```

The example provided uses my fork[2]

Compatibility: This addon has been tested in OF 0.8.1 with OSX 10.8.

---

[1]https://github.com/timscaffidi/ofxVolumetrics
[2]https://github.com/wasawi/ofxVolumetrics/tree/addon_ofxVolume

1.4 Conclusions

This thesis has approached the topics of brain atlases and neuronavigation from multiple perspectives. The main challenge for this thesis was to provide a broad perspective of the field of study, wide enough to embrace distinct disciplines; from the scientific, the technical and the creative fields.

The research conducted in this dissertation has emerged from the realisation of two interrelated projects, A-me and BrainCloud. Both projects reuse technological developments to pursue a common goal, the development of technologies for the visualization and interaction with brain atlases and neuronavigation tools. Furthermore, both projects are constructed through an interdisciplinary group of researchers achieving a collaboration between the scientific, the technical and the creative fields. A-me is an interactive installation evolved from a surgical training tool, which has been presented as an artistic intervention to enable the public the interrogation of current neuroscience discourses on localization. BrainCloud is a consequence of the technical development of A-me, resulting in a tool to facilitate neuroscience research.

Practice-based research contributed to the optimal design and development of A-me and Braincloud. A-me, as a creative project, has produced scientific publications, artistic exhibitions and software modules. BrainCloud as a technical project aiming at the support of the neuroscience community, has produced scientific publications and software module releases and a prototype.

On a research perspective, the current thesis has demonstrated the effectivity of the Practice-based research in developing the design, the conceptualization and the production of art and technology research perspectives with the interactive installation A-me and the software application BrainCloud. The current thesis has also explored a unique research and development methodology by modifying the Spiral Model and using quantitative and qualitative assessment methodologies to study the quality of the systems produced.

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All%26queryText%3D%28%22Design+study+methodology%3A+Reflections+from+
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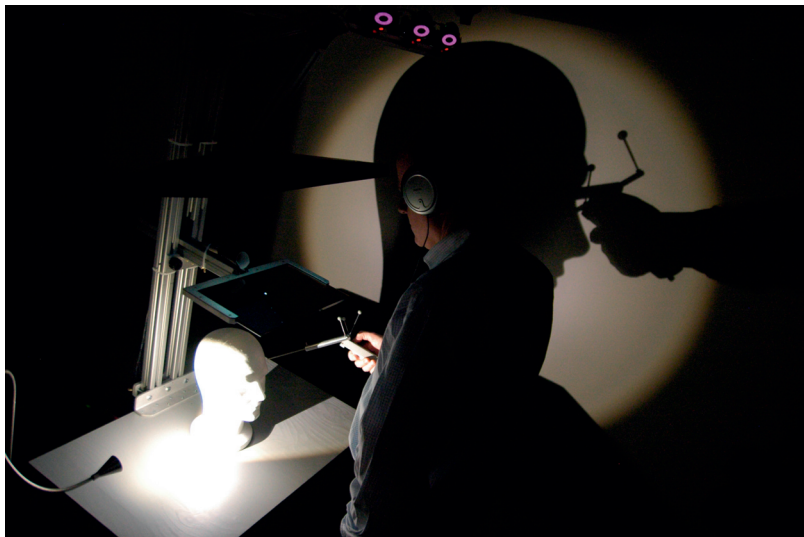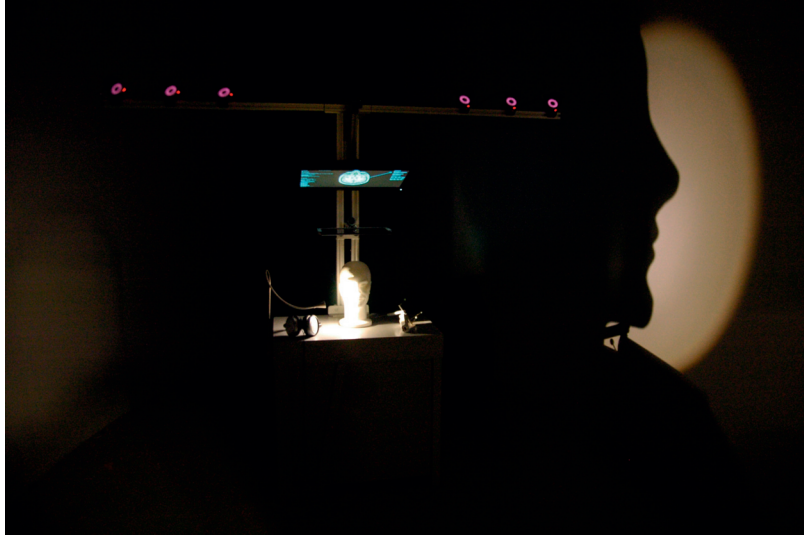
Chapter 2

Appendix A

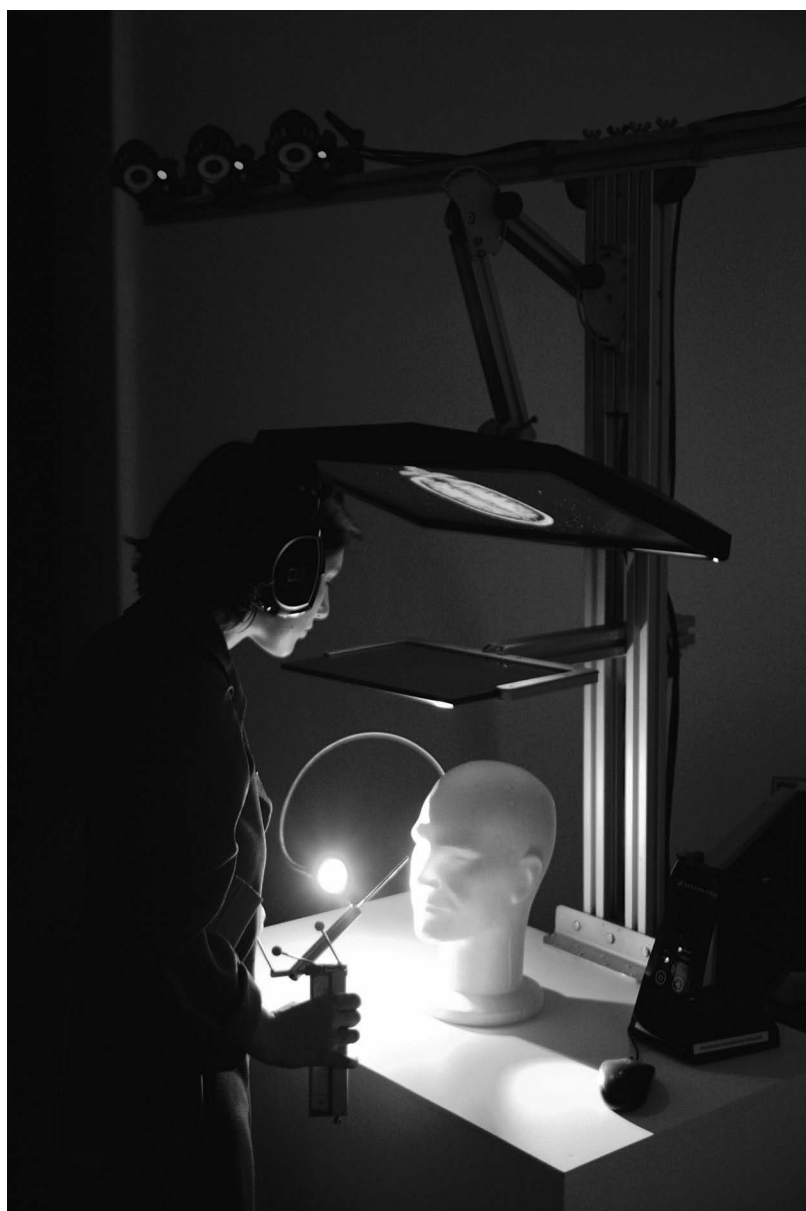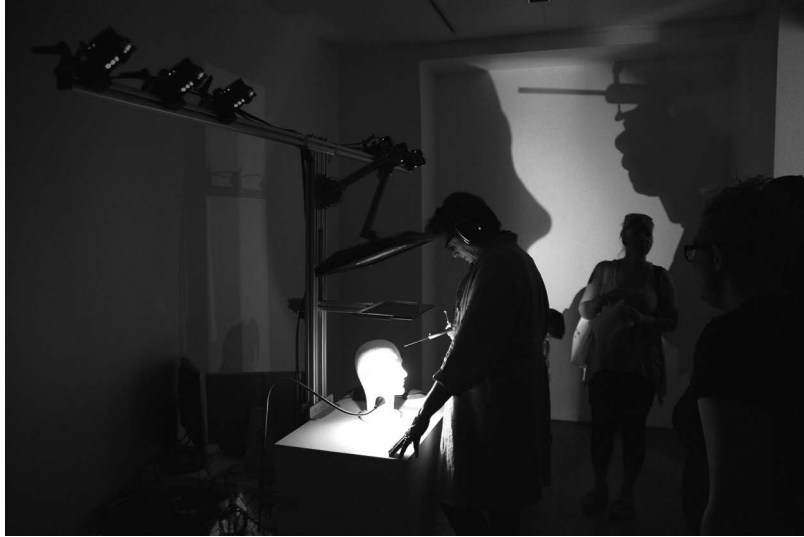This additional chapter contains the photographic documentation of the A-me exhibition at STRP.
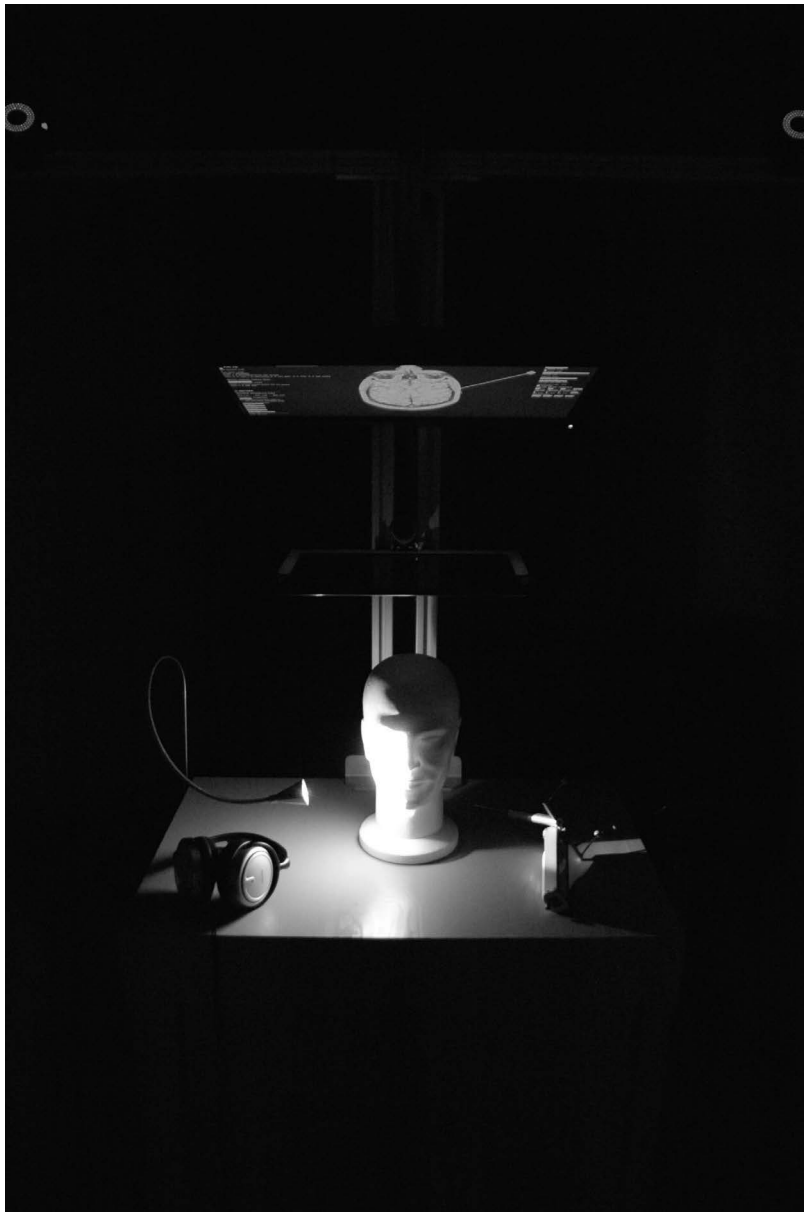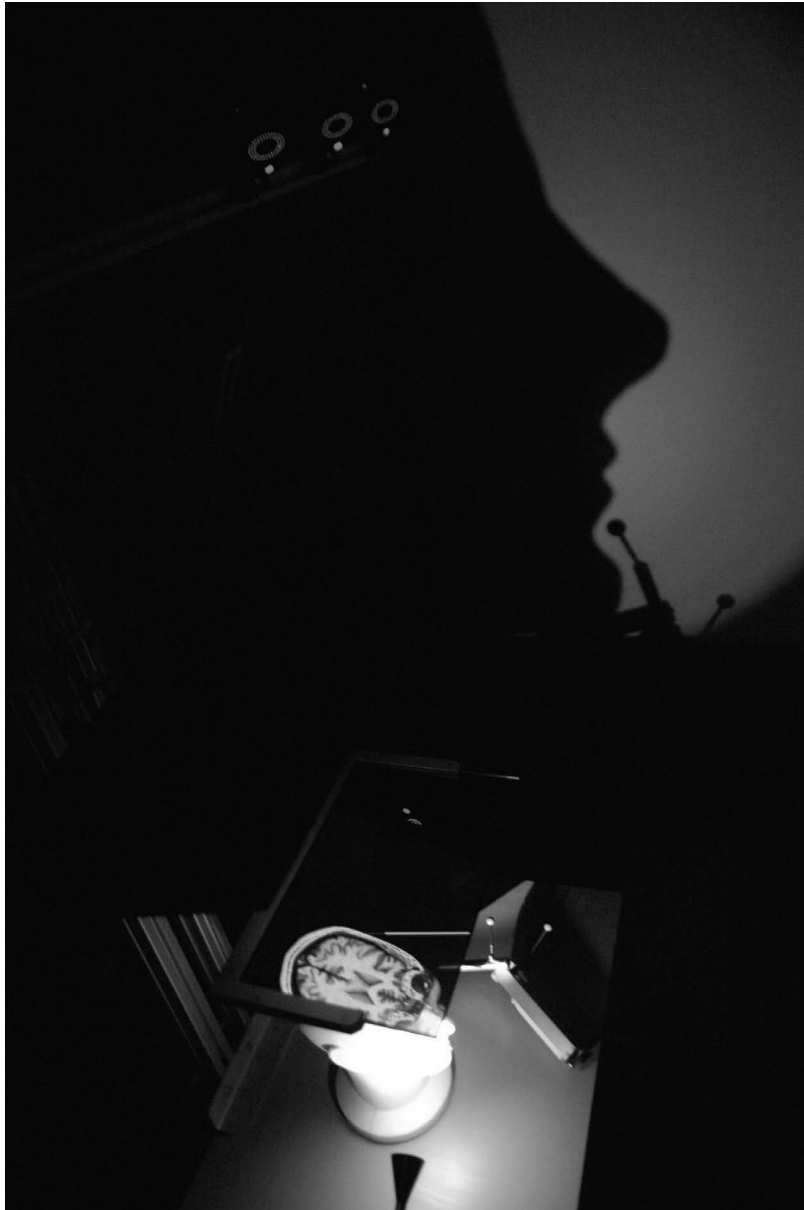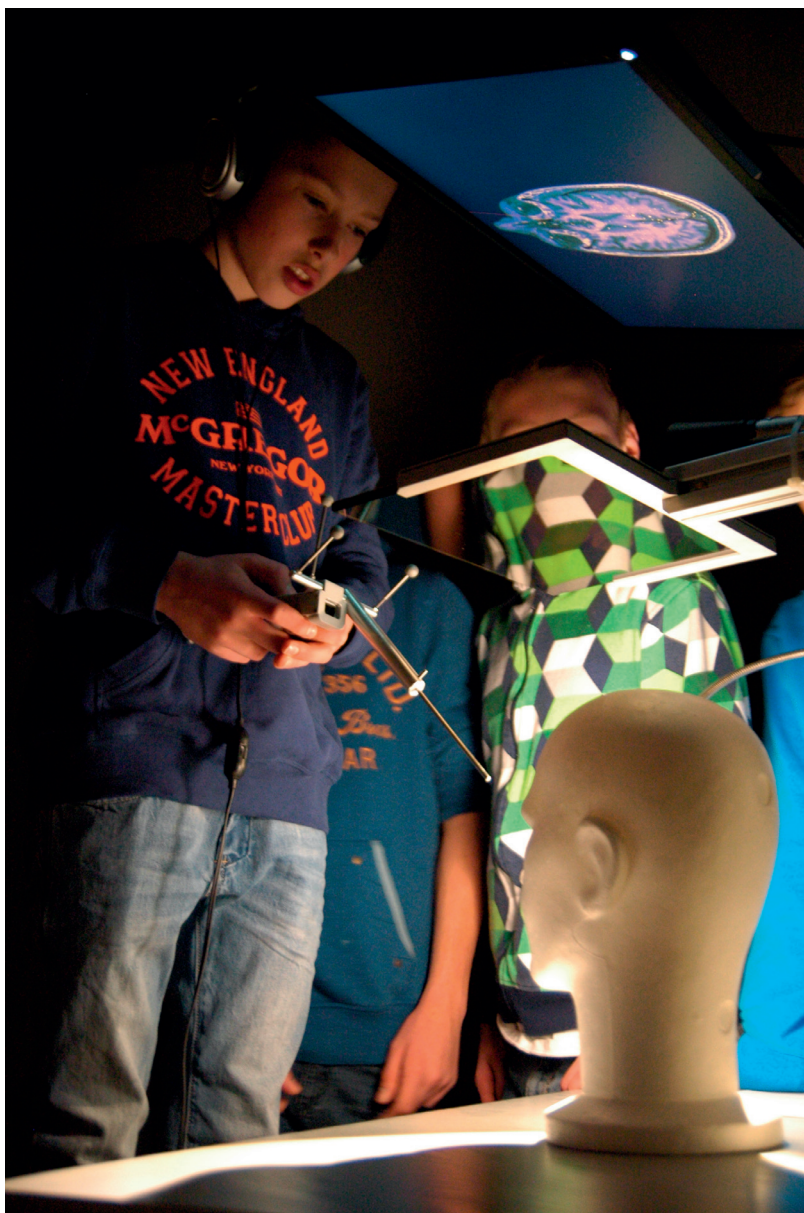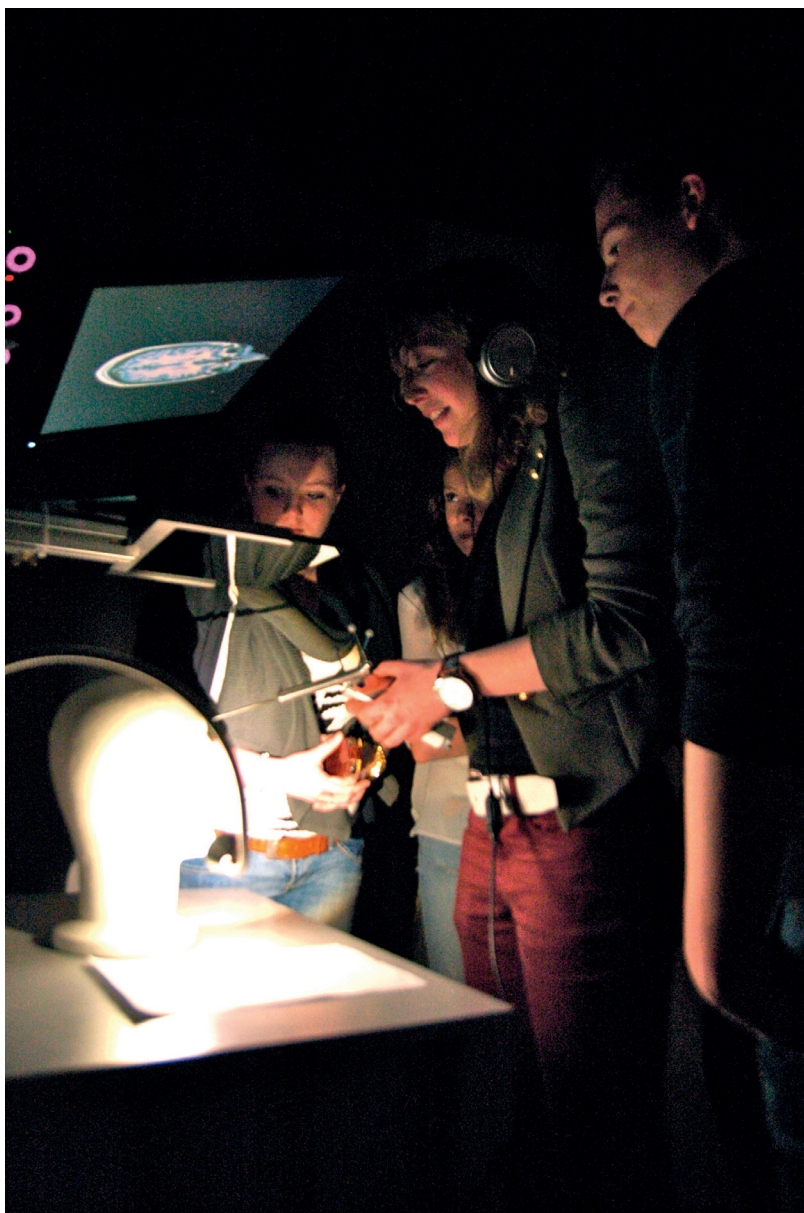
Chapter 3

Appendix B

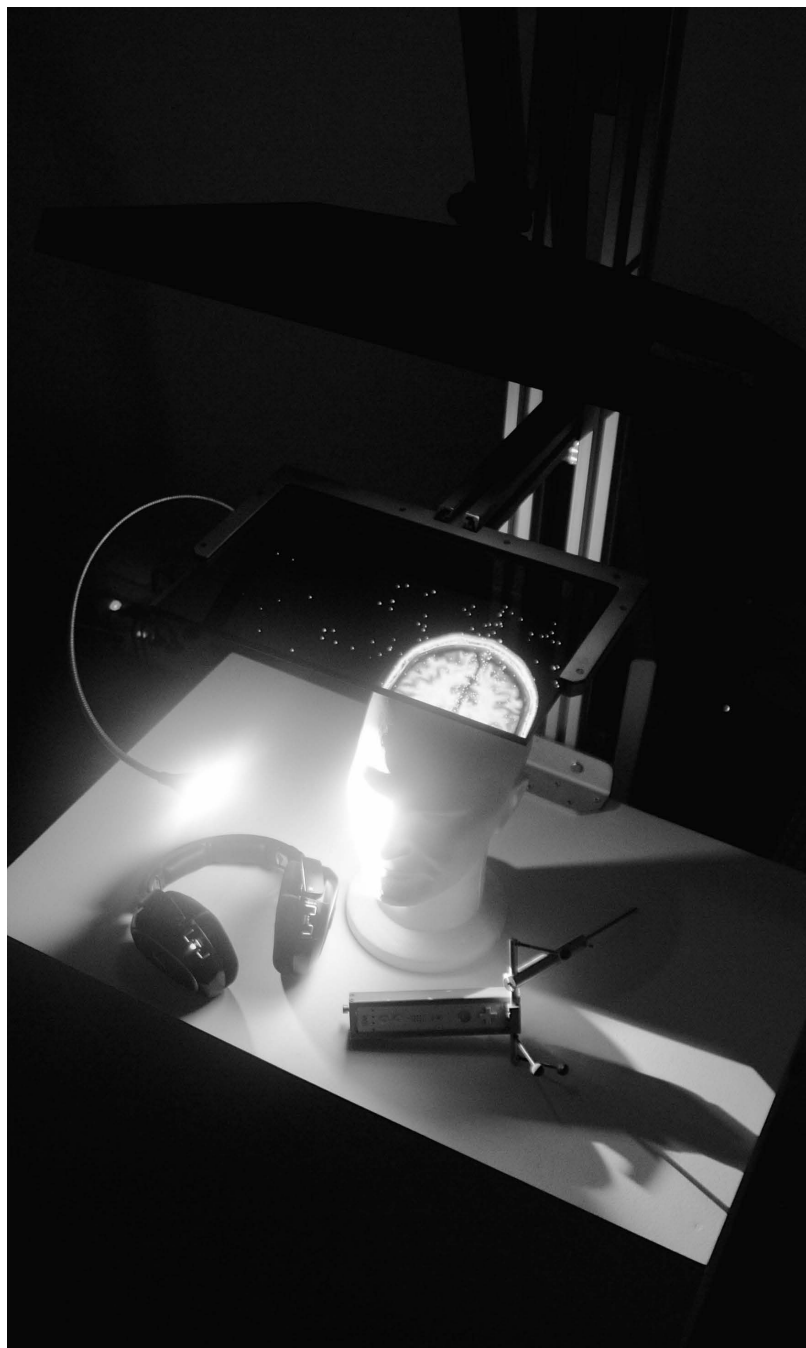This additional chapter contains the photographic documentation of the A-me exhibition at Babel Gallery.
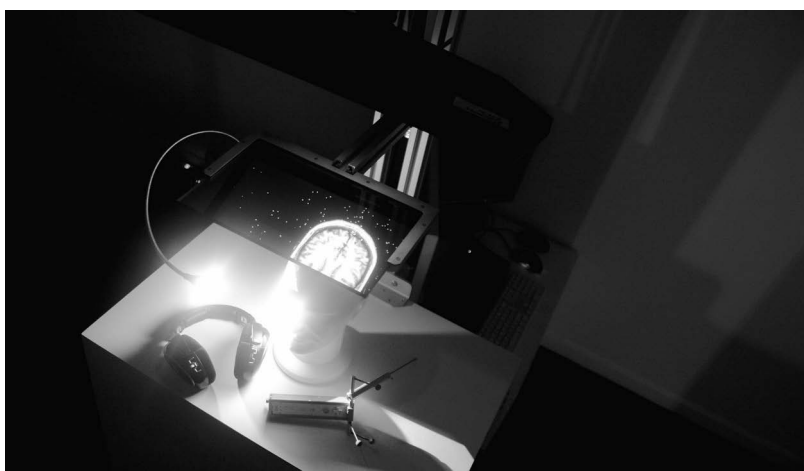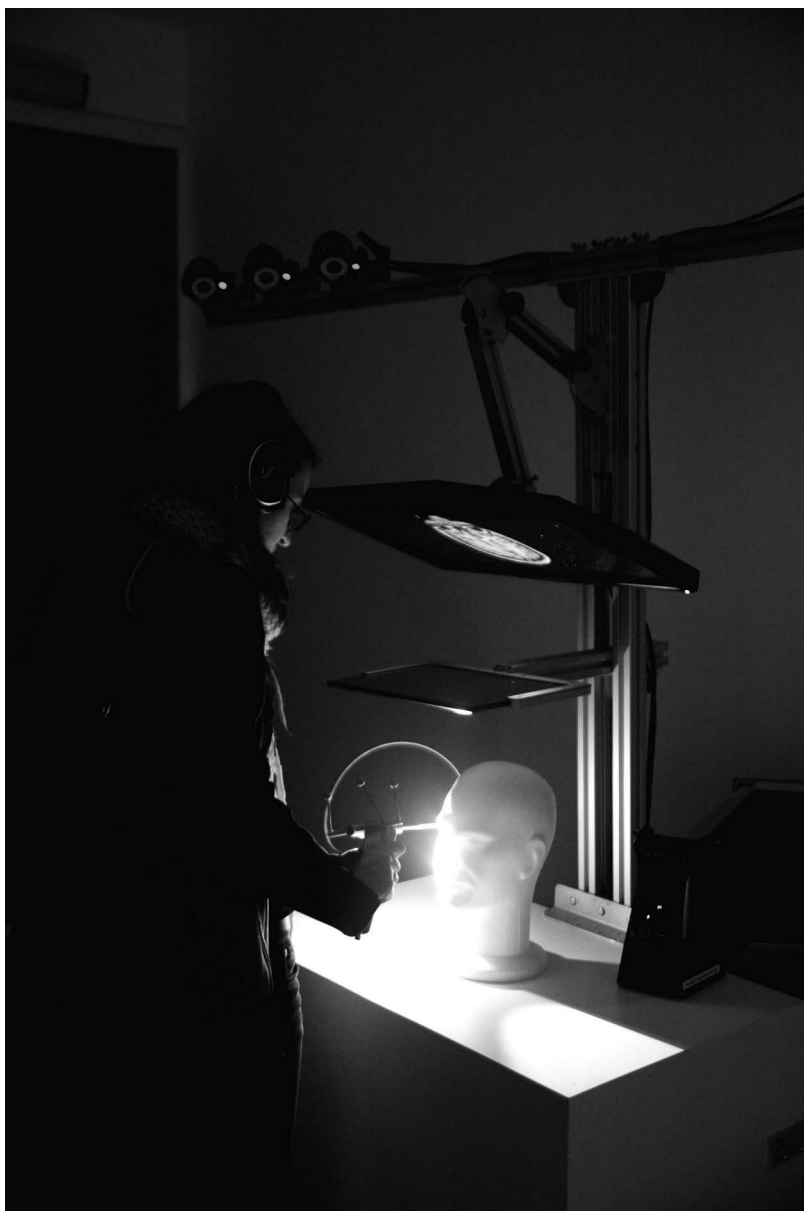
Paper A. Towards an efficient methodology for evaluation of Quality Of Experience in Augmented Reality

Jordi Puig, Andrew Perkis, Frank Lindseth, Touradj Ebrahimi

Abstract

The goal of this paper is to survey existing quality assessment methodologies for Augmented Reality (AR) visualization and to introduce a methodology for subjective quality assessment. Methodologies to assess the quality of AR systems have existed since these technologies appeared. The existing methodologies typically take an approach from the fields they are used in, such as ergonomics, usability, psychophysics or ethnography. Each field utilizes different methods, looking at different aspects of AR quality such as physical limitations, tracking loss or jitter, perceptual issues or feedback issues, just to name a few. AR systems are complex experiences, involving a mix of user interaction, visual perception, audio, haptic or other types of multimodal interactions as well. This paper focuses on the quality assessment of AR visualization, with a special interest on applications for neuronavigation.

1. Introduction

Joint efforts have been made to standardize quality measurement for audiovisual communications. Quality of experience (QoE) is not well defined although efforts are underway to better understand its meaning and mechanisms. The prevailing definition is often referred to that by the International Telecommunication Union (ITU) as: "The overall acceptability of an application or service, as perceived subjectively by the end-user". This is well known and much used in the audio-visual communications field from an engineering perspective and is usually applied to assessing audio or video perception. Their methods comprehend objective quality metrics and subjective quality assessment tests. The ITU has described non-interactive subjective assessment methods for evaluating the one-way overall video quality for multimedia applications in ITU P.910. This work has allowed important advances for the media industry.

However, most of the work regarding the assessment of perception of multimedia systems has focused on individual modalities, i.e., audio and video separately. Although important work has recently been performed on perceptual- based audio–visual quality metrics [1], and a taxonomy of QoE for the assessment of multimodal human-machine interaction has been defined in [2], it seems that these evaluation methods are still very far from fulfilling the current needs for AR assessment. Current assessment methods seem to be not applicable to AR systems since they usually assume the end user as a passive entity. AR systems are based on interaction and more importantly in an active perception and experience of the content.

Augmented Reality (AR) refers to the addition of a computer-assisted contextual layer of information over the real world, creating a reality that is enhanced or augmented. Azuma [3] defines Augmented Reality (AR) as systems that have the following three characteristics:

- 1) Combine real and virtual

- 2) Interactive in real time

- 3) Registered in 3D

It is an obvious fact that AR has been traditionally related to visual feedback. Milgram describes in 1994 "A taxonomy of mixed reality visual displays" [4] giving the first insights to differentiate the relations between the real and the virtual in the well known "virtuality continuum". Furthermore he sets several dimensions to differentiate display types i.e. "Extent of World knowledge", "Reproduction Fidelity" and "Extent of Presence Metaphor". Therefore every display type has different implications and consequences on the user experience. At this point "see-through" displays like head- mounted displays (HMD's) and "monitor based" displays are discussed and categorized depending on their use.

A decade later Bimber [5] presents an extensive work on displays for "Spatial augmented reality" where many other types of displays are discussed, e.g. "projector based", "optical overlays", "retinal displays", "auto-stereoscopic displays", etc. Thus there are many different ways of presenting virtual information, and some might constitute a better solution depending on their actual use. We will understand a display as something very heterogeneous, frameless, very far from the dogmatic conception of a limited square enclosing content. There are two major issues related to visual quality in AR. At first, perceptual issues can be addressed depending on the characteristics of the display devices. Secondly, closely related but clearly of a different kind, are the perceptual issues derived from semiotics and visual design issues of the rendered application. Issues of the first group were early addressed by Drascic & Milgram in [6] where problems like depth cues e.g. pictorial depth, kinetic depth, physiological depth or binocular disparity are discussed. The list on perceptual issues on device engineering is long and has been recently revised and extended in [7]. All those problems do not take into account the aspects related to visual design of the graphical user interfaces.

There are visualization aspects in AR being approached from a designer's perspective. Leaving aside the concerns on the display technologies used, one can solve the need for a visual feedback using a number of different metaphors. Strategies like masking, zooming, highlighting, or offering different levels of visual information load can be highly determining on the final quality of an AR system. Examples of these solutions have been shown in [8] and [9]. To summarize this point, there are different levels of quality for an AR system, from the more tangible aspects of device physical properties to the visual aspects of the virtual information

displayed. All of them approached and evaluated from distinct perspectives depending on their focus.

AR technologies have been introduced in the medical field over the last decade [10], and continue to advance the field [11]. The discussion on which AR systems have a better performance in the laparoscopic field has been discussed in [12] with the conclusion of a lack of a consistent assessment protocols for such technologies. Another major work is focusing on the current AR visualization technologies [13]. However, there is a lack of focus on the assessment methods for their evaluation.

The set of computer-assisted technologies used for the treatment of neuronal injuries are denoted as neuronaviation systems. Nowadays surgeons can use AR neuronavigation during pre-operative planning to assess the properties of a lesion. Such systems demand a high visual and interactive quality to ensure successful operations.

Still today there is no consensus on how to assess the quality across different visualization aspects of AR. In section 2 we discuss how scientific disciplines have tackled distinct assessment methodologies with different consequences. Section 3 discusses the differences between the fields. Section 4 gives an introduction on the need for assessment methods in neuronavigation. Section 5 focuses on the special requirements of assessment methods in AR visualization. Section 6 proposes a methodology derived from the existing methods from the fields of ergonomics, usability and Quality of Experience (QoE) to approach the question of quality assessment in AR visualizations. And section 7 is a proof of concept on the method. Finally, section 8 summarizes the conclusions of this research.

2. Aspects of QoE in AR

Human Computer Interaction (HCI) is traditionally assessed according to usability and ergonomics, which are characterized as human factors. The other disciplines working on this context are closely related, but they refer to different aspects when describing the quality of their system.

Usability

Although usability is an interdisciplinary concept, it is understood as the field concerned with the usage of a system. Usefulness is a concept typically composed by factors such as learnability, efficiency, memorability, satisfaction and errors [14]. A usability analyst assesses the mentioned aspects separately and the outcome is applied to a product or application.

Ergonomics

Even though ergonomics appears to be similar to usability, it has had a very different history and development. The word was born in the Ancient Greece and could be translated to "natural laws in work" which points to the need of finding best practices at work. Today it is most commonly used in industrial design and basically considers the relation of the objects to the human body. Ergonomic studies aim at reducing body strain injuries and to optimize the forms of the objects to economize body movements amongst others. A major work relating ergonomic quality of interactive systems has been described in [15].

Human Factors

Human factors could be understood as the interdisciplinary field that comprehends all aspects for the study of HCI technologies. In HCI, heuristic evaluation is a usability- testing technique carried out by expert usability consultants by using guidelines, checklists, standards, etc. The evaluations are carried out in real environments, saving time resources. This is known as soft criteria, because it relies on the experience of the evaluator.

Ethnography

The case of ethnographical assessment is slightly different. The main focus is set on the cultural factors influencing HCI. The basis is that humans have strong cultural interactions, hence the main goal is to evaluate how well a system supports the knowledge and activities

of a group of people. These assessments are especially relevant when the evaluated system is used by groups of people.

Subjective Quality Assessment

Subjective assessments can be used to evaluate a given quality, when putting the user as the focal point. It does not rely on the eyes of an experienced evaluator. Instead it uses large amounts of user data and statistical processing. When "statistical significances" emerge from the data, scientific conclusions are drawn. These methods are very reliable when applied to perceptual measurements where cognitive interactions are minimized. When subjective assessments are carried out, the subject gives answers to questions about the quality of the stimulus. This fact assumes that the user can consciously give a correct and accurate answer to what is being asked. Another particularity is that the tests are carried out in laboratories, which means that external variables are intentionally minimized. These methodologies do not rely on the experience of an evaluator but rather rely on the self-assessment of each individual subject, which is processed by statistical means to extract a reliable conclusion. Quality assessment in the fields of signal processing, food science and acoustics are typically using such methods.

Psychophysics

The methods in psychophysics are of harder criteria. Usually there is no self-assessment; the cognition of the subject is not represented in the measurements. The aim is to quantitatively assess the relationship between physical stimuli, which can be an image or a sound, and the perceptions they create. In this case the tests are also carried out in a laboratory isolating the subject from many external parameters present in the real world.
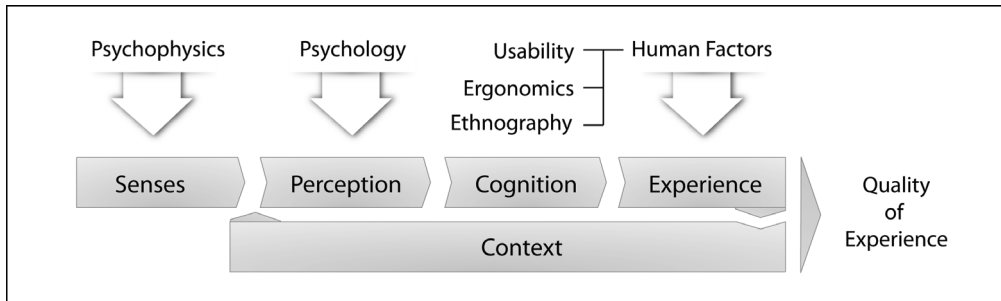
Figure 1: Quality of a stimulus assessed at a different stages and the target fields of study.

3. The differences between fields

We could intuitively assume that the so called "inspection methods" or "qualitative methods" performed by ethnographers, and Human Factors scientists are wider. They can target multiple issues at the same time but they have softer empirical grounds of truth. Furthermore, QoE is narrowing the chances for wrong conclusions by narrowing also the assessed variables and the undesired noise from reality. But the main difference between both methods is that QoE has rarely been used in interactive systems while in human factors the assessments always focusing on human-computer interaction.

The relation between the quality of a stimulus assessed at different stages and the target fields of study is depicted in Fig. 1. While Pereira [15] proposes a triple sensation- perception-emotion user model for approaching multimedia experience, we envision a direction with five stages starting from the senses of the subjects when receiving a stimulus. At this stage quantitative psychophysical methods may be applied to assess them. From the senses more complex perceptions may develop, leading to the second stage. Subjective quality evaluation is the assessment method to evaluate the perceived quality of the stimulus. While the understood stimulus interact with the attention processes and memory we enter in the cognitive domain, also being under the field of QoE. Closely related and in a higher level the cultural effects interact with the cognitive processes. At this point ethnographical methods are suitable to assess such cultural influences. At the end of the quality process the final experience is determined. At this point heuristic evaluation is used to study the overall quality

of a multimedia experience. Finally, we understand the context as the phenomena existing from perception to experience.

4. The case of Neuronavigation

The need for evaluation methods is tangible since several technologies are already being commonly used. The medical field has adopted AR technologies since their appearance and nowadays they are already utilized on an everyday basis.

In surgical interventions surgeons rely on imaging technologies during the entire process, and AR systems are increasingly being used. This is especially true in the planning phase right before the procedure starts. A major challenge during the intervention is the fact that AR systems are not well adapted to the surgical workflow. In addition few studies have been conducted to assess the benefits of AR systems compared to more traditional visualization techniques. The result is that only enthusiasts use intra- operative AR systems and most surgeons resolve slicing through the image volumes. AR would probably be more useful bridging the gap between the information from modalities like Magnetic Resonance (MR) and Computed Tomography (CT) in one side and real-time 2D data from endoscopes, microscopes and ultrasound on the other side. Today this information is often found on separate displays and it will be crucial to merge all the information in the future. In order to achieve this it's important that AR equipment is adapted to the surgical field and to have methods to assess their quality.

Within the national center for ultrasound and image guided therapy in Trondheim, Norway (a collaboration between SINTEF, NTNU and St Olavs University hospital), surgeons and engineers have been working closely together for over 15 years in order to advance the neuronavigation technology. This has been done by letting engineers participate in the operating room and by conducting qualitative analysis and informal interviews. Current research has disclosed an increasing need for quantitative assessment methods to assure quality for the systems currently under development.

5. Quality assessment for AR Visualizations

As previously stated, AR systems are complex. Interactivity, haptics, virtual visual and auditory perception merged with an enacted perception [16] of reality. Quality assessment is still required and nowadays becoming crucial. AR assessments cannot escape from the fact that evaluations must include interaction. Therefore quantitative methods must adapt to this context. Ergonomic scientists have usually assessed AR systems by offering users to perform a task to reach a goal [17]. However, most of these studies have been focusing in the overall performance of the subject. We want to focus on quality metrics for the visual perception on AR. The fact that AR systems clearly make use of action during the perceptual process is what pushes us to present a task dependent methodology to quantitatively evaluate AR visualizations.

6. The proposed method

Our proposed methodology uses subjective assessment and objective measurements. The subjective measurements can be in the form of questionnaires, subjective user ratings or judgments. Objective measurements are processed through a task to be accomplished by the subject. The task is carried out using a tracked device, which allows the recording of the user interaction in an accurate manner. The performance of the user is analyzed by processing time to completion (TTC), accuracy or error rates by statistical means. By running a sufficient amount of subjects through two experimental conditions, i.e. visualization A versus visualization B, it will be possible to conclude whether there is a statistical difference between the performance of users. These conclusions will be combined with the outcome of the analyzed scores of the user ratings. This method can be carried out in a laboratory with non-expert users.

In case the results of the experiment are conclusive further evaluations can be conducted in the real environment to achieve deeper understanding of the future needs for the system. At this stage a qualitative assessment is recommended to improve any aspects related to the

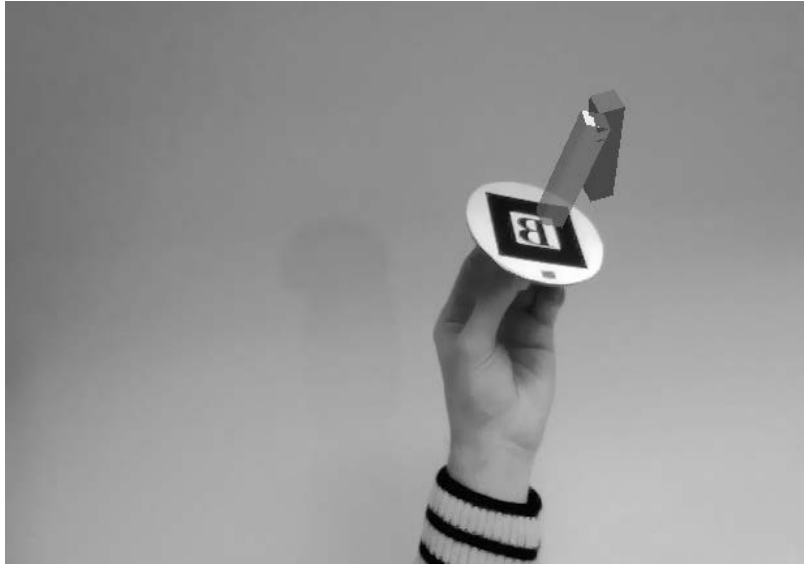efficiency of a given technology in the real environment.

Figure 2: Matching position and orientation task for a pilot experiment.

7. A proof of concept

We conducted a pilot experiment following the proposed method but concentrating only in objective measurements. Subjective assessments have to be tailored to specific experimental designs; therefore such measurements are not suitable for a pilot experiment. A full implementation of the proposed method is to be detailed in future publications. The experiment consisted in the comparison of two different presentation types i.e. a computer screen and a projection of a bigger size. The task to accomplish consisted in matching the position and orientation of a virtual object (Fig. 2 in red) by manipulating a tracked marker with an augmented similar object (Fig.2 in white). Although this task does not emulate a realistic neuronavigation system (basically because it does not use the same visualization system), it is similar in terms ergonomics, interaction and human behaviour. The subjects have to co-ordinate the visual feedback on the presentation with their movements in order to precisely

match the position on the real space. The task was repeated sequentially using the same presentation type.

A total of 10 different positions had to be completed. Once the first presentation type was assessed, the same task was completed in the other presentation type.

Subjects 1 and 3 started with presentation type A and subjects 2 and 4 with type B. For the pilot experiment TTC was measured for each position. The improvement in the learning curve of the subjects was more evident in presentation type B compared to type A (see Fig. 3 and 4). Subjects required some minutes to match the first targets and reduced the times to some seconds at the end of the measurements. The proof of concept is promising and will be used as a guide to refine and optimize our methodology.

Preliminary studies show that this method can offer successful results in objective evaluations by giving evidence of the performance in compared presentation types. On the other hand, subjective ratings and questionnaires can better explain the source of performance rates obtained.
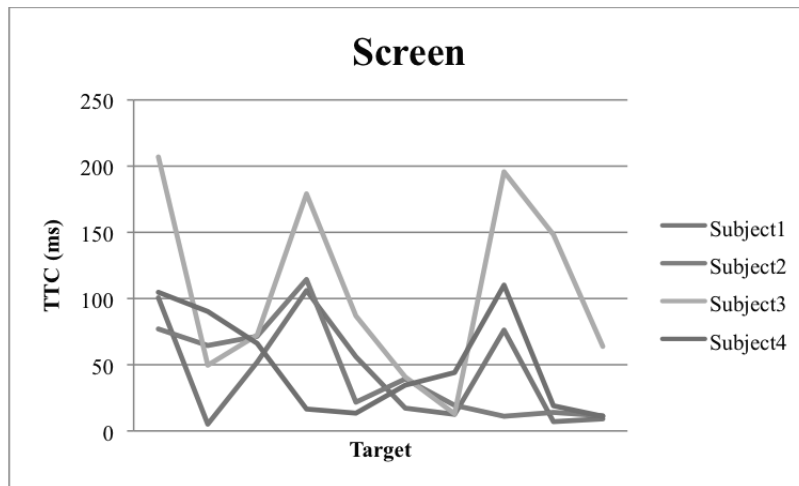

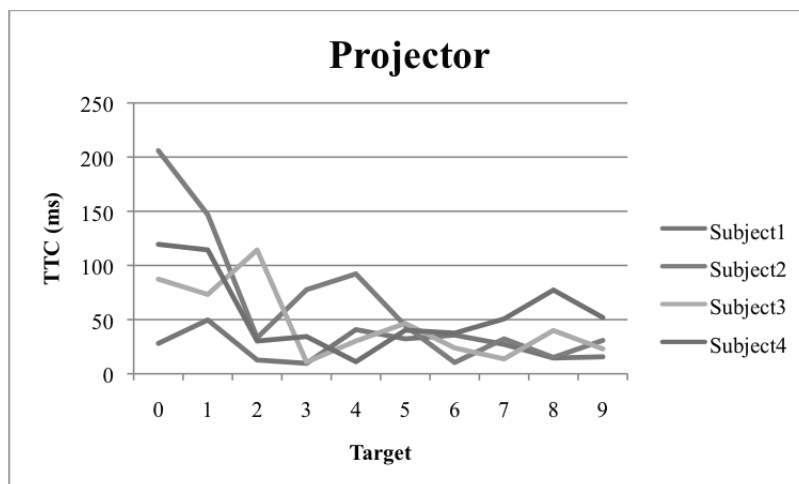Figure 3: TTC Scores for presentation type A.

Figure 4: TTC Scores for presentation type B.

8. Conclusions

We exposed the issues and disciplines related to quality assessment methodologies for AR visualizations. We proposed a quality assessment method for AR visualizations. The method is based on quantitative evaluation with a mixed approach using subjective assessment and objective measurements. The intention of this research is to apply the method to assess technologies in the neuronavigation field.

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Paper B. A-me: Augmented Memories

Jordi Puig, Andrew Perkis, Aud Sissel Hoel, Alvaro Cassinelli

Abstract

A-me is a fictitious memory-evoking apparatus at the intersection of science, art and technology. The system enables users to experience other people's memories as well as store their own by interacting with a volumetric representation (MR) of a human brain. The user retrieves or stores memories (audio traces) by pointing and clicking at precise voxels locations. Triggered by their exploratory action, a story is slowly revealed and recomposed in the form of whispering voices revealing intimate stories. A-me is a public receptacle for private memories, thus exploring the possibility of a collective physical brain. The installation introduces an original optical see-through AR setup for neuronavigation capable of overlaying a volume rendered MR scan onto a physical dummy head. Implementing such a system also forced us to address technical questions on quality assessment of AR systems for brain visualization.

Introduction

Questions such as: "What is the basis of human behavior, though or memory? How do we define actions and decision processes? Can memories be disembodied from the individual that experienced them? Can memories be recorded and shared?" have traditionally been addressed by philosophers and psychologists using introspection and verbal report. While neurologists are looking at the connectivity of neurons, cognitive neuroscientists are seeking answers through behavioral experimentation, neuroimaging and computational modeling. In the young field of cognitive and behavioral neuroscience, psychological functions are partially classified by the localization of their underlying circuitry in specific areas in the brain. The emergence of powerful radiological measurement techniques (e.g., fMRI, PET, SPECT) combined with experimental techniques from cognitive psychology allows neuroscientists to address questions of the human mind such as cognition, emotion or memory by looking for their neural correlates in the physiological brain.

Discussions on brain/mind matters and functionality take place across several specialized scientific disciplines, yet many fundamental questions remain of public interest and are at the core of everyday human experience. A-me offers the opportunity of a free, personal reflection on some aspects of these discussions; for one, the work exposes the ambiguity between the possibility of accurately locating places in the brain, and the uncertainty of defining a place in the world (or the brain) for a mnemonic experience. The installation also forces us to reflect on the ownership of a memory item: Whom do memories belong to? Are memories private events? Can we manipulate them?

Motivation

What is memory? Where is it? Do memories remain the same forever? Are they modified depending on our current emotional state or our will? What is the substance of a memory?

Since these questions are tied to the nature of human experience itself, it's not surprising

Figure 1: A-me being used by the author.

they were explored extensively in philosophy, art and literature well before these could be considered in scientific terms. The problem of localizing 'a memory' is ill posed because the

relation between a place and a memory can be considered in multiple ways. Before the advent of computational theories of the mind, a 'memory' had no other physical correlate in the world than, perhaps, the place where the memory was formed. Writing provided effective methods of externalizing certain important aspects of human memory [1]. It was possible to think about a place for a particular memory: the writing itself, and the support for the writing. But in an obvious sense ink and paper is not the memory itself: without a reader, the set of written symbols remain meaningless. Adding other modalities to the recording (sound, image, etc) may not change the problem a bit - although some philosophers have mused over the possibility that a complete recording of physical reality may also bring about phenomenological experiences, as it happens in the novel "La invencion de Morel" [2]. Leaving aside this intriguing possibility, it seems clear that for a memory to come to life, the symbols, sounds or images need to be interpreted, decrypted and re-associated inside a mind. In other terms, a memory and a trigger for that memory may be different things: remembering is an active, exploratory process. The same set of triggers can end up producing different remembrances if read by different minds. A-me strives to reproduce, or at least to represent metaphorically this exploratory exercise.

Locating where memories that do not require an external record to be experienced are, in the brain, is also a subject of much debate among neuroscientists. The reason for the debate is that the model of encoded data (situated somewhere) + a decoder machinery (situated somewhere else) is an extreme oversimplification of what may be happening - not to say perhaps plain wrong. To start with, the decoder contains information about the thing to decode – in other terms; it is part of the 'record'. Comes then the problem of locating a mind, which may be just a vain pursuit, at least if we look just inside the skull [3].

Still, locating where a memory is in the brain is a problem that needs to be practically addressed in neurosurgery. Wilder Penfield, considered one of the greatest neuroscientists of his time, described some of his most ground-breaking research in the chapter "Gateways to the Mind" [4] of the Bell Labs TV series. He explains the idea that all conscious events are permanently recorded in the brain. In the documentary he explains:

"There is recorded in the nerve cells of the human brain a complete record of the stream of consciousness. All those things of which a man was aware in any moment of time are recorded there, and all the sights and sounds which he ignored and the thoughts which he ignored are absent from that record."

During surgical brain operations performed by him, the patients were conscious and were able to talk. While the patient's brain was exposed, a "gentle electrical current" was applied with an electrode and then a very vivid memory could be re-experienced. When Penfield asked how those experiences seemed to them, they reported that these were "much more real than any remembering", which seemed to imply that the brain is somehow capable of recording multimodal experiences in perfect detail (eidetic memory), and that those memories are stored in precise locations in the brain.

The results of these experiments are regarded today in a more critical manner by the scientific community, but the idea that memories are 'dormant' and can be elicited, erased, modified or even that new memories can be inserted by physical means (i.e., by tampering directly with the brain tissue) is pervasive in science- fiction novels and films. In the science-fiction film "Strange Days" (Kathryn Bigelow, 1995) experiences are recorded, exchanged and finally reproduced by others. Michel Gondry's "Eternal Sunshine of the Spotless Mind"(2004) builds a story around a machine capable of erasing memories at will, briefly bringing peace to the souls of former lovers. (Interestingly, memories are represented as colored spots in a brain scan, and can be selected by a simple pointing device, very much like in the present installation A-me). In Vim Wenders's "Until the End of the World"(1991), a machine is used to record human dreams: the characters become addicted to the device, living only to see their own dreams during the day. In "Total Recall" by Len Wiseman (2012) or Paul Verhoeven (1990), a factory worker discovers that his memories are in fact fabrications implanted by the government.

Will we be able in the future to recall, modify, and/or insert human memories in such a way? Some futurists such as R. Kurzweil are convinced it will be so. By the way, we may be already in the verge of visualizing memories exactly like in Until the End of the World,

as demonstrated recently in [5] using non invasive Brain Machine Interfaces (BMI). In the meanwhile, using AR techniques, A-me simulates this possibility in the present, giving us the opportunity to reflect on its consequences.

Scientific approach

The field of neuroscience has intensively grown during the last twenty years. Nowadays the mapping techniques are much more powerful than those used in Penfield's experiments. Brain atlases are being used in the field of neuroscience to study the regions of the brain creating limits to divide areas of functionality. Therefore, modern neuroscience represents the triumph of a method: reductionism.

There is currently a vigorous debate on how the brain/mind-problem is approached from different disciplines. The reductionist approaches to the brain/mind are controversial and are currently being countered by more holistic views. For instance, phenomenological approaches assume that the human cognition is active, dynamic, and always requires a meaningful context.

On the other hand, what cognitive scientists use as a method to study the brain, namely "the black box approach", aims at describing the underlying processes of a unknown system (seen as an object) by stimulating the inputs while isolating concrete tasks and measuring the outputs. This way of looking at human matters is prominently contrary to phenomenology. A deeper examination of the brain/mind controversy has been illustrated by Beaulieu in her dissertation: "The Space Inside the Skull", where the definitions of the mind and their mappings into virtual brains are extensively discussed [3].

At this point, it is important to emphasise that A-me is not a science communication project nor intended to communicate how current neuroscience explains the mnemonic phenomenon. A-me is a science inspired artistic intervention aiming at a self-reflective activity of the visitor about the neural substrate of human memories through a playful experience.

An art-science project

The development of the device is part of the research project Picturing the Brain and it is used to visualize tomograms of the human brain in Augmented Reality (AR). The development of the device aims at conducting research on Quality of Experience (QoE) in AR.

Augmented reality is already state-of-the-art in neurosurgical planning. Several different technologies are currently being used: displays, tracking systems, interactive systems, and many others. The current challenge is to find successful methods to assess the overall QoE of the end user. Although some work has been performed on perceptual-based audio–visual quality metrics [6], it seems that these evaluation methods cannot fulfill the current needs of AR. However, today's assessment methods seem not to be applicable to AR systems since they usually assume the end user as a passive entity. AR systems are based on interaction and more importantly on active perception and experience of the content. A preliminary discussion about the methodologies employed to assess the quality of AR systems and their challenges has been presented on [7]. The article examines the current scientific fields exploring this goal. Some of them employ qualitative assessment as a basis for experimentation e.g. Ethnography or Usability, and some others use quantitative assessment with subjective metrics to evaluate the quality of a system e.g. QoE applied to Multimedia Signal Processing or Acoustics. Therefore, there is a need for new methodologies to assess the quality of AR systems. The development of this installation is a step towards further research on this technical field, but we believe that being able to assess the quality of experience may be a valuable tool helping to develop and improve sophisticated, AR-based media art installations such as A-me.

From theory to practice

A-me treats memories in a location-based manner. Using a highly accurate tracking system and a tomographic brain visualization, the user is able to find memories in the displayed volume as tiny glowing particles. The visitor activates them by holding the pointer on the

correct position and pressing a button. Triggered by their action, a story is slowly revealed. It consists of a whispering voice (binaurally spatialized sound delivered through headphones), relating parts of intimate stories that were previously stored by another person. The visitor is also able to record his own memories on certain locations of the brain. In this way, A-me also serves as a memory collector (see Figure 2).
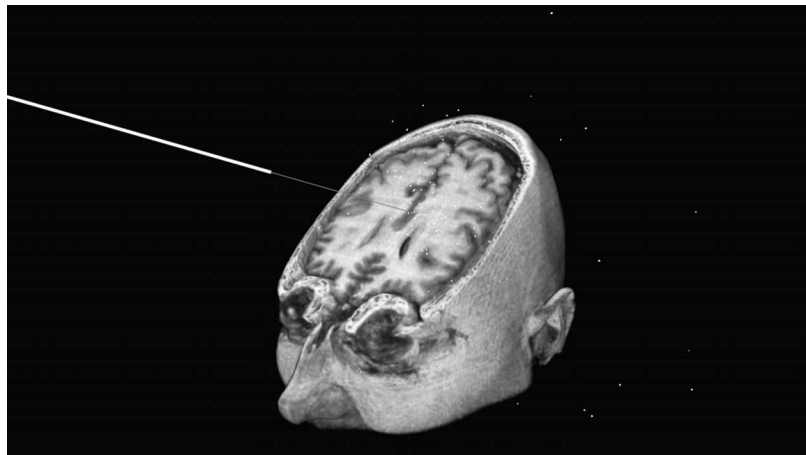

Figure 2: Screen capture of A-me. Each dot is a recorded memory.

The installation requires an exhibition space where there is an area properly equipped to render the experience. One stereo 3D screen, six tracking cameras, a half-silvered glass and a head manikin are standing on a table (see Figure 4). The visitor is equipped with high-end wireless headphones, tracked shutter glasses and a tracked probe. Looking through the glass, the visitor can see the MR volume registered against the dummy-head. The visitor is able to navigate different areas of the brain by manipulating the probe. Active hotspots indicating the location of the memories are visually merged with the real data. Immersive auditory responses are triggered by pointing and clicking at any of them. When moving further away from the hotspot, the device will merge more and more soundscapes of neighboring aural memories resulting in an overlapping of multiple voices. This is similar to the cocktail party effect, where by selective attention (i.e., by approaching the hotspot again), the user is able to focus and make sense of a particular memory.

The device is composed of three parts: the tracking server, the visualization server and the audio server, which will directly react to user interactions (Figure 3).
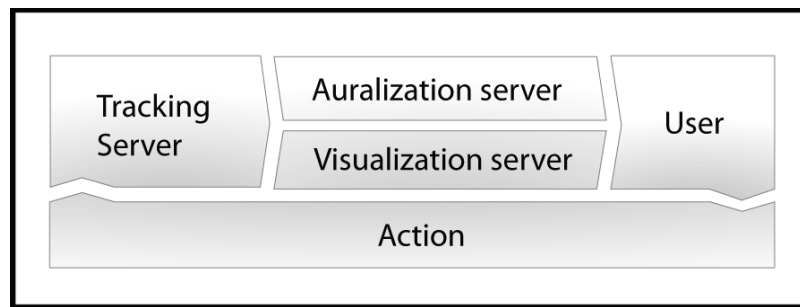

Figure 3: Software and interaction diagram.

Tracking system

The information flow starts on the tracking cameras, which are sending video frames at a very high frame rate (250fps) to the tracking server. Two groups of cameras are located on top of the installation, each group pointing at the user from one side. This positioning is required to cover the possibility of both right- and left-handed users. The cameras have large overlapping fields of view, and each video frame is 832 by 832 pixels. These specifications ensure a precision for the extraction of 6DoF (six degrees of freedom) information for tracked objects to be below 1mm (depending on the area).

The latency of the tracking system is in the range of 4 to 10 milliseconds. Once the tracking server has extracted the 6DoF information for each tracked object, the data is sent over a UDP socket to the other servers. This transmission will occur 120 times per second.

The Optical See-Through AR display

To merge the virtual data from the tomography with the reality we used a device based on The Pepper's Ghost Effect (PGE). PGE is a well-known technique in theatre productions to
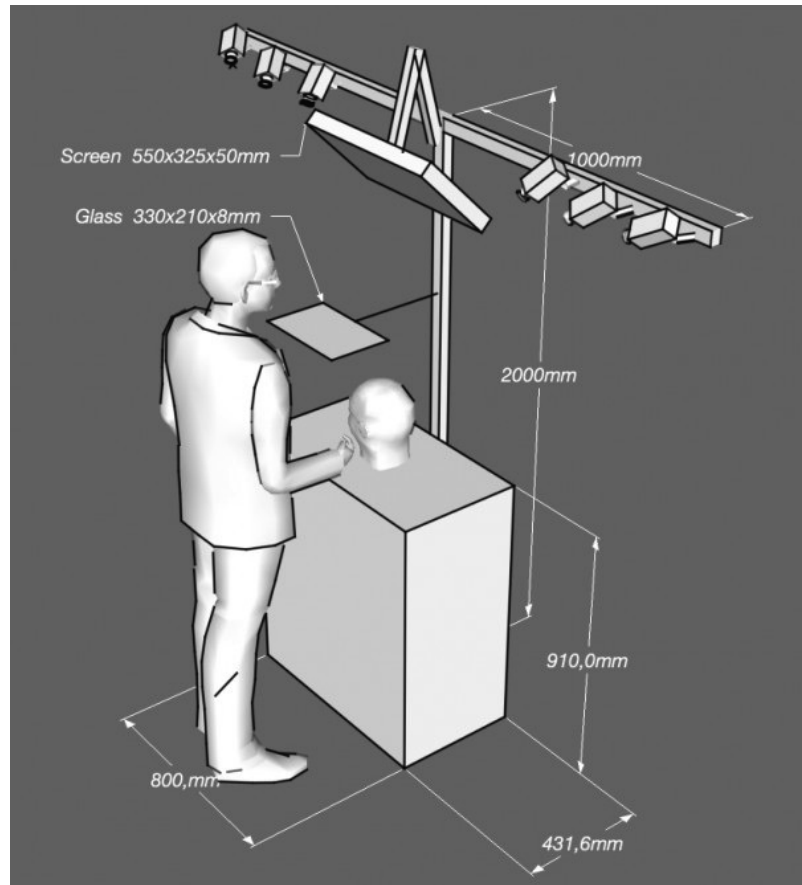
Figure 4: Hardware setup.

make objects magically appear or disappear. This technique, created by John Henry Pepper in 1682, consists of placing a half-silvered mirror in an angle, in such a way that depending on the lighting intensity in the scene, translucent objects appear to float in the air. Lately, this setup has been used with electronic displays in AR allowing interactions between real and virtual environments [8]. This setup is particularly interesting when used in AR because it can solve the known problem of "accommodation and convergence" [9].

Depending on the implementation several terms have been used to refer to this technique. The terms: "holographic display" [10], "fixed optical see-through (OST) display" and "mirror
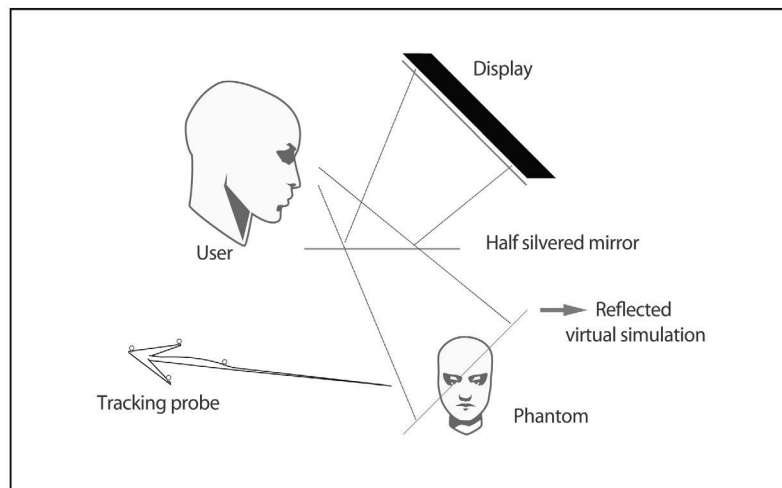
Figure 5: Diagram of the Pepper's Ghost AR system.

based display" are amongst the most widely used. The diagram depicted in Figure 5 exemplifies the disposition of the half-silvered mirror in respect to the screen and the real object where the blending occurs. The red line refers to the 2D image displayed by the screen and its corresponding reflection, which will fall at the opposite position in respect to the mirror. This position and orientation of the reflection appears fixed in the real space independently of the user's point of view.

The development of the device is a work in progress that can be divided in three phases, each of one providing the opportunity of a separate assessment of QoE for independent aspects of the interactive AR system:

Phase 1: OST AR with tracked probe

The first phase is a prototype of an OST AR device displaying three-dimensional (3D) static graphics. No stereoscopy is involved at this stage. Reflections of the display on the glass are used to overlay the real object with the virtual stimuli. Controlled illumination (self illumination or light projection) is used to adjust the similarity between real and virtual stimuli.

Phase 2: Interactive 2D AR

An additional degree of complexity is added by transforming the previous prototype into an interactive device. The user is able to navigate the virtual content by physically moving the dummy head which position and orientation is being registered; this means that moving it physically will affect the virtual stimuli. This implementation necessitates the use of a tracking system in order to register the position and the orientation of the dummy head accurately.

Phase 3: Interactive stereo 3D AR

The final phase is a prototype presenting the virtual simulation in stereoscopic 3D. This will allow the use of volumetric objects on the real stimuli. In order to achieve AR with a stereo pair of images we will also need to track the glasses' position of the user. At this point, the user is able to alter his point of view and to manipulate the real object freely while the system updates the virtual overlaid simulation in three dimensions in real-time.
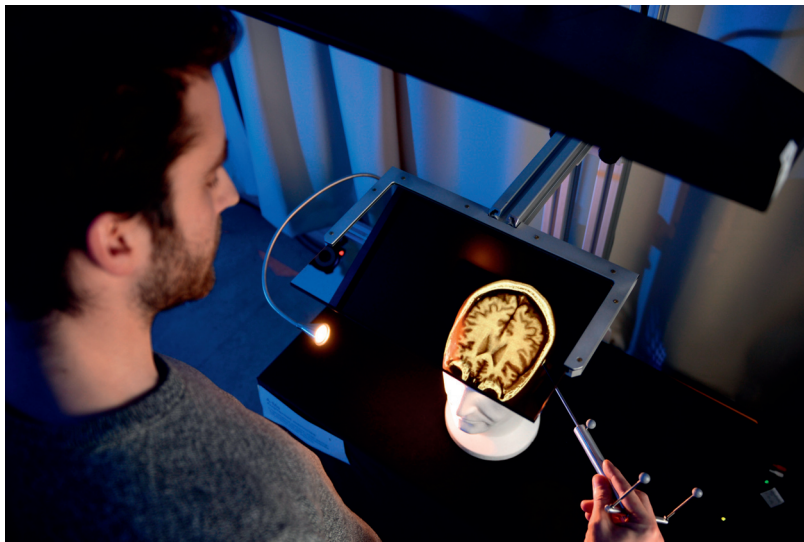

Figure 6: A-me on the Phase 1 development.

Realism of the rendering

As stated in section 4, this device is also part of scientific research on QoE in AR devices. Some perceptual issues can be addressed depending on the physical characteristics of such displays. On the other hand, different kind of perceptual issues derived from semiotics and visual design can also be assessed.

There are visualization aspects in AR being approached from a designer's perspective. Usually computer graphics developers can solve the need for a visual feedback using a number of different metaphors. Strategies like masking, zooming, highlighting, or offering different levels of visual information load can be highly determining on the final quality of an AR system. Examples of these solutions have been shown in [11][12]. To summarize this point, there are different levels of quality for an AR system, from physical properties of the device to the visual aspects of the virtual information displayed. These aspects of quality in AR, especially in PGE devices will be addressed using A-me's equipment in further research publications.

The purpose of A-me is to display a real tomography with an added interpreted visualization, which refers to the location of the memories. The tomography is displayed by using a volume rendering technique based on a fast ray casting procedure [13]. This is a well-known technique, widely used in the computer graphics community. In addition we use a tailored CLUT (color look up table) to reinforce the attention of the user to certain areas of the brain. Meaning that we will color certain groups of voxels depending on their weight to let the user see through some specific regions across the tomography.

Exhibitions and discussion

The random access to memories stored in the physical volume had the effect that each user ended up having a different 'reconstructed experience' (e.g., different sequences of audio recordings). This points to an inherent characteristic of this 'spatialized storage system': unless the user can associate specific brain locations with a certain kind of memories, then the

reconstructed 'experience' will be just a patchwork of random episodes, with unexpected loops and comebacks - essentially a non-linear narrative, which is exactly what happens in most of the science-fiction movies described above. On the other hand, a visual layout of the memory items may speed up retrieval and narrative building if the volume itself could somehow give cues of the content. This is the principle behind the "method of loci" [14], a mnemonic technique that relies on human capacity to quickly and efficiently store new information on an imaginary (and personal) 3d space, sometimes called a "memory palace". A-me points to the possibility of making this "memory palace" an interpersonal, shared space to store and retrieve public instead of a personal, mental one.

A-me was experienced by thousands of visitors during the exhibition at STRP festival 2013, in the Netherlands, for a period of 10 days. The population was generally using native Dutch language and the age groups where very distinct. During daytime many student groups attended the exhibition and during evenings the younger where slowly replaced by older adults.

The most relevant feedback from the exhibition was given through comments from the visitors. Most of them were intrigued by the functionality of the technology at first. After making use of the installation and discovering its capabilities, they were usually surprised and fascinated with the treatment of the memory metaphor.

At the same time, during the exhibition, the tracking system was recording the interaction (position and orientation) of the probe 60 times per second. This data is currently being analyzed to assess the quality of the device. It will provide a good insight on the quality of the depth perception experienced by the users when using the PGE display in this particular setup. The amount of data produced during the exhibition (see Figure 7) would not be possible in a laboratory experiment. For this reason we believe that scientific exploration can also benefit from artistic interventions.
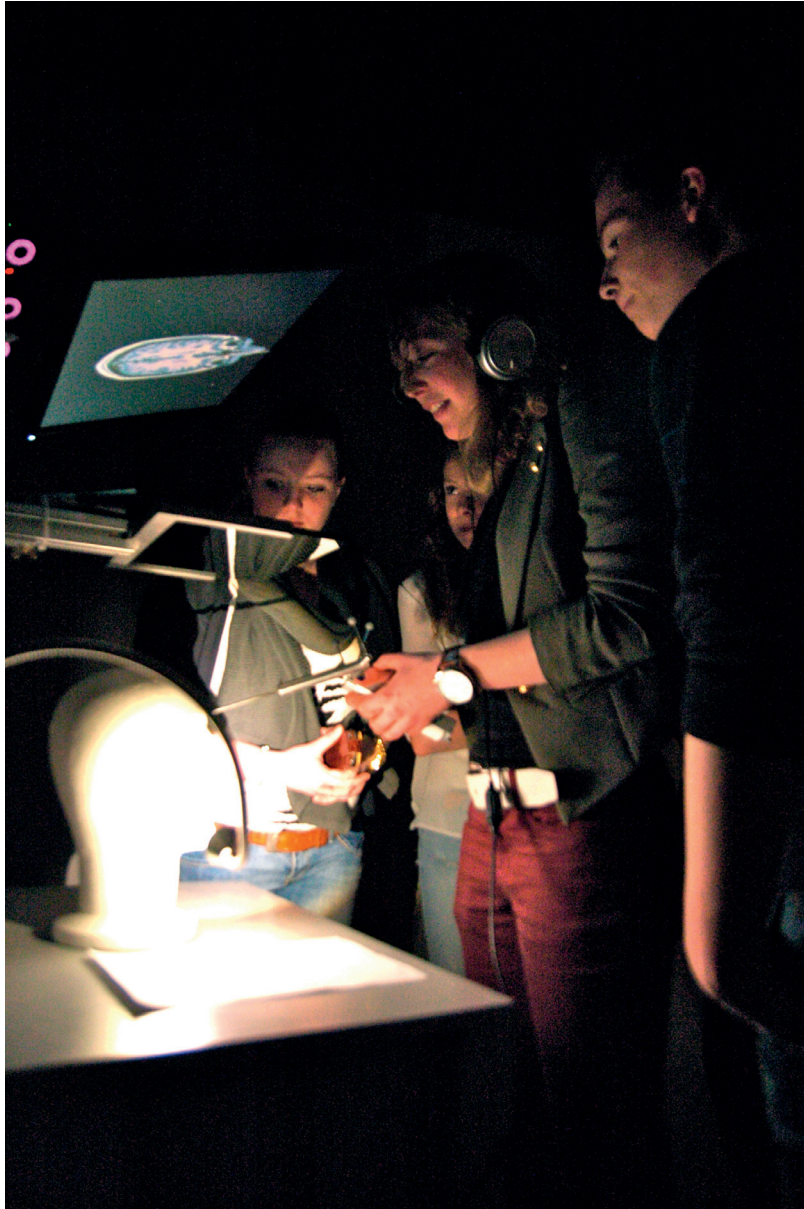
Figure 7: A-me exhibited at the STRP 2013.

Conclusions

By providing a game like scenario, A-me creates the opportunity for a playful reflection on serious topics ranging from philosophy of the mind to technical aspects of neurosciences. The

user is able to navigate the brain by handling a tracked probe similar to the probes that neurosurgeons use to examine brain injuries. While navigating the brain, the user can find active spots in specific parts of the nervous structure; pointing at the spots triggers the recording of an aural memory left at that location by the previous visitors. In this sense, A-me proposes an alternative to the information cloud: a physical, shared repository of private memories.

This work raises questions on the dominant trends in cognitive neuroscience that seek to map aspects of the mind to the physical world, and therefore raises awareness on the possibility, in the near future, of manipulating minds.

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Paper C. The Neuroscience Social Network Project

Jordi Puig, Andrew Perkis, Philippe Pinel, Alvaro Cassinelli, Masatoshi Ishikawa

Abstract

Recent advances in neuroimaging over the last 15 years leaded to an explosion of knowl-edge in neuroscience and to the emergence of international projects and consortiums. In-tegration of existing knowledge as well as efficient communication between scientists are now challenging issues into the understanding of such a complex subject. Several Internet based tools are now available to provide databases and meta-analysis of published results (Neurosynth, Braimap, NIF, SumsDB, OpenfMRI...). These projects are aimed to provide access to activation maps and/or peak coordinates associated to semantic descriptors (cere-bral mechanism, cognitive tasks, experimental stimuli...). However, these interfaces suffer from a lack of interactivity and do not allow real-time exchange of data and knowledge be-tween authors. Moreover, classical modes of scientific communication (articles, meetings, lectures...) do not allow to create an active and updated view of the field for members of a specific community (large scientific structure, international work group...). In this view, we propose here to develop an interface designed to provide a direct mapping between neuro-scientific knowledge and 3D brain anatomical space.

Exposition

The scope of this project has two main research directions. In one hand, we explore visualization techniques to display large datasets and real-time communications. On the other hand, we develop Augmented Reality (AR) and Embodied Interfaces (EI) to place virtual data in the physical space. The spatial localization of notes and comments stored by researchers in the brain space is crucial for the project. Users are able to locate their findings and to discover, in real-time, other researchers' notes within common areas of interest (see Fig.1). At the same time the application generates semantic gradients on different anatomical areas, organized, for instance, by topic, chronology, related bibliography and others relevant association (see Fig.2). The application is an extension of previous work [1] [2] and it is planned to be used in different platforms. Mobile devices and tablets allow fast and easy data insertion on a daily basis. Furthermore, the application is displayed in AR and TI to enhance face to face discussions between researchers. In that situation, the presentation technique will be e.g. a projection mapping on a 3d printed anatomy of the brain, a tracked surface or a immersive environment projected on a CAVE like room. This versatility is achieved by defining a modular software separating the core functionality from the presentation system. The software is developed in C++, using Open Source the libraries Openframeworks (OF), Visualization Toolkit (VTK) and the Insight Segmentation and Registration Toolkit (ITK). The code will be released to the public to promote collaboration from the scientific community.

Our approach

The spatial localization of notes and comments stored by researchers in the brain space is crucial for the project. Users are able to locate their findings and to discover, in real-time, other researchers' notes within common areas of interest (Fig.1). At the same time the application generates semantic gradients (different levels of semantic definitions) on anatomical areas (see Fig. 2 and 3), organized, for instance, by topic, chronology, related bibliography and other relevant associations (Fig. 4). The application is designed for mobile devices and

tablets allowing fast and easy data insertion on a daily basis. AR and EI also enhance face to face discussions between researchers. This versatility is achieved by defining a modular software separating the core functionality from the presentation system. The software is developed in C++, using Openframeworks (OF), Visualization Toolkit (VTK), the Insight Segmentation and Registration Toolkit (ITK) and the Twitter API. The code will be released to the public to promote collaboration from the scientific community.
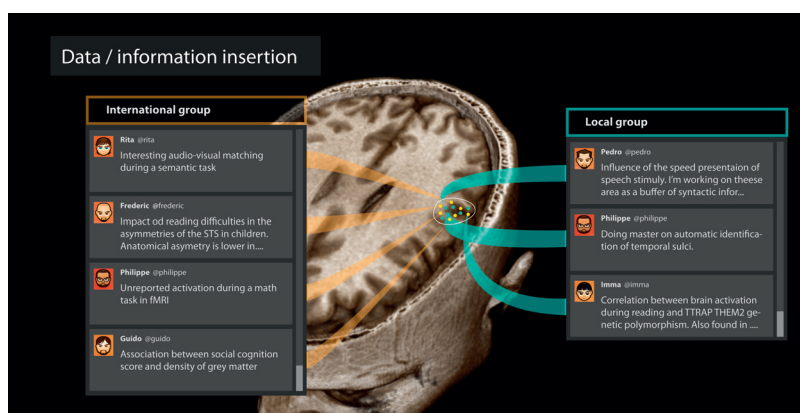

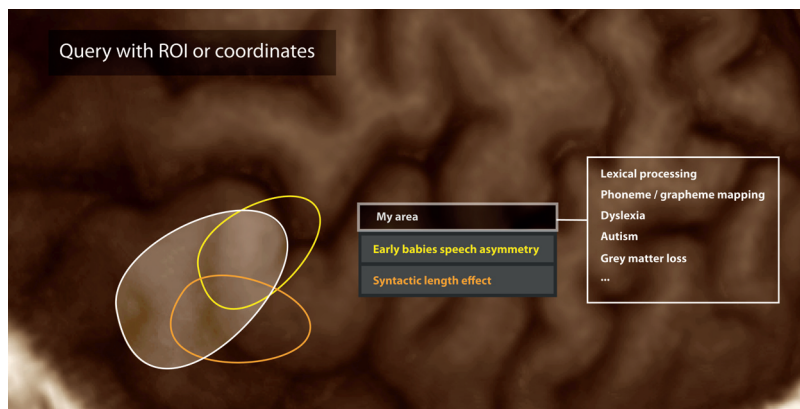Figure 1: Interface for insertion and retrieval of notes related to certain brain space.

Figure 2: Enhanced visualization of related bibliography with selected ROI.
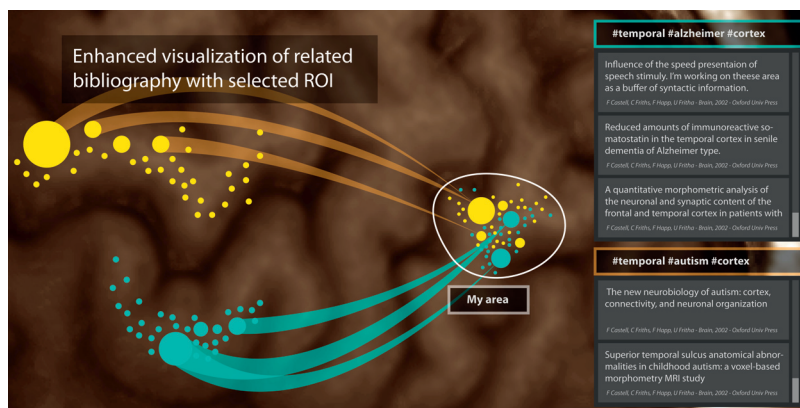
Figure 3: Query with ROI and semantic definitions.

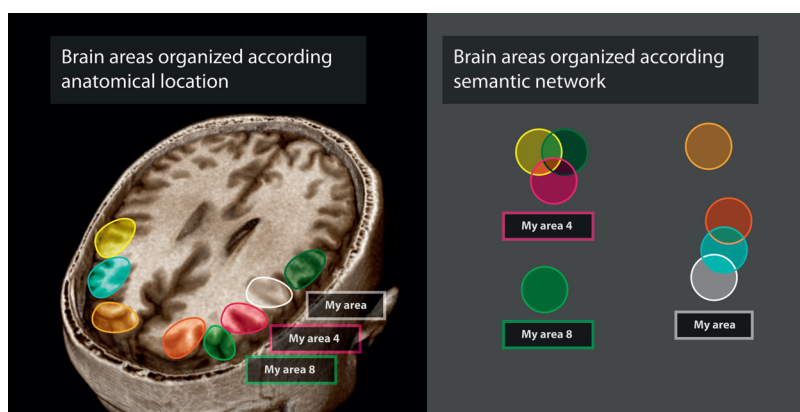Figure 4: The allows application has different presentation modes to facilitate filtering and search tasks.

Features

- The 3D volume is composed of 1x1x1mm voxel. Coordinates (x, y, z) correspond to the Montreal Neurological Institute (MNI) template.

- Researchers' notes are associated with 3D coordinates or brain areas.

- Researcher's areas are normalized to the MNI space and can be uploaded in Analyze format.

- Anatomical queries can use pre-existing anatomical parcellation of the Human brain (Brodmann areas, Automated Anatomical Labeling atlase...) or arbitrary group of voxels.

- Ontology of brain areas is automatically updated by applying inclusion rule onto voxels.

- Possibility to retrieve Pubmed citations with direct links.

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Paper D. Art-science research across neuroimaging: From A-me to BrainCloud

Jordi Puig, Aud Sissel Hoel, Annamaria Carusi, Alvaro Cassinelli, Philippe Pinel.

Abstract

Cognitive neuroscience has become a major player in shaping ideas about the self and about human capacities of behaviour. For this reason, it is crucial that neuroscience should be open to a broad range of perspectives and voices that actively engage in defining research questions and interpretive frameworks. This article reports on two projects that venture across the art-science boundaries, and that experiment with ways of integrating science, technology and society through artistic intervention. Both projects, A-me: Augmented Memories and BrainCloud, explore the central role of localization in neuroscience, or more precisely, the elusive links between cognitive information and brain anatomy.

Introduction

Of all the sciences, cognitive neuroscience is one that has tremendous social and cultural implications as it is a major player in shaping ideas about the self and about human capacities and behavior. For this reason, it is crucial that neuroscience should be open to a broad range of perspectives and voices that actively engage in defining research questions and interpretive frameworks. A major aspect that is often at the interface between neuroscience and its social and cultural aspects are the advanced imaging and visualization methods on which contemporary neuroscience is highly dependent. The research project Picturing the Brain: Perspectives on Neuroimaging [1] emerged from the recognition of the centrality of images to current neuroscience, and the need for a multiplicity of perspectives on them. The project's aim was to bring to bear a more multi-faceted approach to these imaging and visualization technologies, considered as cognitive tools, as perceptual prostheses, and as visual rhetoric. To this end, the project brought together researchers with backgrounds in media studies, philosophy, digital media engineering, medical imaging, neuroscience, and creative arts. The project was conceived as an arena for experimenting with ways of integrating science, technology and society through artistic intervention, so as to create opportunities for (self-) reflexivity and dialogue. We report on two such art-science explorations in this paper.

In recent years projects that cross the art-science boundaries have become far more common and art has proved itself a more than able partner in communicating and interrogating ideas in neuroscience. Prominent examples include the Neuromedia exhibition [2] at the Kulturama Science Museum Zurich curated by Jillian Scott, who is also an artist with an extended body of artwork towards neuroscience. She has produced pieces like The Electric Retina [3], a sculpture symbolising a part of the retina; Somabook, which combines interpretations from a dancer with data about the growth of neural circuits; and Dermaland, a media sculpture that explores our perception of the physical environment. Other recent examples of art-science explorations are the exhibition Mind Gap by Robert Wilson, at the Norwegian Technical Museum; the exhibition [4] Brains: The Mind as Matter by Marius Kwint, at the Wellcome Collection in London; and the Art of Neuroscience exhibit at Society for Neuro-

science annual meeting in Washington, DC. These exhibitions examined the neurosciences from diverse viewpoints – artistic, historical, and scientific – pursuing reflection, documentation, or open interpretation depending on its curator's focus. These exhibitions featured artists who work on neuroscience topics, such as Andrew Carnie, who has undertaken several projects centred around memory, the brain, and neuroscience – primarily in the form of time-based installations, involving 35 mm slide projections using dissolve systems or video projections. A prominent example among these works is Magic Forest (2002), which is an installation consisting on a series of projections presenting colorful tree-like neurons displayed on voile screens. Other artists who have participated in these exhibitions include Greg Dunn, Audrius V. Plioplys, Lia Cook, Helen Pynor, Annie Cattrell, Susan Aldworth, Jonathon Keats, and Katharine Dowson.

The Picturing the Brain project sought to bring about integrated research and creative activities, where, for example, creative practitioners would pursue scientific and technological, as well as artistic aims in close collaboration with science, technology and humanities researchers. In this paper we present two different projects, A-me: Augmented Memories and BrainCloud, both of which explore the central role of localization in neuroscience, or more precisely, the elusive links between cognitive information and brain anatomy. Each project brings together different sets of expertise and research interests. We will conclude by drawing out the challenges and gains of these forms of collaboration, and the different opportunities they provide for self-reflexivity and dialogue.

Background

Neurosurgery is clearly the domain where spatial accuracy is key for precise guidance and orientation, and localization is also a predominant concern in the neuroscience project of mapping cognitive functions onto the physiological brain. Hence, knowledge about regions, areas and the connectivity between them is an intrinsic part of neuroscientists' experiments and interventions. The need for precise localization drove the construction of standardized coordinate systems, of which a classic is the Talairach Atlas, constructed in 1967, from a sin-

gle post-mortem dissected brain, initially developed for stereotactic surgery. This has been superseded by other atlases, in particular the Montreal Neurological Institute and Hospital (MNI) coordinate system, constructed from the averages of multiple brains, and current digital and computational advances are reconfiguring the production and use of brain atlases and their role in neuroscience [5] [6]. As part of the work of the project, two of the authors of this paper undertook a comparison of the practices of neuroscientists and painters with respect to spatial representation and orientation. Drawing on Merleau-Ponty's discussion of painting in 'Eye and Mind', where he sets forth an integrated account of vision, images, objects, and space, the authors argue that the handling and understanding of space in neuroimaging overlaps with that in some forms of painting. For example, they argue that localization is far from being a given in neuroscience, but is instead actively formed through practices of spatial orientation and boundary drawing [7].

The two projects that we describe here both deal with localization, but in different ways. A-Me: Augmented memories is a memory-evoking apparatus that is aimed at general audiences and that allows users to raise and explore questions about the localization of human memories. BrainCloud, on the other hand, is a software prototype that is aimed at neuroscientists and that provides researchers with an interface for interacting with existing data and knowledge about the brain. It forms a social network for neuroscientists that is organized by the metaphor of the physical brain, a brain atlas spatially organized through a coordinate system. A-me was conceived for artistic purposes, and BrainCloud for scientific purposes; yet the two projects share a common core in terms of digital infrastructure: Both projects develop interfaces for interacting with brain information through 3D volumetric visualizations. While A-me allows users to explore and interrogate a brain atlas by listening to the "memories" of other people, BrainCloud allows neuroscientists to connect with each other, and to share their latest discoveries.

A-Me: Augmented Memories

A-me: Augmented Memories is an interactive installation that integrates neuroscience, technology and art. It provides users with navigation and visualization tools normally reserved for clinicians and scientists. The experience of using these tools invites reflection on the ongoing endeavor of neuroscience to explain and map cognitive functions such as memory. A-me was developed as an art installation alongside research into the technological development of Augmented Reality (AR) surgical interfaces. This means that, in addition to provoking reflection on cognitive brain mapping, it contributes to the refinement of surgical accuracy and reliability currently achieved through these tools.

About the installation

A-me consists of a highly accurate tracking system constantly reporting the position and orientation of a wireless probe, an optical see-through AR display presenting a tomographic brain visualization on a dummy head, and binaurally spatialized sound delivered through headphones. Figure 1 depicts the usage of A-me during exploration, and Figure 2 defines the dimensions and location of its components. When exhibited, the installation is placed in a small, darkened space, where the A-me apparatus awaits the user's exploratory activity. On approaching the interactive area, the user sees a visual augmentation through the half-mirror (Fig. 3). The visual augmentation consists of a volume-rendered MRI scan of a brain, which is dynamically updated according to the position of the probe. The MRI image is overlaid on a manikin's head where a grid of tiny glowing points are shown as floating on top of the tomographic brain visualization. The user activates the points by touching them virtually with the navigation pointer and pressing a button. When a point is activated, the user hears fragments of narrated recollections that have been stored by previous users. The user can also record his or her own "memories", placing them in specific locations of the brain. A-me was developed at the premises of the Sense-IT lab at the Norwegian University of Science and Technology, in collaboration with Frank Lindseth and other researchers in

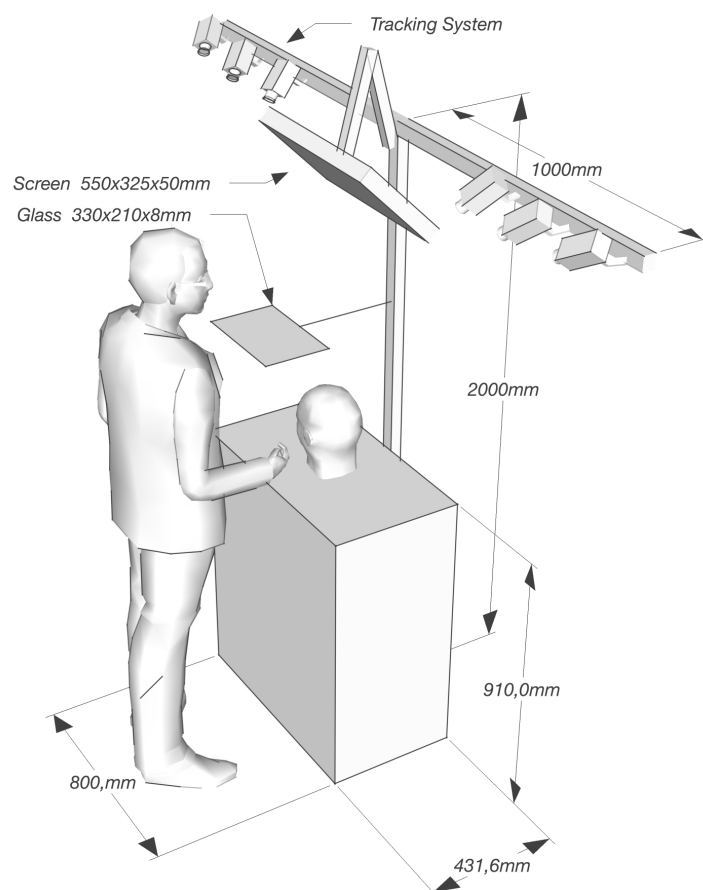Figure 1: Jordi Puig demonstrating the use of A-me. © Mark Stegelman. For a short demo of A-me visit <http://www.vimeo.com/wasawi/a-me>

Figure 2: Sketch of A-me's hardware installation setup.

medical imaging at SINTEF. A-me's technical details and foundations are described in [8].

Research process

The research started with fieldwork at the local university hospital, which included an observation of a neurosurgical tumor-removal procedure that made use of advanced tracking and visualization technologies for improved guidance and control. A further introduction into the promises and challenges of neuronavigation was provided by our collaborators in the Department of Medical Technology at SINTEF. These initial explorations, which directed our attention to navigation and localization issues, were work-intensive and at times confusing, mainly due to the necessary adaptation to the new terminology. Already at this stage we realized the extent of the extra efforts that are needed for this kind of interdisciplinary work. In order to better understand the core elements and basic functionalities of neuronavigation systems, we decided to develop an entire system similar to the surgical neuronavigation setup used at the university hospital. One of the most technologically challenging aspects of this initial work was to build a low-cost prototype with surgical accuracy and reliability within a short period of time. While developing this system, we also learned that AR surgical techniques have been intensively investigated during the last decade [9] [10] [11]. We decided to add an optical see-through AR display that would allow us to experiment with new perceptual techniques. AR setups like A-me's are currently used as tools for surgical training [12] [13] [14]. However, we decided to proceed by exploring A-me as a scientific tool for assessing multiple quality measures like accuracy, latency, ease of use, etc. – measures that, when combined, would result in an assessment of the overall Quality of Experience (QoE) [15]. QoE is a major line of research in the Sense-IT lab where A-me was developed. Thus, at an early stage in the research, we proposed a method for assessing the QoE of AR systems by means of a combination of quantitative metrics and qualitative analyses [16].

The first version of A-me resulted from a collaboration between researchers with backgrounds in media art and interaction design, medical technology, and media technology. The researchers were motivated by partly converging and partly diverging research interests – issues relating to accuracy in navigation not always coinciding with issues relating to the assessment of the QoE. However, whereas the first version of A-me focused on the QoE on AR

systems, we soon decided to develop it in a more artistic direction. The second version focused on the integrative efforts at the heart of the Picturing the Brain project – exploring the potential of artistic interventions for facilitating dialogues across the art-science domains. More precisely, the installation was set up so as to provoke reflection on the widespread and sometimes controversial efforts in contemporary neuroscience to localize mental functions, such as memory, in the physical brain. In this further development, A-me was turned into an interactive installation taking a playful approach to the neuroscientist brain-mapping endeavor. A-me was exhibited as an art installation at the Meta.morf electronic arts festival in Trondheim in October 2012, and subsequently at the art and technology festival STRP in Eindhoven in March 2013 [17] (Fig. 4),where it was explored by a large number of visitors. After that, it was exhibited again in the Babel Gallery in Trondheim in September 2014 [18], during the Picturing the Brain closing conference. The second version of A-me resulted from a different constellation of researchers than the first, this time also including researchers with backgrounds in the humanities. Again, the research interests were both converging and diverging, focusing on issues such as the embodiment of perception and cognition, brain plasticity, technological mediation and the instrumentation of science, as well as on issues relating to the cultural share of scientific knowledge.

Discussion

While it started out as a scientific tool for assessing the QoE of surgical AR systems, A-me ended up as an artistic intervention inspired by the technical needs of neurosurgeons where precise localization is paramount. In the artistic version of A-me, this took the form of storing "memories" in point-like locations. Of course, this is an oversimplification of the highly complex phenomenon of memory; however, the aim of A-me was to develop a technical infrastructure that on the one hand overlaps with scientific use, and on the other encourages reflection about the brain, localization, and common behaviors such as exchanging memory-like experiences. Through their interactions with A-me, users pose questions about where memories might be located, and therefore also about the role of neuroscience in ex-
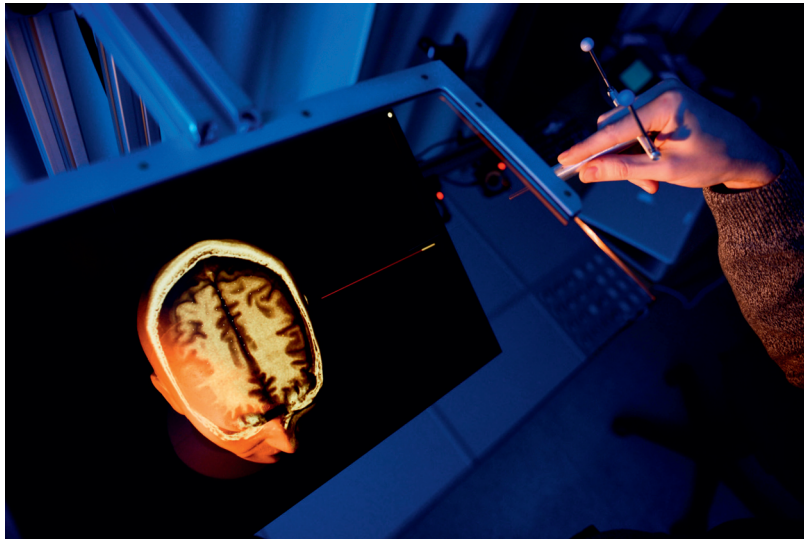
Figure 3: A-me's optical see-through AR display presenting a tomographic brain visualization mapped on a dummy head. © Mark Stegelman.

Figure 4: A user exploring A-me at the exhibition STRP 2013, Eindhoven. © Jordi Puig.

plaining our mental and social behavior. However, A-me also relates to pressing questions for scientists concerning how to delimit the boundaries of brain activity, how current brain

atlases describe cognitive functions, how to map locations across multiple subjects or across the development of the brain over time. As we discuss in the next section, it also relates to another very important issue for neuroscientists, and that is, how to connect and engage with other neuroscientists working on similar topics.

BrainCloud

While A-me was being exhibited, the main author Jordi Puig initiated a collaboration with the Ishikawa Oku Laboratory at the University of Tokyo, which allowed for a further development that turned into an entirely different project, named BrainCloud. During a research visit at the Ishikawa Oku lab, Puig became involved in an existing collaboration between Alvaro Cassinelli, who is a media artist and a scientist specialized in human-computer interfaces, and Philippe Pinel, who is a neuroscientist specialized on neurogenetics. At the time, Pinel was occupied with the difficulty of retrieving relevant information in the ever growing databases of brain sciences and genetics. While being involved in the development of a series of software utilities, Pinel saw the opportunity for a unified and much more powerful strategy for extracting research data from diverse repositories by mapping them onto an interactive interface such as the one used in A-me. Cassinelli, on his side, was conducting a project called Memory Blocks [19], which investigated ways to exploit spatial memory by storing and retrieving pieces of digital information in volumetric spaces navigated by natural gestures [20]. A-me seemed a perfect opportunity for integrating these diverse lines of research, providing an interpersonal scaffold for storing and retrieving neuroscience data. The three projects fused into the development of the BrainCloud prototype, which made use of A-me's basic system for localizing contents in a visualized brain volume.

While A-me is an AR interactive installation, BrainCloud can be seen as an application aiming to augment sociability among neuroscience researchers. The progress of neuroscientists' research depends not only on their own individual capacity to probe the brain, but on their access to other neuroscientists who are working on research questions related to their own. It is sometimes difficult to retrieve information about other researchers: Publications

are scattered in different journals, and not everything that is of interest (such as comments, ideas, work in progress) is included in publications. The idea behind BrainCloud is to visualize this disparate information in a form that is intuitive for neuroscientists, that is, in the form of a brain atlas. Thus information and input are localizable via the brain regions with which they are most closely associated, and researchers will be able to gain access to these by interacting with the interface of the brain volume, navigating it as they would other digital brain atlases. In this way, BrainCloud visualizes and facilitates scientists' interactions with each other, extending these beyond what is possible through research publications, and augmenting sociability through a 3D spatial interface.

About the application

The current implementation of BrainCloud uses a standard brain atlas, the MNI Colin 27 average brain [21], as a reference point for social activity as seen in Figure 5. To display the dataset we use the same volumetric rendering technique as in A-me. This type of rendering allows users to visualize the human brain from any point of view with a high level of detail, as well as to rotate, zoom and slice the volume in order to visualize the sub-cortical areas. When the application is in use, the volumetric rendering of the brain is displayed at the center of the window. The user moves the cursor in the 3D space to navigate the volume and to create selections at any location. To view and interact with the orthogonal slices of the brain (coronal, sagittal and axial planes) the user uses the three pads on the left panel. Dragging the cursor in the pads updates the selected coordinate and the relative information: the current coordinate system, a numerical description of the coordinate, and the anatomical landmark of the brain, which composed by, the hemisphere, the lobe, the gyrus, the tissue type and the cell type. Finally, the social activity (e.g. user's discussions, comments about publications or references to scientific research) is presented in the right panel. The right panel is also used to search and to post messages. In its functionalities, BrainCloud operates like a social network, except that it also performs searches on third party databases like PubMed. It is further distinguished by its brain atlas-like interface.

Research process

The main challenges of designing BrainCloud were related to visualization issues relating to interactive cartographies, mobility, traffic and big data visualization. The data handled by visualization applications are by nature associated with specific locations in space. In Brain-Cloud, the aim was to map a wide range of neuroscience social information onto a brain atlas. To undertake this task, the authors gathered at the University of Tokyo where the development process went through several design cycles. We started out with a brainstorming session driven by a think-aloud strategy accompanied by the drawing of sketches and diagrams on a blackboard (Fig. 6). The session ended up in a list of functionalities relating to brain atlases, scientists activities and publications, combined with sketches of interactions and features. We decided to develop an application that could be used on any device (desktop, mobile, tablet, etc.), as well as in specific setups involving whole rooms. Part of the software could be adapted from the previous development, something that gave us the opportunity to deepen our discussions on functionalities such as what types of scientific data to include in the application, and what kinds of social activity that neuroscience researchers would be interested in. The first design cycle concluded in a publication defining the main vision for the project [22]. After that, we started the development of the first prototype targeting the most basic functionalities such as storing and retrieving comments that researchers place in specific areas in the brain atlas (Fig. 6).

The first prototype gave rise to a series of discussions forming a second design cycle. The proposed modifications were focused on the distribution and scale of the views, the position of the interactive panels and the amount of information to display in every use case. While the first design used four views of the brain atlas, the new proposal moved towards a bigger 3D view to centralize users' attention and interaction. At this point in the design process, two panels divided the interaction, the scientific information being placed on the left, and the social activity on the right. Additional discussions about color codes, interface legibility and interaction metaphors defined the appearance of the current prototype. Finally, to evaluate the new design, we conducted an interview with two neuroscientists at the Insti-

tut Pasteur in Paris, who had not been previously involved in the BrainCloud project. The session was intense and instructive, raising discussions of critical importance to our project, such as the recurrent activities of neuroscientists depending on their research focus, the differences of handling neural networks datasets compared to datasets of localized brain functions and the state of the art of other similar projects like BrainSpell [23], CoactivationMap [24], Neurosynth [25], NeuroVault [26] and CognitiveAtlas [27].
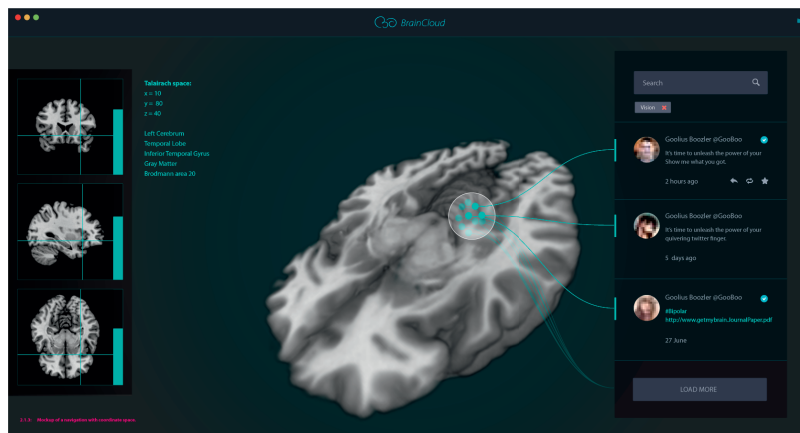

Figure 5: BrainCloud main search interface. The region of interest selected by the user is displayed as a white sphere inside the volume. A set of coordinates match the selected area and the most relevant comments are displayed on the left panel.
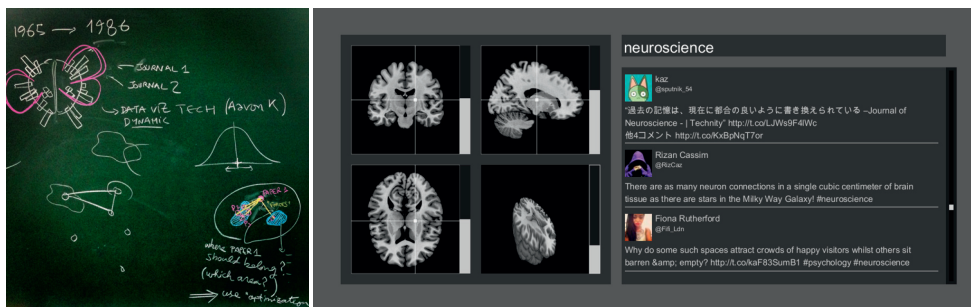

Figure 6: Left, sketches made by Alvaro Cassinelli during the initial brainstorming session for BrainCloud. Right, first prototype of BrainCloud displaying messages located on a brain atlas.

Discussion

BrainCloud aims to provide relevant benefits to the neuroscience community by focusing on improved visibility and cooperation between researchers. It visualizes scientists' experimental data, scientific publications, and their social interaction (comments, discussions, ratings, and so on). It creates an interface for a direct mapping between current neuroscience social networks and brain atlases. The development of this project has required a highly interdisciplinary group of researchers with backgrounds in neuroscience, media art, media technology, and humanities. From our different fields of expertise we have approached the task of handling the complexity of the above mentioned functionalities and expectations. To address this endeavor we identified our challenges and we divided them into three categories: technical, social and scientific. The technical challenges concern practical issues that shape the way the project is materialized. These challenges include both hardware requirements (devices, platforms, communication distribution, etc.) and software requirements (interaction requirements, visualization requirements, and network requirements). Our discussions ranged from design patterns to specific details on libraries and implementations. We were interested in current input and interaction methods such as multi-touch user interfaces for mobile platforms. Although our prototype was initially built with OpenFrameworks (a C++ toolkit), the discussion turned around the possibility of using web technologies (like JavaScript, Three.js, the X-Ray Toolkit, MRIcroGL, etc.) in order to reach a wider range of users. Additionally, we studied database structures, search strategies and other network-related issues in order to implement the desired functionalities. The social challenges concern the users' activity in the network. These challenges involve the designing of the social network's elements and behaviors by addressing users' expectations regarding moderation, privacy, information trust and quality control. These decisions define the possibilities and limitations that users will encounter during a session. Planning the extent of the users' freedom is at the same time planning for the strength of the social network. Even if, in the future, the project will benefit from current social media platforms (e.g. Twitter, Pubmed [28], Github, Figshare, Zenodo, etc.), BrainCloud requires a redefinition of privacy and moderation policies in order to guarantee scientific quality. Currently there are several research

initiatives that deal with scientific trust, for example Altmetric [29], which is a new tool that tracks article impact metrics. However, when it comes to the quality of publications, human assessment is essential, since, in some cases, statistical measures can be irrelevant or misleading. Hence, one of the main challenges is to find the right balance between freedom and control of users' activities. The scientific challenges concern the specifics of neuroscience, like localization issues which were amongst the main topics of discussion in our group. The current prototype uses a single coordinate, coordinates with range, or a set of coordinates. In this way the system is not bound to point-like locations as it was in A-me, but instead it allows areas of varying sizes to be chosen. This implies that a discussion started by a researcher could be linked to a small area of the brain or to the entire brain depending of the subject of study. Brain activity can be very focussed, like the neural basis of language, or less focussed, like the neural basis of Alzheimer's disease. For that reason, the most interesting aspect of BrainCloud is the combination of locative and textual search options, allowing for the selection of a region of the brain atlas to retrieve messages and refining the search by modifying keywords (a pathology, or a cognitive function) in the search field (Fig. 7).
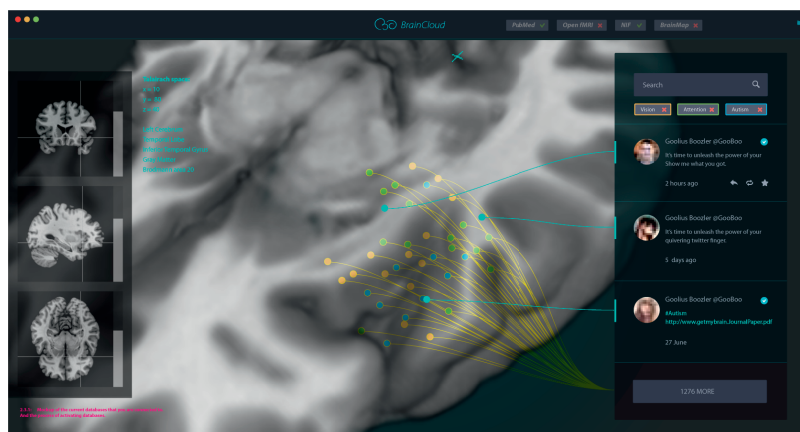

Figure 7: BrainCloud's interface for a search with multiple filters. Multiple keywords help the user to refine a search, each keyword is displayed in a different color. For a short demo of Braincloud see <http://www.vimeo.com/wasawi/BrainCloud>.

Conclusions

A-me and BrainCloud are two closely interrelated projects that reuse technological development for artistic and scientific purposes and aims, extending and recontextualizing them. A-me grew out of a technological development for surgical purposes, and evolved into an art intervention to enable users to interrogate some aspects of the discourse of neuroscience, notably the central trope of localization. BrainCloud builds on this technological development to contribute to the scientific process: once again organized around the trope of localization, but this time in order to enhance the sociability that is necessary for science to flourish. Each iteration of this cycle of technological development can in principle lead to new forms of neuroscience-inspired art-installation experience for the broad public, as well as new forms of the experience of the scientific process for scientists, opening up different arenas of interrogation and activity for both. A-me and BrainCloud thus represent a small but significant step towards closely interconnected and interdependent technologies for art and science. This form of collaboration adds to the close coupling of science and technology that the term "technoscience" designates, by bringing to it the further element of art, thereby showing how crucial processes in art and science overlap. Building on the way in which A-me allowed for a kind of interrogative and reflective play with localization in the scientific and socio-cultural neuroscience discourse, BrainCloud takes up the enactment of that discourse but this time to facilitate the sociability of the neuroscience community, through the trope of localization. How BrainCloud and other efforts like it will ultimately contribute to the future outlook of neuroscience is of course not known; worth tracking, however, is the ongoing evolution of the trope of localization in neuroscience relative to technologies that augment sociability using localization as a central reference point: Will the spatiality of neuroscience be further entrenched, or will it become an entirely different spatiality, one relating to social activities of ourselves as interrogators rather than to mapping mental states and behaviours onto specific brain areas?

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