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# funcLAB/G—service-oriented architecture for standards-based analysis of functional magnetic resonance imaging in HealthGrids

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**Functional MRI is successfully being used in clinical and research applications including preoperative planning, language mapping, and outcome monitoring. However, clinical use of fMRI is less widespread due to its complexity of imaging, image workflow, post-processing, and lack of algorithmic standards hindering result comparability. As a consequence, wide-spread adoption of fMRI as clinical tool is low contributing to the uncertainty of community physicians how to integrate fMRI into practice. In addition, training of physicians with fMRI is in its infancy and requires clinical and technical understanding. Therefore, many institutions which perform fMRI have a team of basic researchers and physicians to perform fMRI as a routine imaging tool. In order to provide fMRI as an advanced diagnostic tool to the benefit of a larger patient population, image acquisition and image post-processing must be streamlined, standardized, and available at any institution which does not have these resources available. Here we describe a software architecture, the functional imaging laboratory (funcLAB/G), which addresses (i) standardized image processing using Statistical Parametric Mapping and (ii) its extension to secure sharing and availability for the community using standards-based Grid technology (Globus Toolkit). funcLAB/G carries the potential to overcome the limitations of fMRI in clinical use and thus makes standardized fMRI available to the broader healthcare enterprise utilizing the Internet and HealthGrid Web Services technology.**


## Introduction

Functional MRI (fMRI) is a rapid image acquisition technique capable to create 3D volumes of the brain in milliseconds. Acquiring a series of fMRI volumes allows tracing regional changes in brain oxygen proliferation, depending on the neural activity in a region. The neural activity changes oxygen demand in the local parenchyma resulting in increased blood perfusion. The regional increase of oxygenated hemoglobin results in luxury perfusion with a net increase of oxygenated hemoglobin in the venous system. As a net result the ratio between paramagnetic deoxygenated and diamagnetic oxygenated hemoglobin is lowered in the venous system, downstream from the small capillaries. Subsequently the regional MR susceptibility is changed under the blood oxygen level dependent (BOLD) effect (Ogawa et al., 1990, 1992) which results in an increase of the MR signal. Comparing the means of the voxel time series distributions of control (rest) and task condition (activation) of the acquired volumes using Student's *t*-test (Friston et al., 1995a,b) allows depicting voxels which have significantly changed under the task paradigm performed by the patient during imaging.

The high temporal and spatial resolution of fMRI, typically 1–5 $mm^3$ voxel resolution, compared to other functional imaging techniques (e.g. Positron Emission Tomography) have made fMRI the primary brain mapping technique used in clinical and neuroscience research applications today. In addition the non-invasiveness of the fMRI technique and repetition in case of patient incompliance to perform a task present further advantages, critical for clinical use. Typically 3–5 min of repetitive functional imaging provides statistical significant data to map a task activated brain region.

fMRI is successfully being used in neurosurgery applications including pre-operative planning and outcome monitoring. For clinical application the 3D brain activation map generated from the low-resolution fMRI data is fused with high-resolution anatomical information of structural MRI, e.g. high-resolution 3D Gradient Spoiled technique (Ashburner and Friston, 1999). Brain mapping of motor, somatosensory, visual, and language lateralization tasks (Moonen and Bandettini, 1999) have been successfully used in

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clinical evaluation and pre-surgical functional mapping and patient-specific neuro-navigation.

In contrast fMRI in neuroscience research typically pools data from a group of subjects in order to increase task sensitivity. Group analysis requires a standard space, or atlas, into which the individual volumes must be transformed. The time series analysis is then carried out within the atlas space for the individual brain voxels and for the combined brain maps (Friston, 1996).

In recent years MRI technology has significantly improved pushing high-field imaging (3 T and up) from research into the clinical arena. High field imaging is an important step for neuroimaging, especially for low signal techniques like fMRI, typically having a 2–5% signal to noise ratio (SNR) on 1.5 T systems. Subsequently, more demand for clinical fMRI applications can be expected in the near future which will further drive the field. An additional advantage of modern MRI systems is the use of the Digital Image and Communication in Medicine (DICOM) standard for radiological images. This makes easy image exchange between health providers possible.

However, clinical use of fMRI is less wide-spread, yet, due to its complexity of imaging, image workflow, post-processing, and lack of algorithmic standards hindering result comparability. As a consequence, wide-spread adoption of fMRI as clinical tool is low contributing to the uncertainty of community physicians on how to integrate fMRI into practice. In addition, training of physicians with fMRI is in its infancy and requires clinical and technical understanding. Therefore many institutions which perform fMRI have a team of basic researchers and physicians to perform fMRI.

In order to provide fMRI as routine diagnostic tool to the benefit of a larger patient population, (a) DICOM-based image post-processing must be standardized and streamlined into an automatic workflow and (b) available at any health provider with a need for neuro-navigation and brain mapping. Typically smaller hospitals and/or private practices do not have these resources available, but increasingly perform neurosurgery procedures which could potentially benefit from the additional functional information.

While solutions for standardized processing of fMRI have been in-depth discussed and open-source solutions are readily available, e.g. Statistical Parametric Mapping (SPM) (Friston, 1996), one only needs to integrate such processing solutions into a common sharing infrastructure. Critical to any such sharing solution for clinical data is patient privacy protection by restricted access to protected health information (PHI) mandated by the Health Insurance Portability and Accountability Act of 1996 (HIPAA, http://www.hhs.gov/ocr/hipaa). PHI can not be disclosed to unauthorized third-parties not covered by the patient's consent. As such, sharing of medical information which includes PHI, e.g. patient name and medical record number in DICOM images, is prohibited. In order to provide a solution for DICOM fMRI resource sharing, one needs to either remove or encrypt the PHI data prior to off-site processing.

Current sharing technologies, most prominently Virtual Private Networks (VPN) lack the flexibility to provide dynamic ad-hoc provisioning of computing and storage resources required for advanced clinical operations like fMRI; VPN is limited to a rigid peer-to-peer topology. Web-based applications can be useful, e.g. an fMRI processing web server, but this would require a tight and inflexible authorization coupling between users and web server. In addition dynamic failover will require redundancy hidden behind the exposed internet address of the web server (e.g. mapping of multiple uniform resource locators). Most importantly none of the above techniques intrinsically addresses domain-specific security considerations, e.g. PHI in healthcare. As such privacy protection is deferred to the next software layer — the application level.

Grid technology presents an alternative approach to overcome the data sharing problem. The Grid is an abstract concept of a loose collection of resources, e.g. storage, processing, monitoring, etc. accessible via public Internet or Internet2. A service controls/manages a resource, e.g. to store/retrieve data from a storage device. A Grid application can aggregate services in the Grid to perform more complex functions, e.g. an fMRI service would invoke a storage service and a processing service. Standards-based user authentication and single sign-on allow flexible and comprehensive access authorization for user–service or service–service interaction. Grid participating sites and users together build the Virtual Organization (VO) of the Grid. The VO operates a security domain and issues credentials (e.g. X.509 certificates), enabling a fine granulated access control mechanism, independent from deployment configuration and resource location.

Recently concepts using Grid computing and data federation in clinical research have been suggested including an fMRI virtual research laboratory (Olabarriaga et al., 2006), image processing of pharmacokinetic modeling in clinical research trials (Blanquer et al., 2006), MRI simulation (Bellet et al., 2006), parameter optimization in large-scale MR imaging (Ordas et al., 2005), and real-time applications of Grid in neurosurgery (Lippmann and Kruggel, 2005). Grid enabled clinical fMRI under regulations of HIPAA has not yet been investigated to the knowledge of the authors.

Driven by the objectives (a) and (b), we describe in this article a systems design, the Grid functional imaging laboratory (funcLAB/G), which integrates standardized DICOM image-based processing using SPM (solution to (a)) with secure fMRI image sharing using standards-based Grid technology (Foster et al., 2001, 2002) (solution to (b)).

## Methods and materials

The Globus Toolkit release 4 (GT4, http://www.globus.org) (Foster, 2005) is an open-source implementation of standards-based Grid technology and is used in this work as the underpinning software architecture. GT4 is widely used in academia (e.g. TeraGrid, http://www.teragrid.org), government (e.g. Earth Systems Grid, http://www.earthsystemgrid.org), and industry (e.g. IBM, http://www.ibm.com/grid) to provide geographically dispersed resource access and data aggregation over public (e.g. Internet) or closed (e.g. military) networks. GT4 uses the Web Services (WS) architecture (Web Service Resource Framework, http://www.oasis-open.org) and adds services for the common functions of security, data transport, data management, monitoring, and job execution.

funcLAB/G itself consist of four major components: (i) Secure access of Protected Health Information, (ii) image data and meta-data storage and management, (iii) funcLAB web service interface, and (iv) funcLAB fMRI processing engine. Components (i–iii) address our requirement (b), (i) addresses requirement (a). The methods described in the following sections build on previously described methodology to manage DICOM images in Grids (Erberich et al., 2007) and extend these to the use of Grid-based fMRI processing.

### *Protected Health Information (PHI)*

In this work we use a previously described encryption methodology (Erberich et al., 2007) to protect PHI access in Grids. In summary each user has a standard X.509 security certificate assigned by the VO's authority. The certificate is similar to a passport and allows a service invoked by the user to verify its authorization. Using this technique, DICOM fMRI images can be shared and provided for third-party fMRI processing. Here we make use of the fact that such an image processing service only requires the image content (3D image voxels), not the medical identifiers (PHI). One can leverage on this fact and only publish images with encrypted (message digest) PHI.

*funcLAB/G Web-Service*

The function of this service is to accept and perform fMRI processing requests received either by a service or by user interaction (e.g. Grid Portal invocation). In order to be compliant with established Grid security and data models we build the service layered on Globus MEDICUS (http://dev.globus.org/wiki/Incubator/MEDICUS), the Biomedical Informatics development extension to Globus Toolkit, providing DICOM compliant image management and storage (Erberich et al., 2007). Once deployed in GT4, the service becomes discoverable in the entire Grid through the VO's index service (MDS, Zhang et al., 2003). Upon invocation by a user/service, the WS performs access authorization by evaluating the presented X.509 certificate credential. Authorized requests are scheduled in a database to preserve the state in the event of system failure. The presented DICOM study and series unique identifiers (UIDs) of the functional/anatomical image series are used to discover the physical storage location within the Grid. We use the Replica Location Service (RLS) (Fig. 1; 3.1) to provide the mapping between UIDs and DICOM Object Storage Service Provider

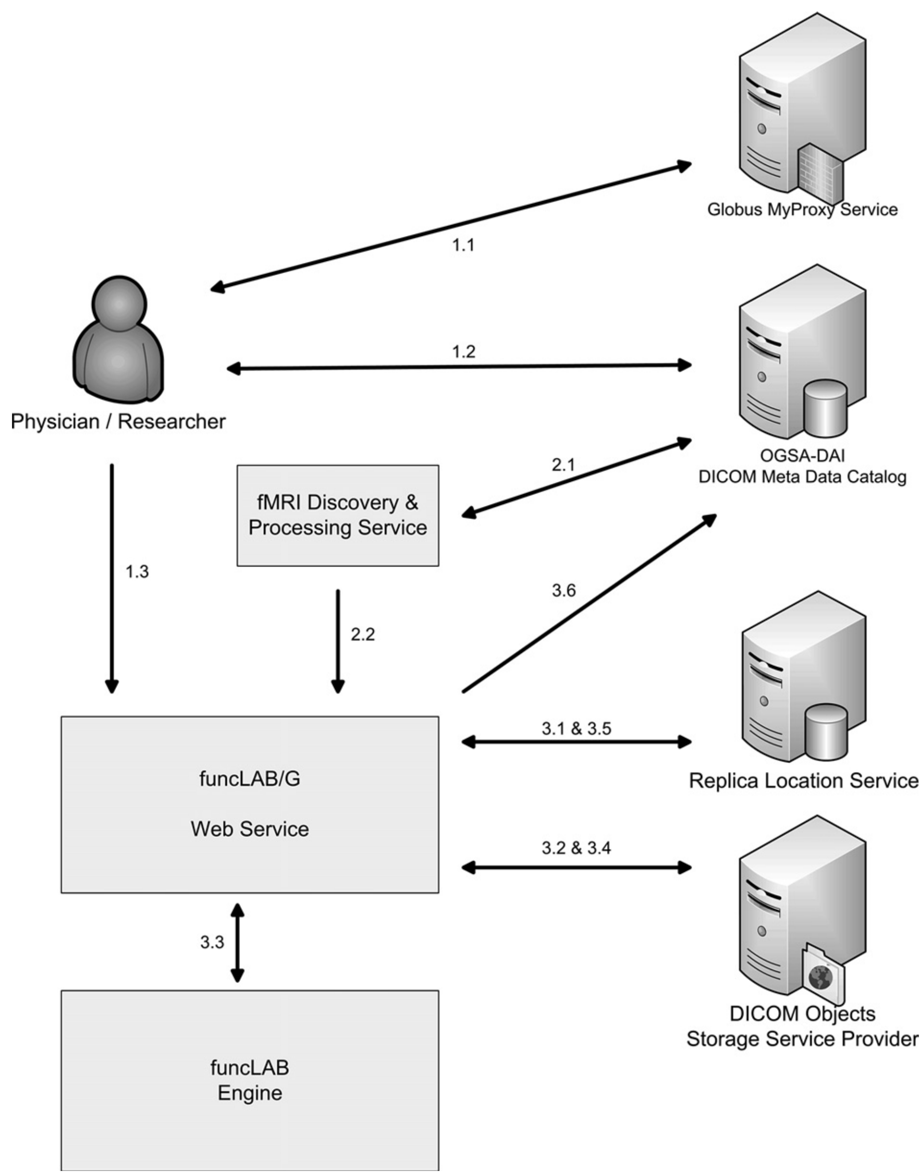


Fig. 1. Grid Web Service-based fMRI processing with funcLAB/G using the Globus MEDICUS framework. *Image Discovery*: User or automated service initiated query of fMRI images in federated Grid DICOM meta catalog (1.2, 2.1). *Image Processing and Analysis*: Web-Service invocation (1.3, 2.2), image series retrieval (3.1, 3.2) and process execution (3.3). *Result Publication*: Brain maps are published as PDF and/or DICOM SC objects in the Grid (3.4–3.6).

(SSP) on the Grid. Then MR image series are retrieved from a SSP (Fig. 1; 3.2) containing only encrypted PHI. Then the images are pushed to the funcLAB engine (Fig. 1; 3.3).

The service monitors the funcLAB engine database and detects whenever the processing of the fMRI study is concluded. Then the resulting fMRI report, a secondary capture DICOM object containing head motion, co-registration parameters, statistical analysis results, and the colorized activation maps, is published to the Grid.

*funcLAB engine*

The funcLAB engine (Fig. 2) itself executes three steps: fMRI preparation, fMRI processing, and fMRI visualization.

*fMRI preparation*

The first step of the funcLAB engine (Fig. 1; 3.3) is the preparation phase (Fig. 2; 4.1, 4.2). The images obtained from the Grid are stored on filesystem by a DICOM storage class provider (SCP) and are referenced in the database (DB) for further processing. The fMRI scheduler (Fig. 2; 4.3, 4.4) detects the newly referenced fMRI series in the DB and matches the predefined task model with the received data. Next, the fMRI series images are automatically converted to ANALYZE format (http://www.mayo.edu/bir/Software/Analyze/Analyze.html) and sorted according to the spatial–temporal model of task paradigm and data. A MatLab (The MathWorks) program is generated describing the data model and execution of the standardized SPM (versions SPM2 or SPM5) processing steps (Friston et al., 1994).

*fMRI automatic processing*

The execution of the fMRI processing steps is organized as a pipeline (Fig. 3). funcLAB discovers newly prepared series and initiates their processing and its monitoring in SPM. Multiple executions can be triggered at a time, depending on the number of processors available at the hosting environment. funcLAB can be deployed for parallel execution utilizing computer cluster technology to scale with the number of requests from the Grid. In addition, one can also deploy multiple instances of the service to increase processing capacity.

*fMRI spatial processing*

The first processing step of the fMRI pipeline (Fig. 3; 5.1–5.5) is slice timing correction, followed by motion correction, and spatial registration (Ashburner and Friston, 1999). For clinical fMRI the individual anatomical reference, commonly a high-resolution T1-weighted MRI, is used as spatial reference for the functional time series volumes. For research application one can select to use an anatomical atlas instead, e.g. the MNI reference of the Talairach atlas (Talairach, 1988), which is used by funcLAB. Both individual and atlas co-registered functional volumes are smoothed in the final step. Spatial smoothing reduces noise and introduces a Gaussian distribution to the time courses, required for the following statistical analysis. Smoothing kernel sizes are automatically determined from the voxel size.

*General linear model analysis*

The General Linear Model (GLM) is now estimated (Fig. 3; 5.6) as defined by the fMRI preparation step to express the observed responses as a linear combination of the explanatory variables, the experimental design of epochs/events of rest and activation conditions and an error term (Friston et al., 1995a,b; Friston, 1996). The GLM is used as multiple regression analysis to test for differences in distribution means between control and activation conditions. Regressors for the main effects, describing control and activation conditions, have been modeled from onset

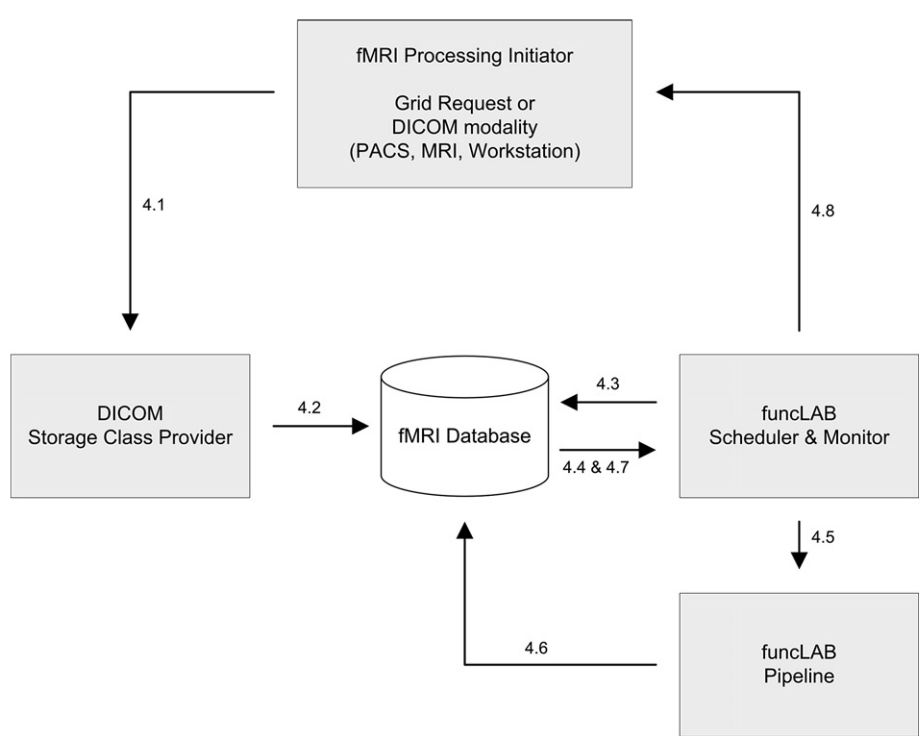


Fig. 2. funcLAB—Automated fMRI processing and statistical analysis architecture comprising fMRI image storage, task paradigm database, processing pipeline for clinical and research studies, and DICOM result publication.

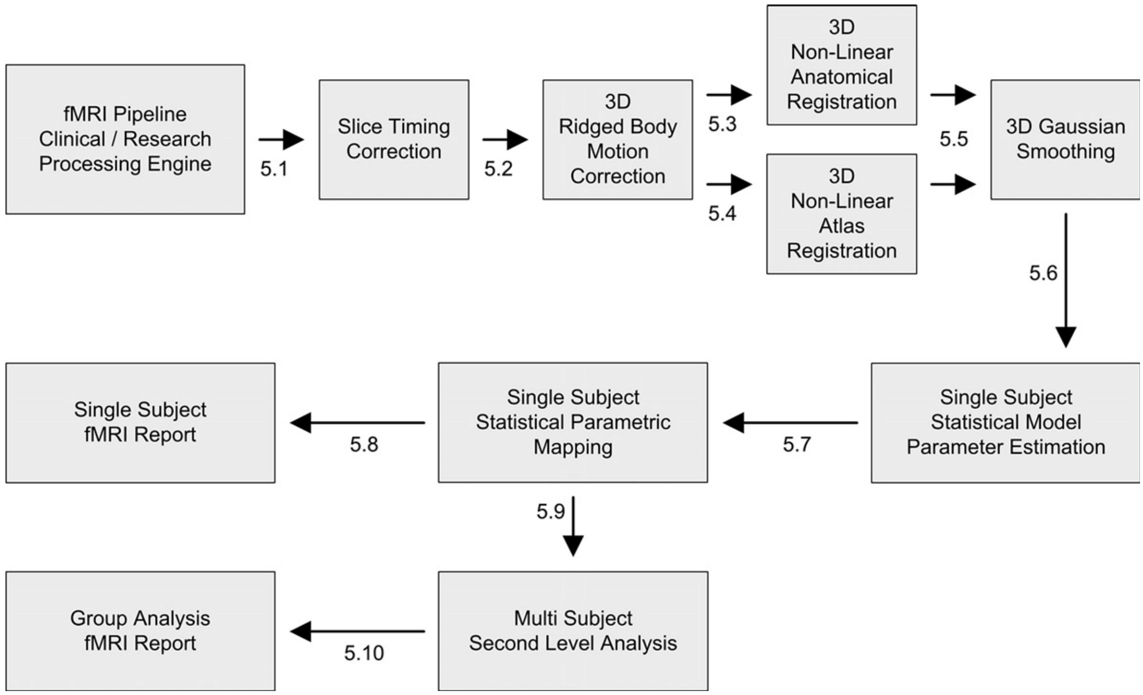


Fig. 3. funcLAB pipeline uses the SPM engine (versions 2 or 5) and Matlab (The MathWorks) processing environment for automated analysis of clinical or research fMRI data. The pipeline includes spatial preprocessing (5.1–5.6), statistical analysis (5.7–5.10), and result visualization and reporting.

and duration of the conditions. The ramp-shaped regressors of the GLM were then smoothed with a hemodynamic response function (HRF) derived from human brain physiology (Friston et al., 1995a, b) of adults. To remove low frequency noise, a model appropriate high-pass filter was added to the GLM. Then the error between model and observed data is estimated for each voxel using least squares minimization. The main effects of activation and deactivation under the task conditions are now contrasted from the GLM. Per-voxel variance-corrected comparison (Student's $t$-test) between mean values of control and activation distribution of the model's estimated time series is then carried out for all brain voxels. The result is the statistical parametric map (SPM_t) describing the likelihood of voxel being affected under the task condition. Values are reported as $z$-scores.

*Single subject analysis*

The SPM_t is used to create a 2D and 3D rendered view of areas of activation (red to yellow color codes) and deactivation (blue to green color codes) overlaid onto the anatomical or atlas reference image. Each rendered page can contain an axial, coronal, or sagittal projection for the given statistical significance threshold, the $p$-value. Typical $p$-value range can be stored in the task-specific processing profile.

*Group analysis*

In addition to single subject results, research subjects can be pooled into a group analysis. funcLAB automatically creates a new group or updates an existing group, and performs a second level analysis (Friston et al., 1999), when statistically sufficient group members exist. The resulting group SPM_t is then reported as Group fMRI report (group brain activation maps), one map per task.

*fMRI report grid publication*

Finally, the pipeline concludes by updating the fMRI database with the fMRI report. The fMRI report (Fig. 4) contains spatial preprocessing information; motion measured for translation and rotation in 3D, co-registration goodness of fit, and the brain maps as defined by the task processing profile. Each report is stored as PDF file and/or DICOM secondary capture (SC) object. Now the funcLAB/G WS detects the newly created fMRI report in the DB and performs an update (publication) to the Grid. First the newly created DICOM SC object is stored in the Grid SSP (Fig. 2; 3.4), then the RLS is updated referencing the SSP entry (Fig. 2; 3.5) and finally the series information is updated to the MCS (Fig. 2; 3.6). At this point, Grid users can discover the newly created fMRI report as a new series to the fMRI study.

## Results

The results of deployment of funcLAB/G can be measured by usability, performance, and cost effectiveness for health providers.

*Grid deployment*

Prior to Grid deployment, one needs to have fMRI acquisition and task presentation capabilities in place. Deployment of GT4 software at a health provider requires good knowledge about Grid and GT4, database installation, networking, and UNIX operating systems. A trained Grid engineer typically requires about 3 h installing a new Grid site (e.g. health provider) including GT4, Globus MEDICUS, and PACS setup. This setup allows discovery and publication of DICOM fMRI images and results in/to the Grid with health provider-specific access credentials. The funcLAB/G service requires about 5 h of overall installation by

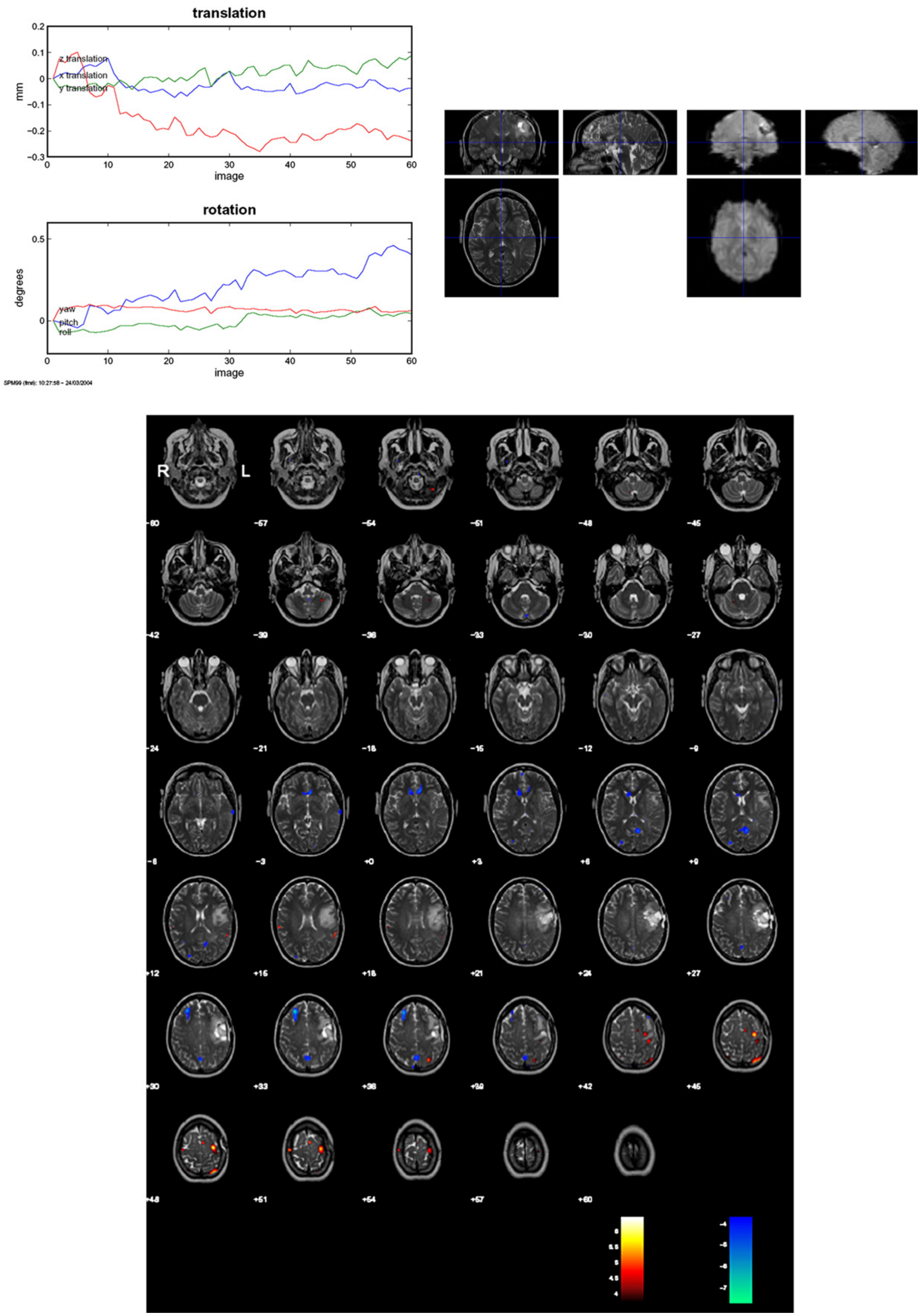


Fig. 4. The fMRI report describes relevant information about the analysis process: (Top left) Spatial motion correction of translation and rotation in space during imaging. (Top right) Spatial co-registration between fMRI and structural MRI. (Bottom center) Example of single subject brain activation map highlighting motor area adjacent to lesion (red–yellow, activation; blue–green, deactivation).

an equally qualified engineer. Additional experience with MatLab is required.

*Performance*

fMRI processing performance is determined by the funcLAB engine and varies greatly by the amount of volumes, volume size, matrix size per slice, and task model complexity. In addition, processing performance is affected by the funcLAB Engine hosting environment, e.g. single processor or cluster and performance of the CPU(s). A typical deployment of the funcLAB Engine has been tested on a Dual Core AMD Athlon server, 2GB RAM, 1TB RAID-1. Using this server, a typical clinical fMRI study ($128 \times 128$ slice matrix, 32 slices, 60 volumes) is processed in an average of about 5 min. Discovery and publication to the Grid are neglectable for performance evaluation (<1 s), only depending on the network performance of the service providing institution.

*Cost effectiveness of service-oriented architecture*

fMRI acquisition and task presentation equipment presents the highest costs for any health provider; commercial systems typically range between $40,000 and $180,000. Any commercial or research fMRI presentation equipment can be used with the funcLAB/G system and are out of the scope of this work. Cost effectiveness of the Grid is achieved through the Service-Oriented Architecture (SOA) concept for (i) shared image post-processing resources (hard- and software), (ii) unified task designs shared within the VO, and (iii) training and knowledge exchange between users of a unified system design. The Grid deployment cost of a funcLAB/G service within a VO is about 40% of the cost of comparable commercial systems, but the service is shared by many health providers compared to individual installations. Thus optimal utilization is achieved.

## Discussion

The current workflow for fMRI in clinical and research settings usually consists of manual interaction to import and process the functional images and to create a color coded brain activation map. The funcLAB Engine presents an automated processing solution and thus a simplified workflow from the MRI to the PACS (Picture Archiving and Communication System). This is of ample relevance when fMRI is used in a clinical setting where typically an MR technologist will be charged with image post-processing. Here no additional work is required, helping the MR technologist to focus on imaging rather than being sidetracked with fMRI processing and keeping up with the MRI schedule. The funcLAB Engine presents standardized fMRI processing applicable to a wide range of clinical and research fMRI — a solution to our requirement (a).

Avoiding manual processing and doing automatic processing offline from the MRI workflow does not only preserve the workflow, but potentially reduces processing and medical errors caused by subjective bias and lack of user experience. Detailed understanding of the techniques, physics and imaging aspects of fMRI are required in order to manually perform fMRI processing. funcLAB carries this expertise in the form of the software, predefined task designs, statistical models, and process descriptions derived from the research literature and many years of expertise by the fMRI research community.

The second requirement (b), establishment of a PHI safe shared environment for fMRI data and processing resources, can be solved by Grid technology as demonstrated. However the Grid paradigm and its services are not operating in real-time. As such, delays in communicating data to/from Grid databases can occur and are not controllable by the Grid. These delays are inherited from the underpinning software and hardware, predominantly by the network performance (bandwidth and latency) between Grid services or service–user interactions. Real-time application, e.g. intra-operative surgery planning and image guided intervention drawing from prior large scale images, require specialized real-time programming and high-bandwidth, low-latency networks like Internet2. The Message Passing Interface (MPI), integrated into GT4, enables near real-time capabilities with cluster computing. An example of a Grid application in image-guided intervention is described in Chrisochoides et al. (2006).

The dominant concern for any shared environment remains the data security. PHI has been addressed in the presented Grid solution, but PHI could even become a concern when image data includes identifiable data itself. For example, an X-ray image of the chest contains barely any specific features making the image itself identifiable. However, images which show still pictures or movie material of patients, e.g. a video EEG or high resolution 3D MRI rendering of soft-tissue, present another challenge to any system sensitive to patient privacy. This problem is further extended for DICOM secondary capture formats and DICOM structured reports; both use DICOM format as wrapping to deliver a variety of multimedia formats, e.g. JPEG images, text, annotation. Altering the medical data is prohibited by law preventing one from blurring facial features in the images. Further research will need to address how such data can be properly exposed without changing the medical data and without exposing patient sensitive information. Such cases illustrate the complexity of the PHI problem and one has to balance between burden and benefit on new approaches like Grid.

HIPAA defines that data should not be easily accessible for unauthorized third-parties. In that respect the Grid technology and the image workflows described here do employ the necessary protection using certificates and encrypted DICOM attributes of PHI to restrict access to the data. Because novel technologies like Grid are pushing the envelop beyond current practice, unprecedented benefits and new challenges arise.

An example of Grid technology used in medicine is the Biomedical Informatics Research Network (BIRN) (www.nbirn.net), one of the earliest adopters of Grid technology used for exchange and post-processing of fMRI data. The focus of BIRN is on cognitive human and animal research and how data across multiple centers can be acquired to be pooled into group analysis. Latter increases the sensitivity of the functional observation, but requires low variability of effects of no-interest (e.g. head-motion, MRI sequence geometrical distortion artifacts and thermal noise). To reduce site-specific MRI artifacts, the BIRN has developed a comprehensive array of calibration capabilities deployed at each site to perform image acquisition quality assurance (Friedman and Glover, 2006). However this is not of relevance in clinical fMRI, discussed in this article, because fMRI data of patients is not pooled during statistical analysis. However the lack of sophisticated image quality control, as done in BIRN, presents a shortcoming in funcLAB/G. Processing results will suffer and subsequently the fMRI report will present false-positive activations whenever the image quality is low, e.g. large amount of head motion. However, funcLAB/G is not intended as computer-aided diagnosis (CAD) system which concludes clinical treatment. It is a reporting tool and requires a well informed physician to interpret the diagnostic value of the imaging, but eliminates the subjective interactive fMRI analysis performed by radiology staff on similar systems. As such, one can determine image quality from the additional information besides the brain maps in the fMRI report. Thus head motion artifacts can be easily detected from the fMRI report (Fig. 4, top left).

Because the funcLAB engine is based on SPM, the most commonly used analysis methodology in Neuroscience, it allows both clinical and research users full degree of experimental freedom and an easy translation from research to clinical protocols.

## Conclusion

Here we present a Grid-based SOA to overcome the major problems in fMRI: (a) Standardized fMRI processing by codifying functionality, thus eliminating errors associated with user interaction for repetitive or simple functions; (b) Availability of fMRI expertise and processing resources by using open-source and standards-based Grid technology for distributed data and resource sharing and fMRI analysis provisioning.

The authors believe that Grid technology carries the potential to be a well-suited application platform to reach a large number of fMRI users in clinical and research settings. The funcLAB/G WS presents a model for other institutions to benefit from processing services available on the Grid, typically deployed at expert sites (e.g. University centers). PHI safety of the Grid allows sharing of fMRI processing resources on a truly global scale. As a net benefit, data processing can be harmonized and thus results become compatible. Subsequently, acceptance of fMRI as a clinical tool by physicians is likely to increase.

The low total cost of ownership of a standardized Grid solution for fMRI processing and archiving of medical images compared to the high fMRI onsite costs (imaging and task presentation) make it feasible. However Grid costs are in addition to the fMRI onsite costs and present a financial burden, especially to smaller community-based health providers. One can offset these high onsite costs by using simpler task presentation techniques, e.g. audio instead of video, which can reduce costs by about 80%.

Grid technology can be used to provide easy access to medical information and thus to better inform physicians and subsequently improve care of the patient at any health provider. Now community practices and hospitals can share resources in the Grid and thus enable broad and rapid availability of new technologies, like fMRI. The overarching service-oriented architecture presents new avenues not only to provide better services and availability, but also to reduce the total cost of ownership to operate such technologies by optimal utilization.

Grid-based fMRI is only one example of the revolution from silo architectures of today's healthcare IT systems toward SOA. The benefits of having the complete health information available at the point-of-care are obvious and undeniably what one expect from the hospital of the near future. Grid technology can play a viable role in the next stage of health informatics, e.g. for near real-time image processing during surgery (Chrisochoides et al., 2006), surgery planning when a trauma patient is still in transport to the hospital.

PHI management in the Grid presents a major challenge. Encryption of PHI embedded in DICOM images, adopted in this work, is complex, time-consuming (e.g. reduces its use-fullness for ad-hoc image review), and not inclusive (e.g. DICOM secondary capture and structured reports). Each image must be investigated by the encryption algorithm for PHI—a tedious and error-prone process. The authors conclude that a more sophisticated way to remove/restrict PHI must be employed and is currently investigated by this group.

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