Leonardo Just Accepted MS.
doi: 10.1162/LEON_a_01382

A-me and *BrainCloud*: Art-Science Interrogations of Localization in Neuroscience

Jordi Puig (researcher), Department of Electronics and Telecommunications, Signal Processing Group, Norwegian University of Science and Technology, Norway. Email: <jordi@iet.ntnu.no>.

Annamaria Carusi (educator and researcher), Department of Medical Humanities, Medical School, University of Sheffield, U.K. Email: <carusi.annamaria@gmail.com>.

Alvaro Cassinelli (researcher), Meta-Perception Group, Ishikawa-Watanabe Laboratory, The University of Tokyo, Japan. Email: <cassinelli.alvaro@gmail.com>.

Philippe Pinel (researcher), Cognitive Neuroimaging Unit, Neurospin Center, French National Institute of Health and Medical Research (INSERM) and French Alternative Energies and Atomic Energy Commission (CEA), France. Email: <philipinel@gmail.com>.

Aud Sissel Hoel (educator and researcher), Department of Art and Media Studies, Faculty of Humanities, Norwegian University of Science and Technology, Norway. Email: <aud.sissel.hoel@ntnu.no>.

Manuscript received 5 May 2015.

Abstract

This article reports on two art-science collaborations, *A-me: Augmented Memories* and *BrainCloud*, that interrogate the central role of localization in neuroscience—including the use of technologies that augment sociability using localization as a central reference point. The two projects result from a series of interactions where a science/technology development fostered art, which in turn led to a science application, which potentially may lead to further artistic activity. *A-me* is an art installation that repurposes navigation and visualization tools normally reserved for medical clinicians and scientists, inviting reflection on the ongoing endeavor of neuroscience to explain and map cognitive functions such as memory. *BrainCloud* is a software prototype that provides neuroscientists with an interface for interacting with existing data and knowledge about the brain. Organized visually as a brain atlas, it forms a social network that allows neuroscientists to connect and share their ongoing research and ideas.

Cognitive neuroscience has tremendous social and cultural impact, 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. Of particular interest is the ongoing evolution of the trope of localization in neuroscience, as well as the development of technologies that augment sociability using localization as a central reference point.

In recent years projects that cross the art-science boundaries have become far more common [1], 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 symbolizing 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. They featured artists who work on neuroscience topics, such as Andrew Carnie, who has undertaken several projects centered 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. 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 research project *Picturing the Brain: Perspectives on Neuroimaging* [5] emerged from the recognition of the centrality of imaging and visualization technologies 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. The guiding idea was to integrate research and creative activities allowing creative practitioners to pursue scientific, technological and artistic aims, in close collaboration with science, technology and humanities researchers. This article reports on two such art-science interactions, *A-me: Augmented Memories* and *BrainCloud*, both of which interrogate the central role of localization in neuroscience, and with that, the elusive links between cognitive information and brain anatomy. The interrogations include an exploration of the communicative and community-building potential of localization imagery when combined with technologies that enhance interaction, cooperation and interpersonal visibility. Each project brings together different sets of expertise and research interests. *A-me* is a memory-evoking apparatus that is aimed at general audiences and 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 provides researchers with an interface for interacting with existing data and knowledge about the brain. 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 share their ongoing research and latest discoveries. Even though *A-me* was conceived for artistic purposes and *BrainCloud* for scientific purposes, the two projects are not completely separated but form a trajectory of art-science interactions where a science/technology development fostered art, which in turn led to a science application, which potentially may lead to further artistic activity. The two projects are also connected in that they share a common core in terms of digital infrastructure: Both projects develop interfaces for interacting with brain information through 3D volumetric visualizations.

A-Me: Augmented Memories

Neurosurgery is clearly a domain in which spatial accuracy is key for precise guidance and orientation; and localization is also a predominant concern in the neuroscience goal of mapping cognitive functions onto the physiological brain. Hence, knowledge about regions, areas and the connectivity among 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 [6–8]. *A-me: Augmented Memories* is an interactive installation that repurposes navigation and visualization tools normally reserved for medical clinicians and scientists, inviting reflection on the ongoing endeavor of neuroscience to explain and map cognitive functions, in this case memory.

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 Augmented Reality (AR) display presenting a tomographic brain visualization overlaid on a dummy head, and headphones that deliver binaurally spatialized sound. Figure 1 depicts the usage of *A-me* during exploration, and Fig. 2 shows 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 at specific locations in 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].

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Fig. 1. Jordi Puig demonstrating the use of *A-me.* (Photo: © Mark Stegelmann) For a short demo of *A-me* visit <http://www.vimeo.com/wasawi/a-me>.

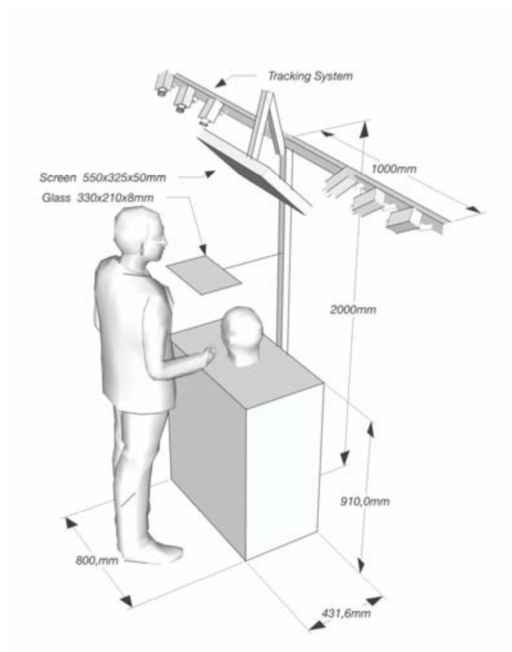

Fig. 2. Sketch of *A-me*'s hardware installation setup. (© Jordi Puig)

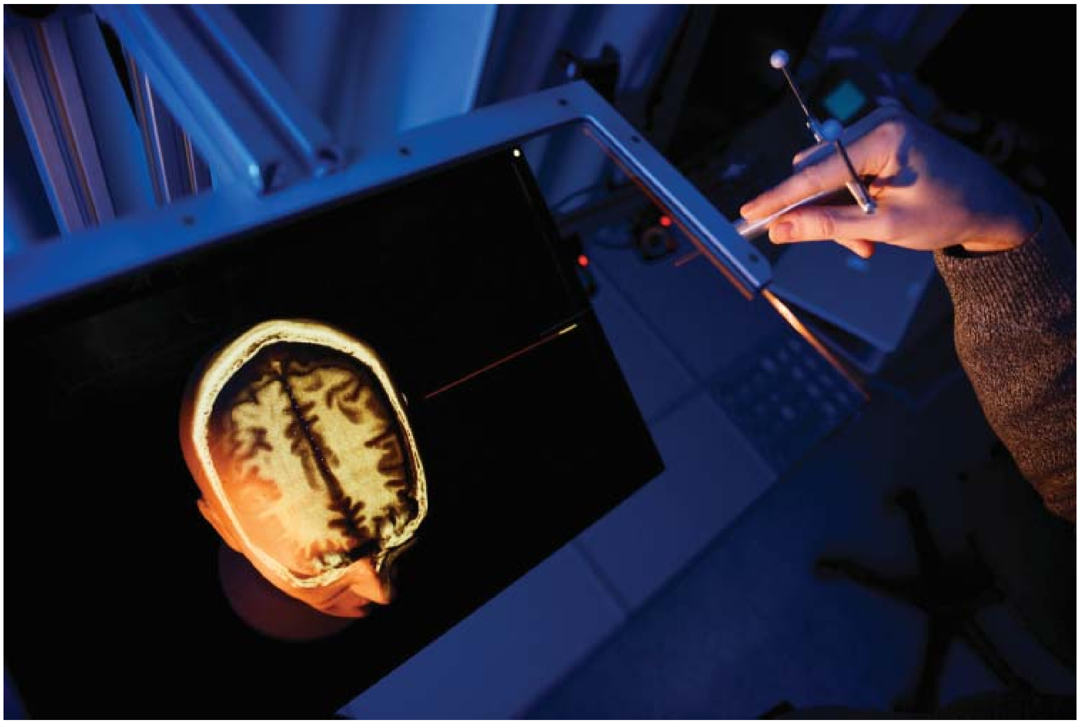

Fig. 3. *A-me*'s optical see-through AR display presenting a tomographic brain visualization mapped on a dummy head. (Photo: © Mark Stegelmann)

Research process

The research started in the spring of 2011 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. 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 directed our attention to navigation and localization issues. In order to better understand the core elements and basic functionalities of neuronavigation systems, we decided to develop a system similar to the surgical neuronavigation setup used at the university hospital. The initial challenge, then, was to build a low-cost prototype with surgical accuracy and reliability. While developing the system, we learned that AR surgical techniques have been intensively investigated during the last decade [11–13]. Wanting to explore these latest developments, 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]. On the basis of these explorations, we proposed a method for assessing the QoE of surgical AR systems by means of a combination of quantitative metrics and qualitative analyses [17]. Thus, at an early stage the work on *A-me* was science-oriented, contributing to the refinement of surgical accuracy and reliability currently achieved through these kinds of tools.

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 assessment of QoE of surgical-oriented AR systems, we soon decided to develop it in a more creative direction. The second version of *A-me* focused on the integrative efforts at the heart of the *Picturing the Brain project*—exploring the potential of artistic interventions for facilitating dialogues between science/technology and society. 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], 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.

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BrainCloud

The progress of neuroscientists' research depends not only on their own individual capacity to probe the brain, but also on a timely access to the corpus of knowledge generated by fellow researchers. Now, while this is crucial, nowadays it is more and more difficult to organize and keep up to date with relevant information, as it may be buried by the amount of available data: Publications are scattered in different journals, and moreover, not everything that may be of interest (such as comments, latest ideas and work in progress) is included in publications. The idea behind *BrainCloud* was to visualize this disparate information in a form that is intuitive for neuroscientists, that is, in the form of a brain atlas. Thus in this application, various kinds of information, including comments and nascent ideas, are stored and retrieved via the brain regions with which they are most closely associated. Researchers gain access to the disparate information by navigating through it as they would through a digital brain atlas. In this way, *BrainCloud* operates like a social network for neuroscientists: It visualizes and facilitates scientists' interactions with each other, extending these beyond what is possible through research publications, encouraging prepublication exchanges and discussions and augmenting sociability through an interface familiar to them, a 3D spatial interface.

About the application

As seen in Fig. 4, the current implementation of *BrainCloud* uses a standard brain atlas, the *MNI Colin 27 average brain* [20], as a reference point for social activity. 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 subcortical 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 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

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brain (composed by the hemisphere, the lobe, the gyrus, the tissue type and the cell type). Finally, social activity (e.g. user's discussions, comments about publications or references to relevant research) is presented in the right panel, also used to search and post messages. Thus, 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.

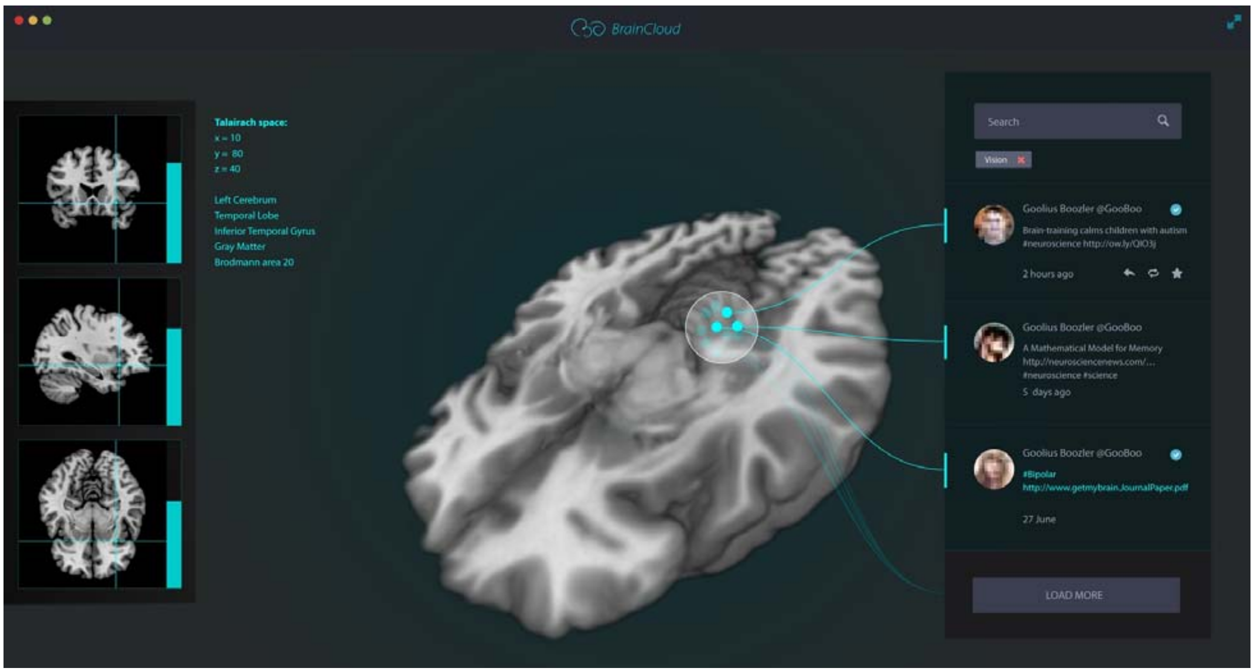

Fig. 4. *BrainCloud* main search interface. The region of interest selected by the user is displayed as a white sphere. A set of coordinates match the selected area and the most relevant comments are displayed on the left panel. (© Jordi Puig)

Research process

During the spring of 2013, while *A-me* was being exhibited, the main author Jordi Puig initiated a collaboration with the Ishikawa Oku Laboratory at the University of Tokyo. There, he 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* [21], which investigated ways to exploit spatial memory by storing and retrieving pieces of digital information in volumetric spaces navigated by natural gestures [22]. *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.

The main challenges of developing *BrainCloud* were related to visualization issues concerning 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, we 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. 5). The session resulted 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.). 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 would be interesting for a neuroscientist to keep track of. 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 storing and retrieving comments placed by researchers in specific areas in the brain atlas (Fig. 5).

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 be displayed in different use cases. While the first design used four views of the brain atlas, the new proposal moved toward 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. In December 2014, to evaluate the new design, we conducted an interview with two

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neuroscientists at the Institut Pasteur in Paris who had not been previously involved in the *BrainCloud* project. The interview raised questions of critical importance to the project, such as the informational needs of practicing neuroscientists, the differences of handling neural networks datasets compared to datasets of localized brain functions, and last but not least, the state of the art of other similar projects [24].

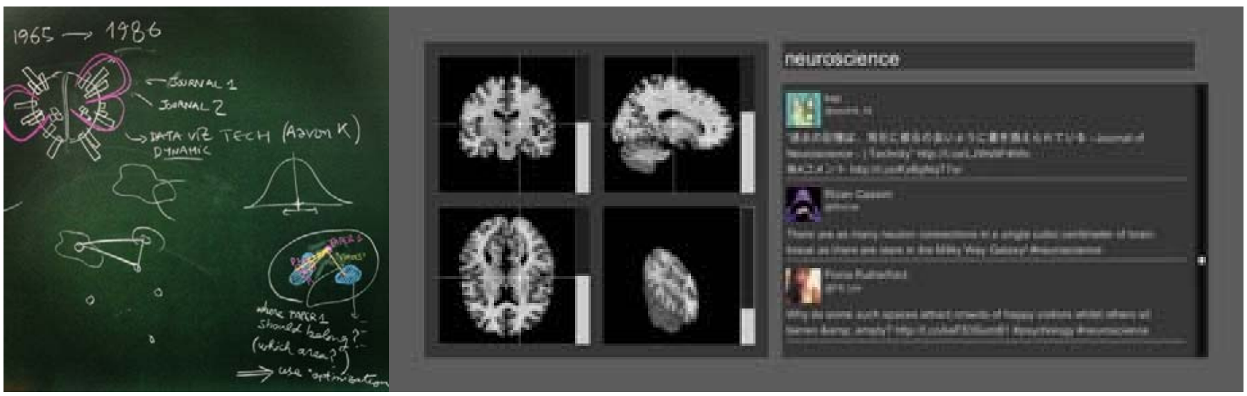

Fig. 5. Left, sketches made by Alvaro Cassinelli during the initial brainstorming session for *BrainCloud*. Right, first prototype of *BrainCloud* displaying messages located on a brain atlas. (© Jordi Puig)

Discussion

A-me and *BrainCloud* both exemplify how crucial processes in art and science can overlap, sometimes leaving it undecided what in these development processes would count as "art" and what would count as "science." Both projects involved a highly interdisciplinary group of researchers with backgrounds in medical technology, neuroscience, media art, media technology and humanities. Although *A-me* has been referred to here as an art project, it grew out of a technological development for surgical purposes; and although *BrainCloud* was developed to contribute to neuroscience research, it built on the development of an interactive art installation. Each iteration of this cycle of technological development can in principle lead to new forms of neuroscience-inspired art-installations for the broad public, as well as new perspectives on the scientific process for scientists, opening up different arenas of interrogation and activity for both.

Both *A-me* and *BrainCloud* interrogate aspects of the discourse of neuroscience, notably the central trope of localization. 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 that on the other hand encourages reflection about the brain, localization and common behaviors such as exchanging memory-like experiences. Through their interactions with *A-me*, users are prompted to pose questions about where memories might be located and, therefore, also about the role of neuroscience in explaining our mental and social behavior. The installation also relates to pressing questions concerning how to delimit the boundaries of brain activity, how current brain atlases describe cognitive functions and how to map locations across multiple subjects or across the development of the brain over time. *A-me* has been very well received at the STRP festival and other exhibition venues, where audiences have been queuing up to explore the interactive apparatus and deposit their personal recollections. Nevertheless, among the group of researchers involved in the development of *A-me*, a recurrent concern has been whether or not the use of point-like locations for storing "memories" may promote misguided ideas about memory, by not paying attention to the embodied and distributed nature of mental functions. The installation does emphasize, however, that memories have a collective dimension to them, and that memory sometimes makes use of external props.

BrainCloud is, once again, organized around the trope of localization, but this time in order to enhance the sociability that is necessary for science to flourish. It aims to provide relevant benefits to the neuroscience community by focusing on improved visibility and timely cooperation among researchers. It does this by creating an interface for a direct mapping between current neuroscience social networks and brain atlases (i.e., a spatialized social network). From our different fields of expertise, we approached the task by identifying our challenges and dividing them into three categories: technical, social and scientific. The technical challenges concern issues that shape the way the project is materialized, including hardware requirements (devices, platforms, network infrastructure, etc.) as well as software requirements (interaction, visualization, 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 [25] 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. Even if, in the future, the project will benefit from current social media platforms *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 [27], which is a new tool that tracks article impact metrics. However, when it comes to the quality of publications, human assessment is essential because, 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 that were among 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 a larger, more distributed area depending of the subject of study. Brain activity can be very focused, like the neural basis of one component of a cognitive network (e.g. Broca's area for language), or less focused, 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. 6).

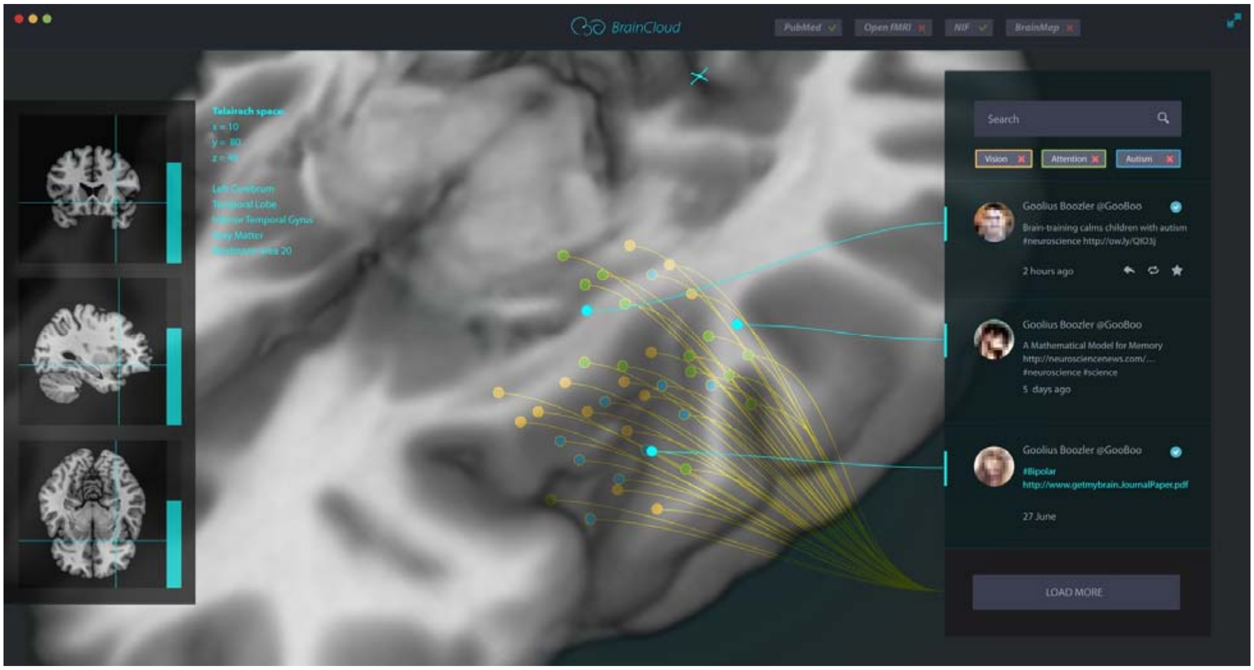

Fig. 6. *BrainCloud*'s interface for a search with multiple filters. Multiple keywords help the user to refine a search, each keyword is displayed in a different color. For a short demo of *BrainCloud* see <http://www.vimeo.com/wasawi/BrainCloud>. (© Jordi Puig)

Conclusions

A-me and *BrainCloud* represent a small but significant step toward 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 and humanities perspectives. 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. How *BrainCloud* and other similar efforts will ultimately contribute to the future outlook of neuroscience is of course not known. 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 behaviors onto specific brain areas?

Acknowledgments

This work was supported by the Research Council of Norway under Grant 203311. The sequence of authors conforms to the “first-last-author-emphasis” norm.

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