fMRI: A Benediction to Neuroscience

Vijay Khare[1,*], Shaurya Singh[2], Neha Mehra[2], Shamim Akhter[1] and Chakresh Kumar Jain[2]

[1]*Department of Electronics and Communication Engineering Jaypee Institute of Information Technology Noida, India*

[2]*Department of Biotechnology, Jaypee Institute of Information Technology Noida, India*

Abstract: Functional Magnetic Resonance Imaging (fMRI) is a looming technique utilized to study local brain functions *in vivo* on a large dimensional and temporal resolution. The technique is less expensive and completely noninvasive hence it has swiftly become one of the most preferred choices for brain mapping. It establishes on Magnetic Resonance Imaging and helps to identify neural correlations and brain-behavior relationship by detecting the changes in blood flow. fMRI is one of the most frequently used technique in the field of neuroscience which has provided researchers with unparalleled access to the brain in action.

The imaging data generated from different neuroimaging techniques (primarily fMRI) is a time series data. A typical fMRI study provides huge volume of noisy data with a complex spatio-temporal correlation configuration. Statistics play a vital stint in apprehending the attributes of the data and gaining appropriate conclusions that can be used and understood by neuroscientists.The data is huge and is characterized by volume, velocity, variety and veracity. These attributes makes it fall under big data further raising the issues of big data analytics.

Upcoming technologies such as cloud computing, Spark and massive parallel computational methods /algorithms could provide the possible solutions for analysis and mining of data. The review highlights fMRI as a source of Big Neuroimaging data, different databases & repositories where data is available, its role in healthcare, problems in the data analysis and how the present technologies provide possible solutions for data analysis.

Keywords: Big data, Neuroimaging, fMRI, Spark, Cloud computing.

1. INTRODUCTION

Big Data is one of the hottest topics of today. After transforming the fields of Physics, Astronomy, Security, IT Sector, and Banking it is all set to revolutionize the fields of Biology and Biotechnology. The explanation for Big Data is changing quickly as genomics data is being produced. After Genomics and Healthcare, Big Data is now metamorphosing the field of neuroscience with current challenges as depicted by Figure **1** [1].

Neuroscience is a field that studies about the structure, function, development, genetics, biochemistry, physiology, psychology and pathology of nervous system [2]. The augmentation of *in vivo* neuroimaging has determined an astonishing amount of digital knowledge related to the brain. While much is made of the data barrage in neuroscience, neurological imaging depicts the dominant boundary of advance in “big data”. Variety of neuroimaging data basing advances have well organized the communication, repertory and dispersal of information from corresponding brain imaging investigations [3]. An explosion of image acquisition tools, analytical software capabilities, post-processing algorithms, and data-sharing infrastructures are all part of the current era of “Big Data” in neuroimaging. The data in neuroscience exists at an astonishing range of both scale and time that is obtained from various techniques ranging from patch clamping to optogenetics to fMRI [4].

fMRI is a non-obtrusive strategy for deciding neural relates of mental process in people. In fMRI, brain action isn't estimated at the level of regions but instead regarding volumetric pixels (voxels) [5]. The information created are huge and high dimensional. fMRI gives adaptable data as full scale macro structural, microstructural, and thick connectivity matrices. Enhanced fMRI testing techniques deliver time-series information on different blood oxygenation-level-reliant volumes of brain [6]. Due to non-intrusive element, numerous fMRI machines continue checking distinctive subjects and always new imaging information giving it the attributes of data [7].

2. DATA FORMAT AND DESCRIPTION IN FMRI

fMRI, a buzz in field of cognitive neuroscience since it allows a superior comprehension of the brain-behavior relationship. Based on the blood flow and transitions in blood oxygenation levels in reverberation to neurological movement fMRI overshadows all the other neuroimaging techniques. The bulk of information

*Address correspondence to this author at the Department of Electronics and Communication Engineering Jaypee Institute of Information Technology Noida, India; Tel: 9891372671; E-mail: vijay.khare@jiit.ac.in

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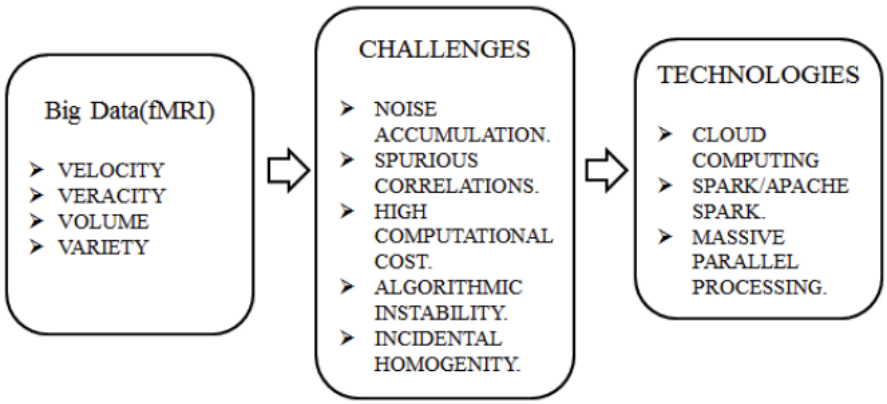

Figure 1: fMRI challenges and solutions.

collected with BOLD weighted fMRI is bewildering. With economically procurable devices it is standard to accumulate 1064*64 pictures for each second persistently for 60 minutes. [8]. fMRI researches produce enormous volume of intricate data and are exorbitant to organize as exhibited in Figure **2**.

The data collected in fMRI modality is 4 Dimensional since volume images are acquired across time. Basically the data is collected in 3D and then stored in 4D [9]. The fMRI data is of two types – Raw Data and Processed Data.

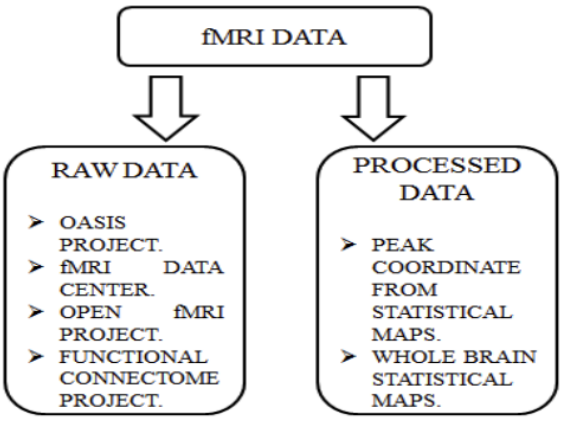

Figure 2: Types of fMRI data and the repositories where it is available.

Raw or Source data is the information which has not yet been processed for getting used. It is widely used to examine a variety of new hypothesis but is quite tedious to scrutinize. The repositories available for raw data include OASIS Project (Open Access Series of Imaging Studies) which intents at producing the data sets of brain complimentarily accessible online to the world. Open fMRI allows free and open sharing of data. The objective of this undertaking is to help charge less and exposed conveyance of crude and handled neuroimaging datasets, concentrated fundamentally in entire brain datasets from task based fMRI examines [10]. Finally, 1000 functional connectome venture likewise makes the information accessible to analysts around the world. The information is likewise accessible at Functional Magnetic Resonance Imaging Data Center (fMRIDC). It was entrenched in 1999 with the goal to create a system for efficient and effective sharing of functional neuroimaging data [11]. The fMRIDC compiled 107 datasets that stay accessible for shipment by means of physical media. fMRIDC is prodigious attempts to collect, pastor, and transparently share the total informational collections from distributed research articles of brain activation studies utilizing fMRI [12].

Processed data is one that is basically collected and manipulated to produce an interpretation or meaning in a lesser time, but it is less flexible when it comes to testing of hypothesis. The sources of processed data include brain maps; the peak coordinates from one or more statistical maps and whole brain statistical maps.

Therefore, fMRI data is available in various file formats -

1. Digital Imaging and Communications (DICOM) in Medicine is established for therapeutic images and widely utilized in hospitals. The data is taken straight from the scanner and the result is generated in 2D. A DICOM file consists of a header and image data sets packed into a single file [13].

2. ANALYZE, developed by Biomedical Imaging Resource (BIR) Mayoclinic, is the most commonly used format in fMRI data analysis. It is a standard for both SPM and FSL. Analyze breaks the header and image component of DICOM format into separate files.

Analyze can also store 3-D and 4-D data in separate files [14].

3. NIFTI (Neuroimaging Informatics Technology Initiative) is the most widely recognized file type utilized for depicting fMRI information, which is a gathering of arrays imitating various dimensions of the fMRI image, in addition to some header data. This image format is used by SPM-8 and FSL. Files are saved as (.nii) or (.img) or (.hdr). NIFTI serves as a standard for fMRI analysis in which files can have more than three dimensions [15].

4. AFNI data is generally given as a four dimensional data cube in one file [16]. In AFNI there are two basic types of file anatomies and functions. Anatomies include high resolution brains and BOLD time series data. On the other hand, functions are basically activation maps derived or calculated out of anatomies and include correlations, t-results and other activation maps.

5. MINC is basically an extension of NetCDF and the files are stored as (.mnc). It is a flexible data format [17].

Though data is available online in the above mentioned repositories and formats, but it is not sufficient since it is either used many times or not shared. The possible reasons why the data is not shared could be the time constraint as it takes a lot of time to systemize the data from a study into an exemplar format and then its transfer to an online repository. The other reason could be related to researches - the publication issues and the reanalysis of a particular study by people due to availability of data. Also there is lack of tools which are available to share data or there is no such database that can be created. These are the major possible reasons because of which the data is not yet shared but if once the data sharing begins, it will be a boom in the cognitive neuroscience field [18].

3. TOOLS FOR FMRI ANALYSIS

In the above section we have discussed about various repositories and sources from where the fMRI data is available, here we are discussing about the tools used for analyzing the fMRI data. These include COINS, SDM, AFNI, Bioimage Suits, Brain Voyager, CONN, FSL, MRIcro, MRVision, PyMVPA and Olea Sphere.

Olea Sphere is a picture transforming tool deliberated for picture chronicle, post handling and transmission. Its major role is viewing and analysis of fMRI datasets. The tool analyzes the data that is available in DICOM format. It has various applications in the field of neuroscience but the user interface is quite complex. SDM (Signed Differential Mapping) uses statistical techniques for meta-analysis researches on variations in brain movement or structure utilizing neuroimaging procedures, for example, PET, fMRI, and so forth. Results produced are unbiased but can sometimes be inaccurate also. PyMVPA (Multivariate Pattern Analysis in Python) helps in multi-variate design examination of fMRI information. It allows handling large datasets but the implementation time is quite slow [19]. MRVision is image analysis software. It allows fMRI brain activation mapping. It provides a simple layout but its user interface is outdated. MRIcro is helpful in analysis of fMRI, PET and MRI datasets. The tool is quite well planned to sight and export Brain images but its user interface is outdated and lacks useful information. FSL is a athenaeum of investigation apparatus which emphasizes on functional, anatomical and diffusion MRI brainimaging information. It provides GUI and command line interaction but the major disadvantage is that it is used only in windows with virtual box [20].

CONN is cross-platform matlab based software which provides GUI for analysis of fMRI [20]. COINS (The Collaborative Informatics and Neuroimaging Suite) are a platform for uploading, importing and fast entry options of data. It allows storage, sharing and communication of datasets. The data include fMRI, MEG, EEG, ERP, MRI, etc. The main advantage of this tool is that it helps in exporting data in various data formats available but the problem is that it is web based. Bioimage Suite is medical image analysis software used for fMRI analysis. It provides a large no. of tools for user convenience but we need to install extra packages for specific packages [21]. Brain Voyager is used to analyze and visualize multimodal neuroimaging data. It provides a multimodal neuroimaging package but the tool is not free. Brain Voyager is comparatively simple to handle, though problems associated to file format and a rigid directory structure make it more difficult to incorporate into a processing pipeline [22].

4. FMRI AND HEALTHCARE

There has been a great awareness in using fMRI to aid in clinical verdict and management, with favorable

demonstrations of viability in a number of fields. Both resting and task-specific regional brain activity can be measured, primarily utilizing alterations in regional cerebral blood flow (CBF) as an alternate marker for neural function [23, 24]. In this section we are primarily focusing on various applications of fMRI.

4.1. Neurosurgery Candidates

In this area fMRI helps individuals by assessing the fact that whether they should undergo for any type of neurosurgery or not. Pre-surgical localization of critical functional regions of brain to enable a safer and comfortable surgery is one of the best established applications of fMRI in clinical practice [25]. This can be in regard to seizures foci, neoplasms and vascular malformations [26]. Here the neuroimaging techniques such as PET, fMRI, EEG, MEG are used to identify and map eloquent brain areas before undergoing a surgery. Knowledge about different areas of brain prevents the risk of damages to those regions and thereby preventing disabilities development in the patients. fMRI helps in locating primary sensory and motor areas as well as areas related to high cognitive functions such as language, memory etc. [27].

4.2. Traumatic Brain Injury

Here fMRI has its role in examining the neural basis of subjective and objective cognitive deficits after a traumatic brain injury. fMRI studies diversifications in cognitive processes related to traumatic brain injury [28]. fMRI studies play a significant role after the traumatic injury in identification of various brain activation patterns post-surgery.

4.3. Multiple Sclerosis

fMRI has yielded a spectrum of insights into the progression of disease. fMRI investigations help in understanding the functional consequences of Multiple Sclerosis Injury which includes the impact on cortical functions and other mechanisms [29]. Patients suffering from multiple sclerosis have abnormal connectivity patterns compared to the healthy ones; these differences are detected by resting state fMRI (rs-fMRI) signal correlations which show the changes in functional connectivity [30]. In Multiple Sclerosis fMRI studies recognizes cortical region which is majorly affected in this disease [31].

4.4. Pharmacology fMRI

fMRI identifies the brain changes associated with treatment. Pharmacology fMRI has its contribution in the field of the translation of disease models and drug discovery. For example, acetyl choline agonist treatment may improve memory in Alzeihmer Disease also in the pre and post treatment with Aricept [32, 33] [34, 35]. fMRI can help optimize CNS drug discovery by providing a key metric that can increase confidence in early decision-making, thereby improving success rates and reducing risk, development times and costs of drug development [36].

4.5. In Psychiatry

fMRI provides a means to assay differences in brain systems that underlie psychiatric illness, treatment response, and properties of brain structure and function that convey risk factor for mental diseases. fMRI also finds applications in Developmental disorders such as Autism, Aphasia (to predict the outcomes of acute or sub-acute phases) [37], Depression studies, Attention Deficit Hyperactivity Disorder(ADHD), Obsessive Compulsive Disorder(OCD), Mood Disorders, Mild Cognitive Impairment and Alzheimer's Disease, etc. [38].

4.6. Analysis of Oral Functions and Diseases

Not only the identification of oral diseases fMRI has its application and is helpful to study various oral functions such as somatosensory system, olfaction and smell, jaw movement, chewing, mastication, speech and language also [39].

4.7. In Epilepsy

fMRI has received a lot of attention when it comes to its applications with regard to Epilepsy, this is due to various reasons. Firstly, fMRI is a functional ataxia that may not be accompanied by structural imaging techniques. Also fMRI examines changes in brain function associated to ictal or interictal states. fMRI also gives information related to language, memory and many other functions as a part of preoperative evaluation of patients for surgery [40]. The results of fMRI obtained in a patient with epilepsy give insight into the mechanism of the disease in comparison to normal brain functions. fMRI studies also have role in pre-surgical determinations of brain function in patients with epilepsy and tumors. Basically fMRI serves as a diagnostic tool for pre-surgical evaluation in epilepsy [41]. Also information is provided about the different regions of the brain and their function hence it is a function preserving and a safer technique [42].

4.8. In Alzheimer's and PD

fMRI can be used for the identification of Alzheimer's illness in its most punctual stage, identifying subclinical decay of the memory activity. fMRI amid intellectual ideal models and the resting state holds guarantee to enhance early indicative and treatment alternatives in AD [43]. A spearheading representation of this approach was a fMRI based memory investigation of a gathering of sound subjects in danger of advancing initial onset of Alzheimer's illness. One year after fMRI checking, the individuals who were on a beginning to develop memory problems in early clinical elucidation of assumed Alzheimer's sickness were distinguished [44]. Researches and studies have demonstrated that Alzheimer's patients gather beta-amyloid plaque and tau proteins in the brain years before Alzheimer's shows up. Studies demonstrate that fMRI could distinguish disturbances at about a similar time that beta-amyloid stores started to increase and tau levels began to diminish in spinal fluid [45].

fMRI might be helpful to anticipate the future decay of memory in individuals with hereditary contingencies . Observing of the functional improvement of post-stroke brains might be another promising clinical utilization of fMRI [46]. Functional MRI (fMRI) gives an *in vivo* intends to look at changes in brain function identified with the soonest appearances of AD, potentially before advancement of noteworthy irreversible morphological impairment. fMRI amid tasks testing episodic memory, which is the cognitive function most naturally hindered in early AD, are specifically noteworthy [47]. Resting-state functional magnetic resonance imaging (fMRI), a method used to picture inherent functional brain connectivity, is viewed as a promising biomarker for Alzheimer's infection (AD) as functional brain changes are thought to go before structural brain changes [48].

Functional neuroimaging strategies give essential understanding into the pathophysiology of neurodegenerative diseases like Parkinson's disease (PD) in-vivo. As of late, resting-state functional magnetic resonance imaging (rs-fMRI) has been administered as a non-obtrusive tool in numerous investigations to evaluate functional variations seen in PD without the consequence of particular motor or cognitive tasks [49]. Contemporary developments in fMRI take into account imaging of neuronal activation along the whole brain motor pathway including the brainstem and basal ganglia amid the execution of a perplexing motor task. These methods have effectively been administered to healthy individuals and PD patients. Healthy subjects exhibit symmetric activation along whole motor pathway while people suffering from Parkinson's show non-symmetric initiation and diminished neuronal enactment along motor pathway contralateral to their symptomatically more affected side. [50].

Validation for different outlines of brain activation in the patients with respect to normal individuals suggests functional imaging may have the capacity to anticipate extreme clinical refinement among feigned manifestations and an accurate reformation disorder [24]. fMRI is used for development of new treatments for various diseases.

5. fMRI ANALYTICS: CHALLENGES AND SOLUTION

A major challenge is to manage the significant volume of information file. For instance, common stature of an fMRI consider that is added to the Data Center has, up until now, been in the request of 3.26 GB. Yet, there are a few illustrations that surpass 15 GB of image information [51]. Analysis of large knowledge sets require admittance to lofty performance computing systems which is not possible with one system, it requires a network of systems or clusters of systems that are linked together via grid-computer interface otherwise it would take years to analyze a data set using a single system. Lastly instead of sharing data to a single device or computer, techniques like cloud computing should be used that can use cloud storage systems and pick up the data from a database and make it available more easily [52]. The voluminous, veracious and complex data is directly related with big data and their analytics.

Big Data brings new chances to present day society and difficulties to information researchers. Due to immense dimensionality and massive sample size of the information it offers ascend to three noteworthy changes that incorporate noise accumulation, spurious correlations and incidental homogeneity. At the point when high dimensionality is joined with large sample size it makes the issues of high computational expenses and algorithm instability. Massive examples in fMRI are commonly amassed from various sources at various time focuses utilizing distinctive advances [7].

In context to image analysis challenges faced include Preprocessing, Compression, Real time realization and Mapping of images [53]. The other

challenges with respect to fMRI include the lack of availability of data and sharing of available data. Regardless of the professional morals of information sharing, numerous scientific advantages, way for life of experimentation has eased back to move towards open neuroscience and most imaging information stays blocked off [54]. If the availability of data increases or data sharing increases revolutionary changes can be brought in the field of cognitive neuroscience. Another problem is of the data formats, the available data is not in all the formats. In order to run the data in software's like MATLAB or R the data should be available in a particular format which makes it suitable to run in these packages. Problems of Data interrogation and Statistical Analysis of the Data are also faced [44].

In continuity apart from above another line of challenge related with the confidentiality of the data, since it contains various information about the patient his or her life history and medical history which the patient may not always want to share it with others or make it publicly available for researches. This is the major factor due to which there is shortage or non-availability of data. Data representation is another problem that is differentiating between data sets on the basis of structure, size, roughness, approachability, semantics, etc. Often there are high levels of complications present in the data that is available; this creates a problem in the analysis of such datasets. Management and storage of data is also an issue [55]. Recent techniques of information management and storage are inefficient to fulfill the wants of big data, the increasing speeds of storage capacity are not more than that of the data hence a reconstruction of data structure is required. The heterogeneity of data makes storage a problem hence a hierarchal architecture system for storage should be designed to overcome this problem. Security and maintaining the privacy of data is also a great challenge that demands to be met [56]. The analysis of data requires cooperation from different experts from different fields. Internet connection is also an issue; improper signal strength hinders data transfer hence a connection should be such that it has speedy transfer, privacy and data integrity should also be there. Also access to skills and tools must be there in the users so as to ensure proper data analysis and making of sense out of a given set of information [44].

6. BIG DATA ANALYTICS: CLOUD ARCHITECTURE

Addressing and analyzing big data is claiming and tedious and requires large computational networks and infrastructure for proper data processing and analysis. Cloud computing is one such platform or one such technology that performs large scale and complex computing [57]. Cloud computing alludes to the utilizations conveyed as amenities over Internet, hardware and systems software in the data centers which provides those facilities [58].It sums up earlier ideas of administration from framework as-a-benefit (figuring assets accessible in the cloud), and information as-a-benefit (information accessible in the cloud) to software as-a-benefit (access to professional grams that execute in the cloud). This offers extensive advantages from perspectives of service providers (cost diminishments in hard-product and organization), overall use of assets, and better customer interfaces. [59]. Cloud computing and big data are interrelated as detailed in Figure **3**. It administers solutions to the different big data problems & challenges whereas big data accelerates its development [60]. It provides an ascendable and less expensive approach to big data challenges [61]. Cloud gives the solutions to problems on data storage and its processing. The distributed storage technology within the cloud computing technology efficiently manages big data. Parallel computing capacity with advantage of cloud computing

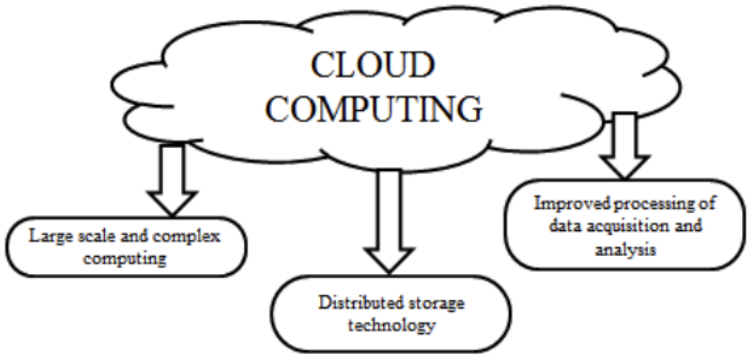

Figure 3: Cloud solutions to Big Data (fMRI).

improves data redemption and analysis. Also cloud users do not need to maintain finance and hardware.

Much of the assembly in big-data biology is implicit, concentrated on cloud computing in which data and software's are present in large, off-site centers which users can ingress on desire, so that they don't need to purchase their own hardware and sustain it. It's also useful for the labs which does not have their own hardware's and therefore create an implicit space for data, software and the outcome which anyone can ingress, or they can also secure the spaces behind the firewall such that few associates can get them [62].

Spark and Apache Spark is another tool that can be utilized as a solution to the problems of fMRI data analysis. Apache Spark is a software library that serves as a fast and dependable source for big data processing. With Spark there is less dependency on hardware and also it is more memory efficient. The major advantage that Spark has is that it supports various programming languages such as Java, R, Scala and Python. This advantage only makes it better than Hadoop. Handling data streaming and real time data processing are the key features associated with Spark. It can also interact with SQL database and data frames. It also has its machine learning libraries which include MLlib and GraphX which is a graph analysis tool that allows users to perform data processing and analysis in a more faster and parallelized environment that can be either a standalone version or can be installed on thousands of nodes [9]. With respect of fMRI Spark is used for scalable analysis of large neuroimaging datasets.Also, Spark provides a consistent API and the unified deployment, which offers a perfect solution for the data computing on the Big Data[63] fMRI based analysis of Parkinson disease [64].

CONCLUSION

Recently available neuroimaging techniques that include the invasive and non-invasive ones are generating huge amount of data and thereby raising computational issues of storage and analysis similar to Big Data. fMRI in present medical science is an essential tool which has a significant part in distinguishing the underlying patterns of brain and relating them with therapeutics which can serve as a landmark for various neuroscientists to explain the clinical interpretation of a disease and its state of diagnosis.

The cloud based techniques and others such as Spark/Apache Spark are one of the paving supports in the investigation of fMRI data and finding out significant regions of interest which further lead to detection of inherent pattern of the fMRI data.

Variation, Size and Quantity of data has always been a challenge for the systemic analysis. Apart from data description and modality its computation with development of effective algorithmic framework has been posing another line of challenges though in few cases these have been solved to certain extent.

Voluminous data is produced by fMRI, and only a part of it is classically analysed. Impartial method, joining developments in computer science (machine learning, and graph theory) along with trials in psychology and leading-edge tools from neuroscience delivers productive dais for novel diagnosis about the human mind.

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