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Title

Brain Art-Science: Explorations through A-me and BrainCloud

Abstract

Cognitive neuroscience has become 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. 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 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 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 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 single 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] [7]. 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 [8].

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.

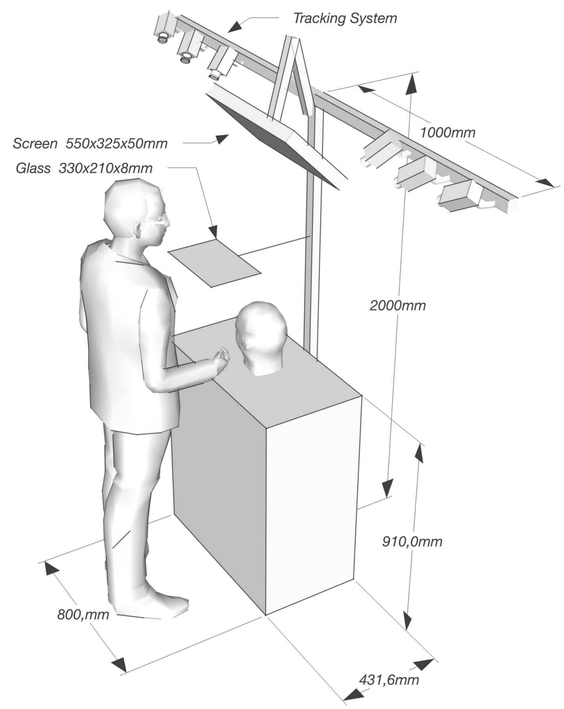

Fig. 1. Jordi Puig demonstrating the use of *A-me*. © Mark Stegelman. For a short demo of *A-me* visit <http://www.vimeo.com/wasawi/a-me>
Fig. 2. Sketch of *A-me*'s hardware installation setup.

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 [9] 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 multiple 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 medical imaging at SINTEF. *A-me*'s technical details and foundations are described in [10].

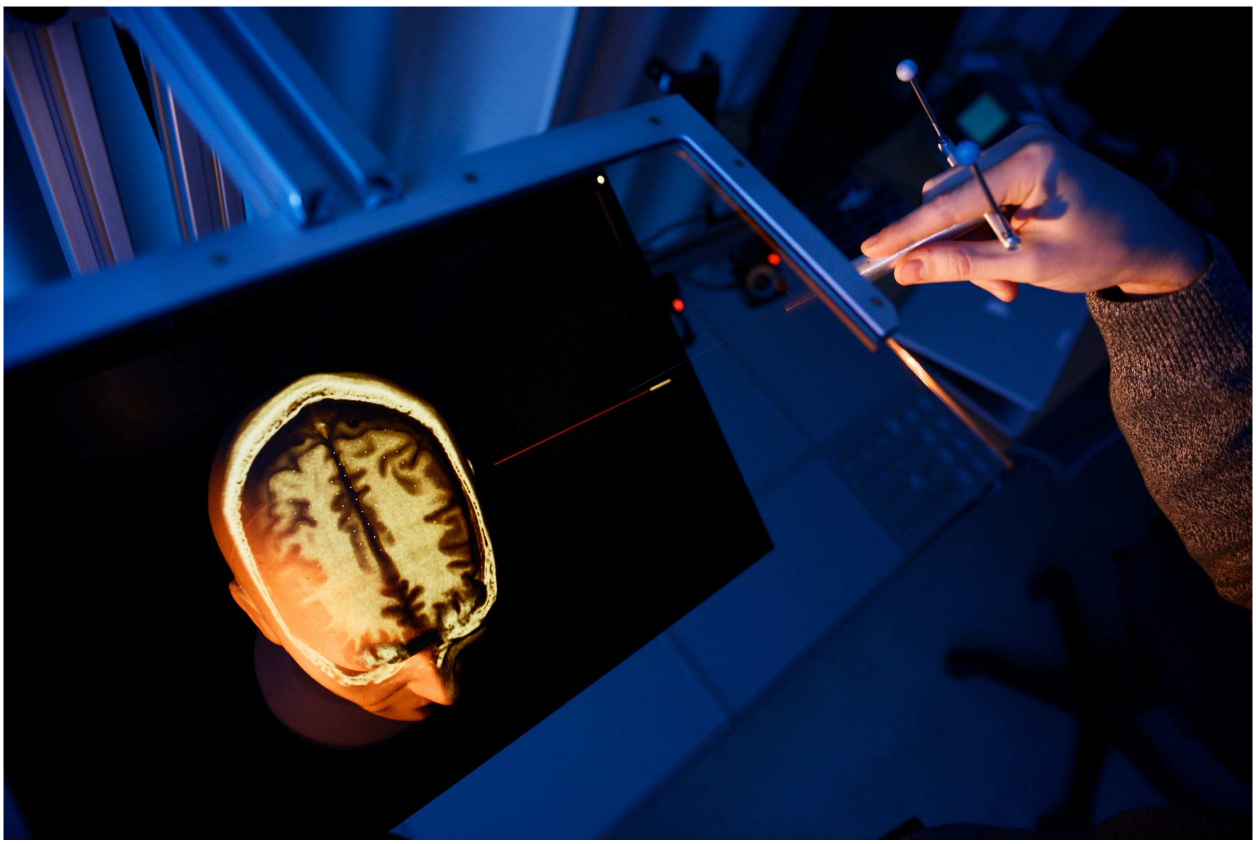

Fig. 3. *A-me*'s optical see-through AR display presenting a tomographic brain visualization mapped on a dummy head. © Mark Stegelman

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 and new technologies. 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 [11] [12] [13]. 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 [14] [15]. 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) [16]. 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 [17].

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 creative 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 [18] (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 [19], 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.

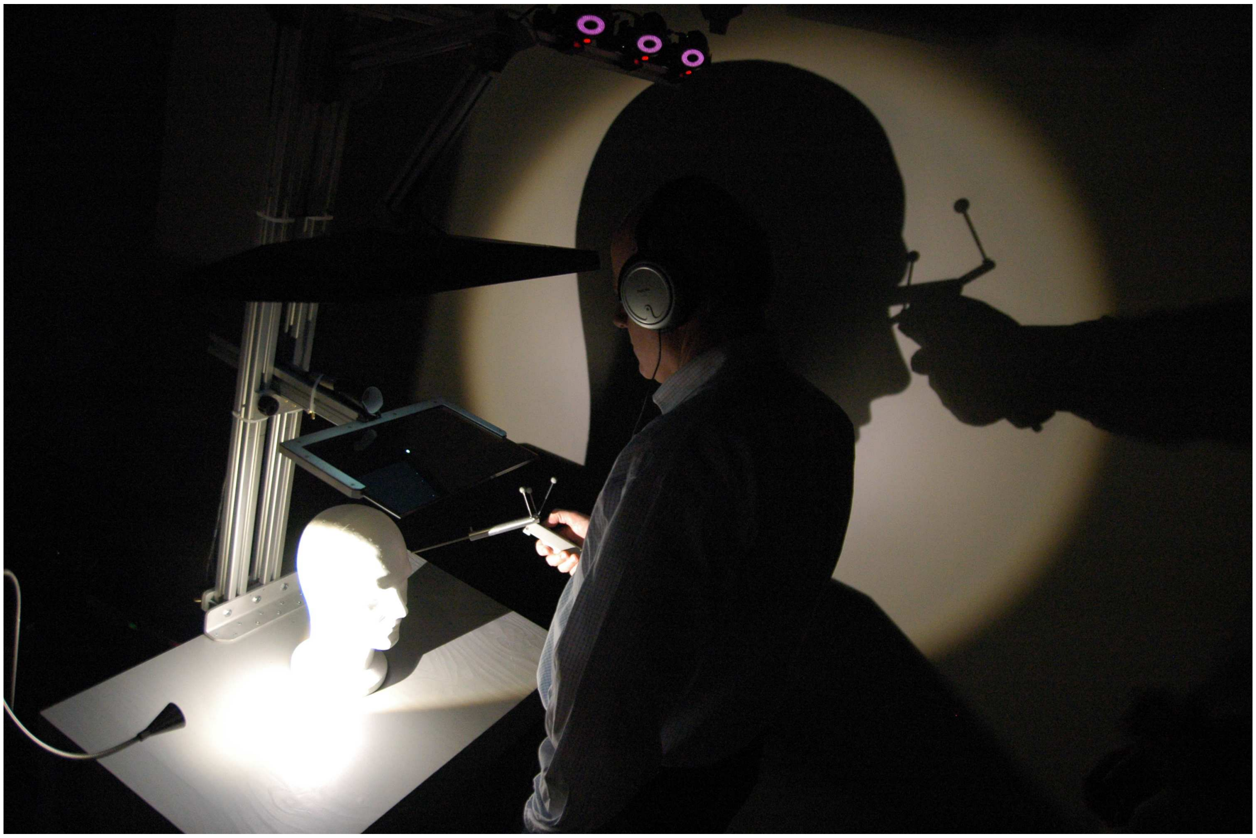

Fig. 4. A user exploring *A-me* at the exhibition STRP 2013, Eindhoven. © Jordi Puig

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 explaining 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* [20], which investigated ways to exploit spatial memory by storing and retrieving pieces of digital information in volumetric spaces navigated by natural gestures [21]. *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, encouraging pre-publication exchanges and discussions 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* [22], 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 brain scans, 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 is 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.

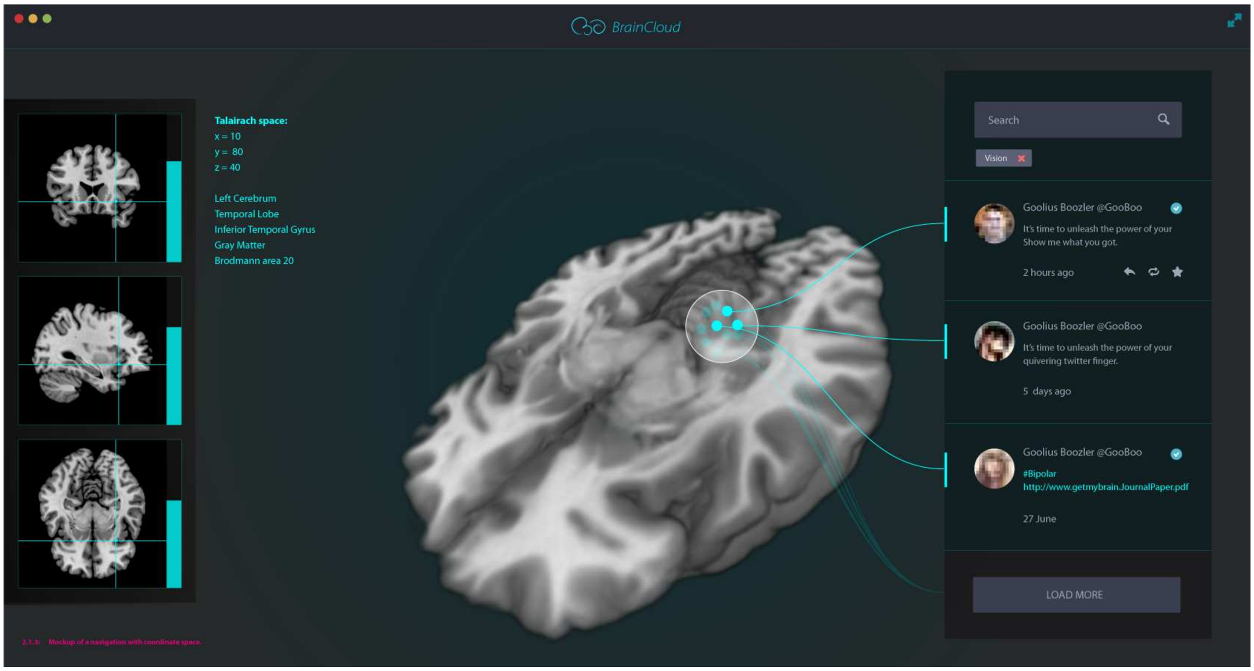

Fig. 5. *BrainCloud* main search interface. The region of interest selected by the user is displayed as a white sphere. A set of coordinates match the selected area and the most relevant comments are displayed on the left panel.

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 *BrainCloud*, 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 [23]. After that, we started the development of the first prototype targeting the most basic functionalities such as to store and retrieve 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. To evaluate the new design, we conducted an interview with two neuroscientists at the Institut 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 [24], CoactivationMap [25], Neurosynth [26], NeuroVault [27] and CognitiveAtlas [28].

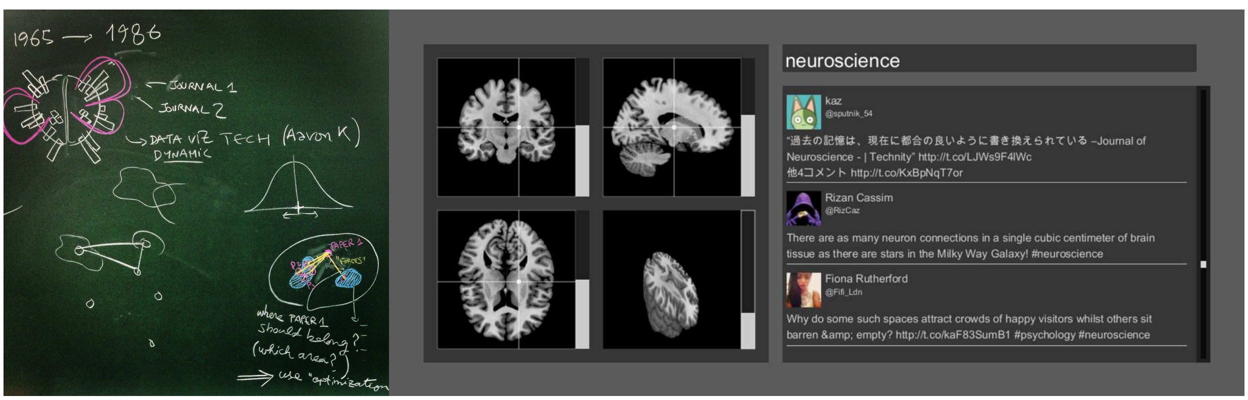

Fig. 6. Left, sketches made by Alvaro Cassinelli during the initial brainstorming session for *BrainCloud*. Right, first prototype of *BrainCloud* displaying messages located on a brain atlas.

Discussion

BrainCloud aims to provide relevant benefits to the neuroscience community by focusing on improved visibility and cooperation between researchers. It 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, network infrastructure, etc.) and software requirements (interaction, visualization, and network requirements). Our discussions ranged from design patterns to specific details on libraries and implementations. Although our prototype was initially built with OpenFrameworks (a C++ toolkit), the discussion turned around the possibility of using web technologies (like 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, 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 one component of a cognitive network (e.g. Broca area for 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).

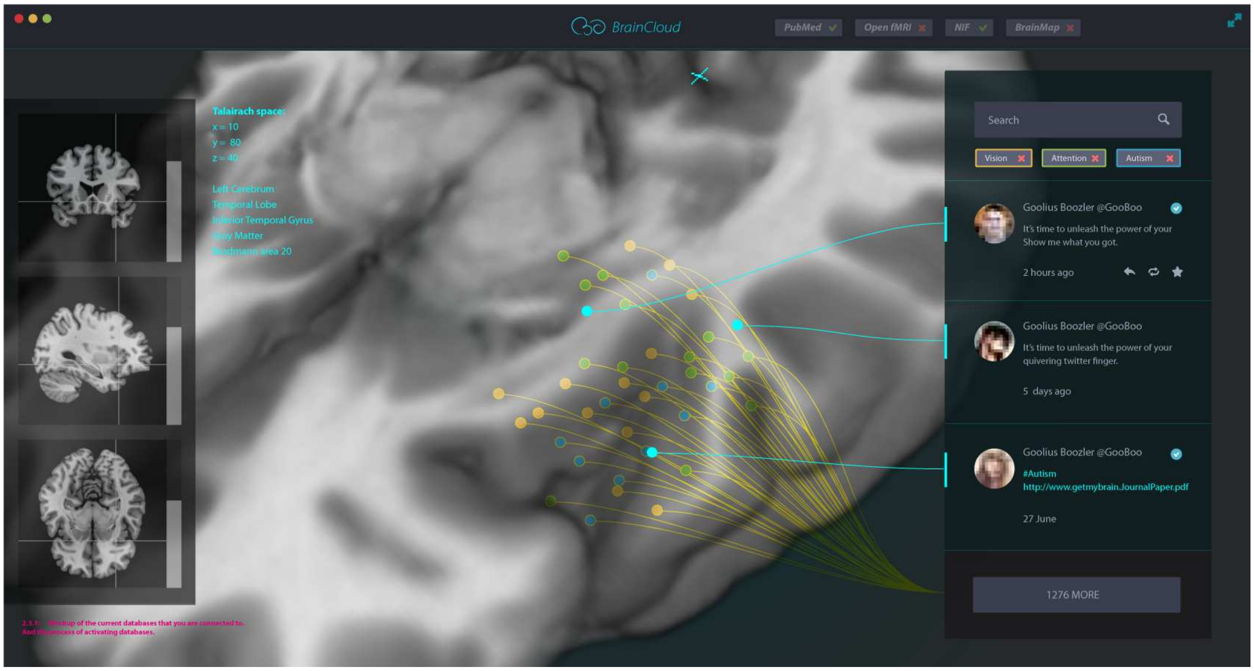

Fig. 7. *BrainCloud*'s interface for a search with multiple filters. Multiple keywords help the user to refine a search, each keyword is displayed in a different color. For a short demo of *BrainCloud* see <http://www.vimeo.com/wasawi/BrainCloud>.

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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