ABrIL - Advanced Brain Imaging Lab.: a cloud based computation environment for cooperative neuroimaging projects

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***Abstract*— Neuroscience is an increasingly multidisciplinary and highly cooperative field where neuroimaging plays an important role. Neuroimaging rapid evolution is demanding for a growing number of computing resources and skills that need to be put in place at every lab. Typically each group tries to setup their own servers and workstations to support their neuroimaging needs, having to learn from Operating System management to specific neuroscience software tools details before any results can be obtained from each setup. This setup and learning process is replicated in every lab, even if a strong collaboration among several groups is going on. In this paper we present a new cloud service model - Brain Imaging Application as a Service (BiAaaS) - and one of its implementation - Advanced Brain Imaging Lab (ABrIL) - in the form of an ubiquitous virtual desktop remote infrastructure that offers a set of neuroimaging computational services in an interactive neuroscientist-friendly graphical user interface (GUI). This remote desktop has been used for several multi-institution cooperative projects with different neuroscience objectives that already achieved important results, such as the contribution to a high impact paper published in the January issue of the Neuroimage journal. The ABrIL system has shown its applicability in several neuroscience projects with a relatively low-cost, promoting truly collaborative actions and speeding up project results and their clinical applicability.**

I. INTRODUCTION

Advances in non-invasive neuroimaging methods led to the acquisition of large data volumes, which need to be stored and analysed. Every day, thousands of neuroscientists collect and process data in an attempt to better understand the pathophysiology of the brain. Significant findings were achieved in neuroscience mainly due to this novel advances in imaging hardware technology [1] [2]. Nevertheless, computational infrastructures which support neuroscience studies have not followed the pace of this progress, as neuroscientific questions become more and more complex, requiring additional cooperation among research centres.

Neuroscience labs usually perform their computational tasks on local software, workstations and servers. This Local Deploy Model (LDM) requires big initial investments, space, cooling, power and low-level system administration [2]. The associated costs to maintain such systems may be substantial when compared to cloud computing [3] or grid computing [4]. Furthermore, the expensive collected data and applications are only accessed by a small group of researchers and it is rarely shared among laboratories [5].

This LDM promotes the lack of standards, is characterised by a very low computational systems interoperability and limits the cooperation between complementary neuroscience centres.

Since neuroscientific research is becoming increasingly collaborative and complex, the policies and systems should maximize the recycling and sharing of data and knowledge [6][5]. Neuroscience collaboration requires computation that easily adapts to different user profiles, locations and workloads, considering that experts are increasingly diverse and dispersed around the world [6].

Virtual Desktop Infrastructure (VDI) approaches can be effective on this environment since cloud is ubiquitous. In addition, a VDI can support standard brainimaging applications and data models. Over the cloud, each center controls their pipelines and data models and, when desirable, they can be shared with others. Furthermore, cloud based models maximize the overall availability, reduce the costs and ease the outsourced maintenance [3] .

Today, neuroscientists can deploy their data and application on the cloud using the following service models: 1) Infrastructure as a service (IaaS) - Scientists lease a virtual private server, this is the basic cloud-service model and is normally associated with data hosting and network services. 2) Platform as a service (PaaS) - Scientists lease a platform, namely operating system, programming language execution environment, database or web server. 3) Software as a Service (SaaS) - Scientists host a particular software (and associated neuroimaging data) on a cloud provider. All these models require a service layer agreement and allow resource allocation according to the needs. Nevertheless, they do not offer neuroimage specific services.

In order to meet the specific demands of neuroscientists we propose, deploy and test a new cloud hosting model. That model extends the existing ones and contrast with dominant local deploys. We called it BrainImaging Application as a Service (BiAaaS). In general, this service model merges a consulting, maintenance and computation hosting services and is physically supported by a cloud VDI. This service is specialized on neuroimaging applications and its semantics.

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It offers to scientists an on-call support that also is neuroimaging specialized.

ABrIL (Advanced Brain Imaging Lab) is a BiAaaS functional prototype. Several neuroscientific projects were hosted on ABrIL until now. These projects members were geographically dispersed and heterogeneous. Their usage patterns were used to assess the impact of the BiAaaS model in supporting neuroimaging projects as well as its costs, usability, availability and capacity to boost knowledge capture and reusability.

In this paper we present the neuroimaging applications available in our BiAaaS prototype, its architecture and assess the strengths of this brainimaging specific cloud service model as compared to current local approach and generic cloud services. We then describe in detail the implementation of such model and provide a concrete description of how it was used on 4 clinical research collaborative projects in the last 18 months.

II. Neuroimaging services

ABrIL offers integrated access to a range of neuroimaging applications that are compatible with virtual and remote desktop interfaces. At the moment, applications such as FSL[7], TrackVis, MRIcron, MATLAB, SPM and 3D slicer are available to the users. Furthermore, a range of tested scripts is also available into this cloud platform. To provide an integrated GUI to all these scripts and enable the composition of complete pipelines for neuroimaging processing we have developed the ABrIL Pipeline Application (PipA).

Each tool belongs to a different module which can be executed separately or combined, forming a pipeline. The main advantage of this system is the possibility the user has to make different combinations of the modules and then create his own pipeline, as depicted in Figure 1.

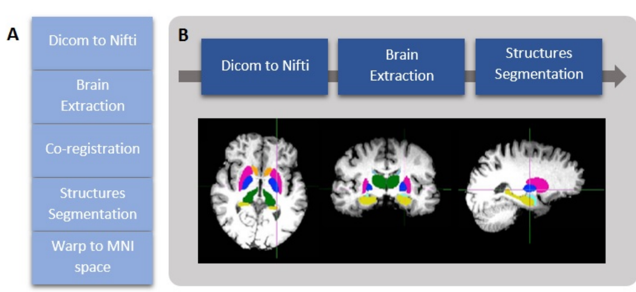

Fig. 1: A - Illustration of the modules presented in ABrIL PipA; B - An example of modules combination to segment some structures in deep brain area.

In Figure 1 A), we show the scripts available for combination and in B) a pipeline was built to segment some of the structures in basal ganglia system. The result is shown interactively to the user after the pipeline is executed.

III. Brainimaging Applications as a Service Model

On the BiAaaS model researchers and clinicians bring their data and pipelines to their VDI. ABrIL is a BiAaaS implementation were data is organized by project and Principal Investigator (PI) is the ultimate responsible. As depicted on figure 2, users can upload, download, visualize and process medical image files thought a VDI. Furthermore, users can manage their computational resources and knowledge bases.

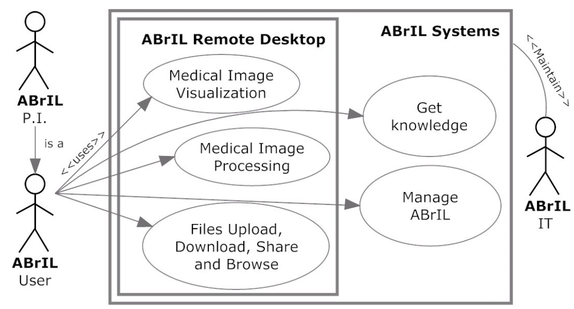

Fig. 2: ABrIL actors and use cases.

As depicted on figure 3, BiAaaS extends the Local Deploy Model by supplying data, application and maintenance over the cloud. Users can access ABrIL VDI and websites from anywhere on the Internet with only one credential and with all communications encrypted. In addition, they can interact with an on-call support through several channels. This helpdesk installs and maintains the hosted pipelines and computation tools.

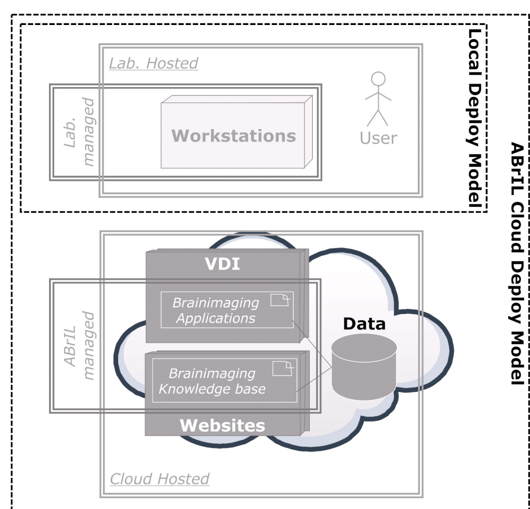

Fig. 3: Computation deploy on ABrIL Service Model vs Local Model.

On the same virtual remote desktop the ABrIL user can manage his data and his processing pipelines. As depicted on figure 2, the user can manage system profiles and interact with its knowledge base. ABrIL knowledge base uses the Redmine CMS [8] platform.

IV. Results

A. Case studies

In this section we present some cooperative neuroimaging projects hosted on ABrIL.

1) Tractography study: Using this computation environment, promising advances in the study of clinical Deep Brain Stimulation (DBS) effects for dystonia patients were found by Rozanski et al. (2014) [9], as depicted in Figure 4.

The migration of data and applications to a cloud environment allowed to the multi institutional partners an ubiquitous access to the project repository. This improved the learning curve and the overall productivity. At the same time, multiple local computational resources clones were not built.

Some pipelines developed in this study are integrated in PipA, namely co-registration and warping to MNI space.

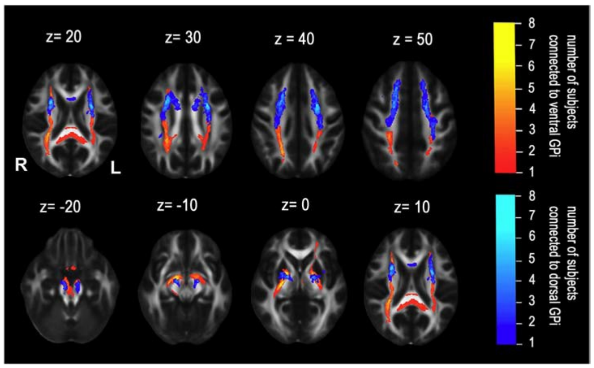

Fig. 4: Subtraction connectivity map of ventral and dorsal GPi electrodes, confirming the clinical evidence that the ventral and dorsal GPi belong to different functional and anatomic motor subsystems. [9]

2) 3D anatomic position of DBS electrodes: For the detection of 3D anatomic positions of DBS electrodes it was developed an additional PipA module (DBSmapping). This module was validated in collaboration with Ludwig Maximilian University of Munich (Moreira da Silva et al., 2014) [10]. Furthermore, this study re-used other available PipA modules, which allowed to obtain faster results and maximizing computational time.

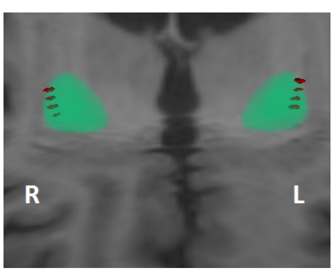

Fig. 5: Anatomic position of DBS electrodes (red) and GPi deep brain structure (green) on a 3D view, using 3Dslicer. Electrodes positions and GPi masks were determined using DBSmapping and Structures segmentation modules, respectively, inserted in a pipeline executed on ABrIL.

The result of this study was already used in a clinical environment by the department of Neurosurgery of Hospital São João, Porto (Figure 5). Several patients benefited already by this newly integrated pipeline into ABrIL. An example of an output of this pipeline can be depicted in Figure 5.

3) Quantitative Volumetric Analysis: In collaboration with the departments of Neurology and Neuroradiology of Hospital São João, Porto, we developed a quantitative volumetric analysis of hippocampus pipeline for epilepsy patients. The aim of this pipeline was to measure hippocampal atrophy, which would help to correctly lateralize the seizure focus in patients with temporal lobe epilepsy.

PipA tool enabled the generation of this pipeline, re-using several modules, enhancing the maximization of computational time.

4) 3D visualization of iEEG electrodes: In collaboration with the department of Neurophysiology of Hospital São João, Porto, we established a 3D model of subdural electrodes over the cortex. This 3D model enables neurologists to perform a finer delineation of the epileptic focus and eloquent areas. The new pipeline re-used some of the existing ABrIL PipA modules and some custom made FSL[7] scripts. The scripts allow to perform the segmentation of subdural electrodes and the removal of cerebellum. This removal improves the visualization of some of the iEEG electrodes.

The resulting mask of electrodes and the MRI dataset without cerebellum were added to MRIcron tool to obtain a 3D representation, as depicted in Figure 6.

This approach assisted the neurologists to perform a more careful correlation of electrodes position with the surrounding tissues.

The pipelines were validated and subsequently used in the pre-neurosurgical evaluation, and used for the resection surgery in 4 different difficult cases.

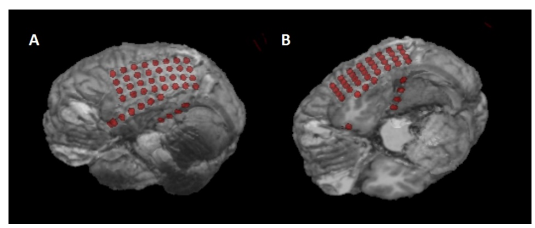

Fig. 6: A - 3D view of skull-stripped T1-MRI overlapped with electrodes mask. B - 3D view of skull-stripped T1-MRI, without cerebellum.

B. Usage Indicators

ABrIL functional prototype is fully operational and running since June 2013. Ever since, it proved to be very productive in supporting neuroimaging collaborative projects. After 4 months of ABrIL operations started, the results of the second mentioned case study were accepted as a paper in the International Conference on Physiological Computing Systems [10]. ABrIL also contributed to the tractography case study, which resulted in an paper published in the January issue of Neuroimage [9] .

ABrIL prototype used (on average) 4 CPUs, 12GB of RAM and 500GB of data storage for a cost of 250 Euros per month with a 3 year contract. The deploy and help-desk support on this pilot phase costed half man-month from a university (and healthcare) I.T. services team. It has served

16 users, from 3 different institution (Aveiro University, University of Porto , and of Munich) and hosted 9 different projects (and groups). Average file transfer rate between clients and server is 1MBps. Average remote session lasted 30 minutes, although some processes run on the server for several days.

V. Discussion

In the presented case studies the BiAaaS approach proved to be both financially and scientifically advantageous. This access to file and application sharing allows neuroscientists to improve cooperation and eases the lab applications validation process, by testing them with data and researchers from different labs. In addition, computational applications and work methods were more easily shared among consortium elements, particularly among distant elements, allowing to obtain faster results and maximize the computational time.

These neuroscientists and clinicians work from several places, beyond the workstation installed on their institutions, namely from home and public networks. Most seniors users report an improvement on the inexperienced elements learning curve. The new project elements began to analyse and process data earlier than usually do on Local Deploy Model.

Project members appreciated the differentiated and dedicated ABrIL computational support. When inquired, the majority of the users said that this type of support has value and complements his University/Hospital I.T. services. The project administrators appreciated the fact that they have a single point with all data, documents and applications. They valued that the critical data circulated solely on encrypted channels. The fact that they have a single system, not several workstations as in Local Deploy model, eases the access and the system maintenance tasks.

The course of these projects also showed the some pitfalls: 1) The availability of only one Linux remote environment restricts the type of applications that might be hosted. 2) Some intensive graphical applications show a bad performance when they were executed remotely on that environment. 3) This Linux remote desktop system based on FreeNX [11] technology showed little tolerance for network failure. 3) During these studies we found several problems with the quality of the network between the server and the client, these network problems were responsible for most episodes of outages and poor quality of service.

VI. Conclusion

The inefficiency of the dominant neurocomputation Local Deploy Model may be a barrier for neuroscientific progress. In this work, we introduced a ubiquitous VDI model, supported by a pool of cloud servers, which may be a suitable alternative to overcome the limitations of the present models.

We have described the implementation of this system and showed concrete examples of the advantages offered by such model and prototype during the analysis of brainimaging data. Implementing such model on research centres is likely to facilitate cooperation between partners and aid researchers in understanding, in a proper way, their data. When compared to Local Deploy Model, BiAaaS has shown significant flexibility, ease-of-administration benefits and comparable security. The case seems strong enough to justify neuroimage consortium leaders attention. It seems desirable to invest on tools that efficiently mitigate the graphical remote desktop access limitations and lack of performance, mainly on poor quality or slow speed networks.

The experiment was scientifically and economically productive for the cited projects, which leads us to conclude that the gains may be even more significant with a larger number of cooperative projects to be performed within ABrIL.

To further improve our system, usability tests should be performed, as well as more operating systems and remote desktop technologies should be explored. ABrIL bottlenecks are its usability, intensive graphical applications performance and network quality, which will be the focus of further developments.

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