# Dynamics of Functional Brain Networks

Rick Evertz 9548866
Supervisor: Prof. Damien Hicks & Prof. David Liley
Swinburne University of Technology

March 7, 2017

**Abstract**

Investigating brain networks of people in conscious and unconscious states.

# Contents

# 1 Introduction

The aim of this research thesis is to investigate the dynamical changes in functional brain networks in humans as subjects are placed under and brought out of chemically induced anesthesia. By inducing unconscious states using chemical anesthesia, Nitrogen Oxide $N_2O$ and Xenon $Xe$, the subject's brain activity is analysed using ECG and MEG simultaneously to provide a suite of data. The activity data is then reduced and converted into functional brain network signals to be analysed using mathematical and physical investigative means. The desire is to observe any dynamical changes in the functional connectivity of the brain networks as the subject experiences a loss of consciousness and subsequent return of a conscious cognitive state. This research aims to begin to quantify *consciousness* as an emergent property of dynamical brain networks.

Since humans and any of our cognitively able evolutionary ancestors have had independent thought, we have wondered on the origins of our consciousness and self awareness. Previously thought to be supernatural origin, the study of the human consciousness has gained the interest of scientists around the globe, attempting to quantify our minds in different forms. Be it the emergence from complex networks, quantum mechanical phenomena or computational information processing, a solid and concrete definition of consciousness currently eludes us. In this research report, we subscribe to the notion of consciousness being an emergent property of the complex network formed by the billions of neurons and trillions of connections. Despite our subscription, we do not attempt to state a concrete definition, but merely investigate the properties of consciousness as the network dynamics evolve in the brain.

We begin the research thesis with a review of the relevant literature, detailing the core ideas and concepts required to understand the proceeding sections. Then, moving onto the methods where we provide a brief explanation of the data collection, and a detailed description of the physics and statistical tools used to investigate the network dynamics. The results obtained are then presented and subsequently discussed, followed by a conclusion where we address future research avenues.

# 2 Literature Review

Several core ideas need to be addressed before the research component of this thesis is explored. The core ideas are: defining nodes and edges in brain networks, data collection MEG/ECG sampling, statistical mechanics of complex networks and consciousness as a complex emergent phenomenon.

Investigations into the emergence of consciousness in the brain has lead to a myriad of techniques used in attempt to quantify levels of awareness and begin to piece together a picture of conscious states. One such tool is the idea of casting the brain and its various components as a vast complex network. The brain is described as an incredibly complicated network made up of various nodes and edges. The way in which the nodes and edges in the brain network are defined ultimately characterize what will be studied. The brain network can be defined at differing resolutions including; individual collections of neurons which are connected via their synaptic interactions, larger groupings of neurons defined by a volume of brain matter or on the larger scale, individual regions of the brain itself (Parietal Lobe, Frontal Lobe, Hippocampus ect.). Modeling the brain as a network allows the application of graph theory and statistical mechanics, enabling a quantification of various network properties and behaviors.

The method employed within this research thesis, is built upon previous works completed by .... The functional connectivity of ... The nodes in the brain network will be defined by segmented brain matter volumes defined using beam forming methods and MEG/EEG data. The interaction between the nodes will be characterized by the correlation in the time series data obtained during the MEG and EEG experiments.

**Node and Edge**

## 2.1 Consciousness emergence from complexity

## 2.2 Complexity

A system that is maximally complex is in a state that has the largest potential for information processing and complex emergent behavior. When a system is maximally complex, it requires the greatest amount of information to define and understand. This provides the ability for the system to exhibit complex behaviors that result in higher level information processing.

Need to understand and be able to define when a system is maximally complex. Stat mech and entropy undoubtedly related. Use computation logic to define a maximally complex state, requiring the greatest information (bits) to describe.

# 3 Methods

- Define nodes as volumes of brain matter by using beam forming techniques and the position of the MEG/EEG sensors.
- Using the time series data, segment it using statistical techniques, enabling the temporal and spatial analysis of brain activity.
-

# 4 Results

Project 4 Neural inertia in the breakdown and recovery of functional brain networks

We will test the hypothesis that the excitatory anesthetic agents nitrous oxide and xenon will exhibit a concentration dependent hysteresis in organizational measures of specific brain networks that, at rest, are well defined by particular functional topological features. The outcomes of this set of experiments will allow us to determine i) to what extent neural inertia can be understood in terms of the functional breakdown and recovery of large scale brain neural networks, and ii) the degree to which the barriers to brain state transitions are independent of the underlying neurochemical perturbations.

The excitatory anesthetic agents, exemplified by nitrous oxide, xenon and ketamine, represent an interesting class of drug. Unlike the clinically more ubiquitous drugs, such as propofol and the halogenated ethers (e.g. sevoflurane), which act principally by enhancing inhibitory activity in the CNS, excitatory, or dissociative agents, act primarily by reducing excitatory neural activity. While operationally both classes of agent can lead to equivalent clinical endpoints they do so by distinct molecular level targets of action. The phenomenon of neural inertia will be considered a central organizing feature in cognition if we show that it is independent of the specific underlying cause of any perturbation to consciousness. On this basis we will measure changes in functional brain network organization before, during and after the inhalation of xenon and nitrous oxide in thirty human volunteers.

We will use a novel and definitive approach to quantifying changes in functional brain network architecture during excitatory anesthesia. This will involve the administration of nitrous oxide and xenon to healthy participants in a balanced two-way crossover design during which they will have simultaneous MEG and EEG recorded. Xenon and nitrous oxide are specifically chosen because i) together with end-tidal gas measurement and pharmacokinetic modelling, their brain effect site concentrations can be continuously measured and ii) pilot experiments have indicated asymmetric changes in total, and band limited, EEG power during concentration increases and decreases. State-of-the-art inverse modelling methods will be applied to the simultaneously recorded MEG and EEG in order to estimate source-level cortical and subcortical neuronal activity. This high-resolution source-level analysis will be used to define nodes (vertices) and connections (edges) for subsequent graph theoretical estimates of concentration dependent measures of functional and effective connectivity.

The experiments and the subsequent data driven computational analyses will provide an unprecedented high resolution panorama of the changes in brain activity that occur in response to systematic neurochemical manipulations of the state of consciousness.

# 5 Discussion

# 6 Project Outline

The aim of this research thesis is to investigate the dynamical behavior of functional brain networks of patients in varying states of consciousness. The functional brain networks will be defined by applying methods from statistical mechanics and graph theory to MEG and EGG data. The data was collected simultaneously from patients who were placed under chemically induced anesthesia, using Xenon and Nitrous Oxide gas. The desire is to be able to characterize the effects of anesthetics and explore the pathways by which they operate to reduce consciousness. The patients are monitored prior, during and post anesthesia, providing a temporally and spatially resolved signal of neural activity in varies regions of the brain. By defining and modeling the activity in the form of functional brain networks, the goal is to be able to quantify states of differing consciousness by the topological or statistical properties of the dynamic networks. The research will be completed under the supervision of Prof. Damien Hicks and Prof. David Liley of Swinburne University of Technology.

# 7 Conclusions

# 8 Reference

[2]

## References


[1] Réka Albert and Albert-László Barabási. Statistical mechanics of complex networks. *Reviews of modern physics*, 74(1):47, 2002.

[2] Thomas E Bartlett. Network inference and community detection, based on covariance matrices, correlations and test statistics from arbitrary distributions. *Communications in Statistics-Theory and Methods*, (just-accepted), 2016.

[3] Ed Bullmore and Olaf Sporns. The economy of brain network organization. *Nature Reviews Neuroscience*, 13(5):336–349, 2012.

[4] Alex Fornito, Andrew Zalesky, and Michael Breakspear. Graph analysis of the human connectome: promise, progress, and pitfalls. *Neuroimage*, 80:426–444, 2013.

[5] Armin Fuchs. Beamforming and its applications to brain connectivity. In *Handbook of Brain Connectivity*, pages 357–378. Springer, 2007.

[6] Michael T Gastner and Géza Ódor. The topology of large open connectome networks for the human brain. *Scientific reports*, 6, 2016.

[7] Wassim M Haddad, Qing Hui, and James M Bailey. Human brain networks: spiking neuron models, multistability, synchronization, thermodynamics, maximum entropy production, and anesthetic cascade mechanisms. *Entropy*, 16(7):3939–4003, 2014.

[8] Mahdi Jalili. Functional brain networks: does the choice of dependency estimator and binarization method matter? *Scientific Reports*, 6, 2016.

[9] Mahdi Jalili and Maria G Knyazeva. Constructing brain functional networks from eeg: partial and unpartial correlations. *Journal of integrative neuroscience*, 10(02):213–232, 2011.

[10] Christof Koch, Marcello Massimini, Melanie Boly, and Giulio Tononi. Neural correlates of consciousness: progress and problems. *Nature Reviews Neuroscience*, 17(5):307–321, 2016.

[11] Levin Kuhlmann, Brett L Foster, and David TJ Liley. Modulation of functional eeg networks by the nmda antagonist nitrous oxide. *PloS one*, 8(2):e56434, 2013.

[12] Heonsoo Lee, George A Mashour, Gyu-Jeong Noh, Seunghwan Kim, and UnCheol Lee. Reconfiguration of network hub structure after propofol-induced unconsciousness. *The Journal of the American Society of Anesthesiologists*, 119(6):1347–1359, 2013.

[13] David JC MacKay. *Information theory, inference and learning algorithms*. Cambridge university press, 2003.

[14] James M Shine, Patrick G Bissett, Peter T Bell, Oluwasanmi Koyejo, Joshua H Balsters, Krzysztof J Gorgolewski, Craig A Moodie, and Russell A Poldrack. The dynamics of functional brain networks: Integrated network states during cognitive task performance. *Neuron*, 92(2):544–554, 2016.

[15] James M Shine, Oluwasanmi Koyejo, Peter T Bell, Krzysztof J Gorgolewski, Moran Gilat, and Russell A Poldrack. Estimation of dynamic functional connectivity using multiplication of temporal derivatives. *NeuroImage*, 122:399–407, 2015.

[16] Matthew Lawrence Stanley, Malaak Nasser Moussa, Brielle Paolini, Robert Gray Lyday, Jonathan H Burdette, and Paul J Laurienti. Defining nodes in complex brain networks. *Frontiers in computational neuroscience*, 7:169, 2013.

[17] Ulrike Von Luxburg. A tutorial on spectral clustering. max planck institute for biological cybernetics. *Tech Rep*, 2006.

[18] Andrew Zalesky, Alex Fornito, and Ed Bullmore. On the use of correlation as a measure of network connectivity. *Neuroimage*, 60(4):2096–2106, 2012.