Neural Synchrony, Causation and Consciousness

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NEURAL SYNCHRONIZATION AND CONSCIOUSNESS

Introduction

The empirical evidence related to brain function and consciousness, and a number of interrelations of this link have been put forward. This poster presents some of the neural modelling and analysis work that we have been carrying out at the Computational Neurodynamics Group in the Department of Computing, Imperial College, to understand the functional aspects of neural synchronisation and its connection with consciousness.

Analysis for Neural Synchronization

- Convert spike trains into continuous time varying signal.
- Identify high power frequencies.
- Band pass filter signal at high power frequencies.
- Use Hilbert transform to identify phase of signal.
- Identify clusters of neurons with close phase relationships.
- Neurons or neuron groups that are in phase (possibly with delay compensation) could be judged to be the conscious parts of the system.
- Contents of consciousness could be identified by looking for correlated representations within synchronous groups whose firing co-varies with states of the world.

- Discard high levels of synchronization found in epilepsy or deep sleep, possibly using coalition entropy (Shanahan 2010a).

Possible Interpretations of the Link Between Neural Synchronization and Consciousness

Neural synchronization facilitates information integration
- Neuron groups have causally active paths between them. Information integration is linked to synchronised, researched neuronal populations.

Neural synchronization implements a mechanism necessary for consciousness
- Working memory, a global workspace and binding could all be necessary for consciousness.

- Von der Malsburg (1998) claims that neural synchronization could be a binding mechanism; Shanahan (2010b) suggests that neural synchronization could implement a global workspace. A system would remain conscious if a different mechanism was used to implement these functions.

Key Challenges

- Fundamental link between synchronised biological neurons and consciousness.

Some metaphysical about synchronised biological neurons could lead to the generation of consciousness. The electromagnetic theory of consciousness (Ma/Fadden 2002, Posdret 2011) would be one example of this type of metaphysical link.

Current Research

Establishing Communication between Neuronal Populations through Competitive Entrainment

While the biophysical mechanisms underlying neuronal oscillation are well studied, the phase dynamics of connected populations of oscillating neurons are not well understood. To explore this process we have developed a computational model of competitive selection between population-encoded stimuli stimulated by phase coherent oscillation. Recurrent synaptic connections between locally connected network of excitatory and inhibitory neurons result in gamma-band oscillation (Pyramidal-integrate-and-fire Network Gamma) and competitive selection of single stimuli (NeMo oscillator). The interaction of the selected stimulus between model regions arises through a coherent phase relationship between stimulating neurons and the entrained receiving neurons, demonstrating a hypothesis known as Communication through Coherence. Through repeated simulation with varying synaptic parameters we identify a competitive neural network driven by the parameter strength of the excitatory inhibitory neuron synaptic loop, where inhibition-induced oscillations result in entrainment of target neurons and the competitive selection of stimuli between connected regions. Within the optimal region we find that competition between stimuli of equal coherence results in model output that alternates between representation of all stimuli, in a manner resembling well-known biological phenomena resulting from competitive stimulus selection such as binaural rivalry. Results were repeated with both Quadratic integrate-and-fire and Hodgkin-Huxley neuron models.

NeMo Network Simulator

Nado is a high-performance network simulator running on off-the-shelf many-core graphics processing units (GPU).
- Simulates leaky integrate spiking neurons or delay-coupled Kuramoto oscillators.
- Supports real-time simulation of ~100,000 realistically connected neurons on a single GPU.
- Can be used for the study of neural dynamics and modelling of neural correlates of consciousness (Figure 5).
- To form a library with APIs (including Python, Matlab, and C).

Complex Oscillations in the Global Workspace

Pyramidal inter-neuronal gamma (PING) oscillations emerge in a population of excitatory and inhibitory neurons. Excitatory neurons drive the entire network whilst the inhibitory neurons only fire in response to providing windows for synchrony. Faster gamma (30-100 Hz) and slower beta (10-30 Hz) rhythms are observed in the cortex and the hippocampus. These rhythms can provide a framework for other faster oscillations to operate such that fast oscillations communicate content while slow oscillations mediate interhemispheric connectivity (Vogt & Carl, 2015). There is a possibility that oscillatory coupling between different brain regions can provide a more complex oscillatory patterns which may be independent from each other and that propagating oscillations via a single PING type population will only provide one frequency of oscillation because there is an inhibitory mechanism with one temporal element. To produce more complex oscillatory patterns therefore requires several oscillating modules working in unison. The consciousness across hypothesis poses the existence of a global workspace in which information becomes available via synchronised activity within often distant neuronal modules (Dehaene & Naccache, 2001).

As one can imagine networks of different oscillators increases the complexity of analysing systems dynamically. In order to understand the issues better some have simplified such systems by using Kuramoto oscillators in place of each oscillatory neural group (Cabral et al., 2011). Kuramoto (1984) found that simple oscillators become fully synchronised when the coupling strength was above a certain limit. However, Anstis and Cymbal (2002) report that even at the global network level using effective long-distance synchronisation between structures that are critical in processing awareness are characteristic in cases of loss of consciousness. Of more interest is metastability and networks with metastable states in the set of well known dynamical systems. The model is a rich field of study to see if metastable oscillating systems can provide a framework for understanding consciousness. What are the conditions necessary for the existence of a metastable state in a symmetric network? Shanahan (2014) explores such a system of Kuramoto oscillators in a small world connectivity architecture with independent frequencies (Hagmann et al., 2008). Other work by Gillett et al. (2012) studied the properties of a system of coupled Kuramoto oscillators with plasticity the connectivity. They found that the evolution of connectivity plasticity gave rise to the coexistence of multiple clusters of different sizes and frequencies, which they term metastability.

The question arises as to how the oscillators models approximately real brain networks and even artificial spiking neural networks. In order to investigate this subject we will explore oscillating module with the more basic artificial spiking neural network models and varying connective and other parameters to quantify the conditions under which they are stable. The project will provide a descriptive analysis of both these conditions for three types of intrinsic response types: symphony, mutability, and chimera states, The work ventures into understanding the mechanics of information through coherence that extends to the creation of coalition of neural modules that ultimately underlines the architecture of a global workspace.

References

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