MSc in Computational Cognitive Neuroscience

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Investigating the emergence of artificial free will in a brain-constrained spiking neural model using information decomposition.

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Overview and Aims

The question that this project aims to answer is whether the spontaneous and seemingly unpredictable ignition of cell assembly (CA) circuits in a biologically constrained model of the cortex constitutes an emergent phenomenon of the system. Previously these models (Garagnani 2013) have provided a cortical-level explanation for the emergence of “free”, endogenous, simple action decisions, such as a button press. This project will investigate this behaviour from an information theoretic perspective and attempt to quantify the level and type of emergence present.

Voluntary Actions and Decision Making

Decision making is a key component of cognition. We are often prompted to make decisions when presented with stimuli. Here we are focusing on voluntary decisions driven by the baseline firing of neurons in the absence of a specific stimulus. The accumulation of this activity causes CA ignition. Given the spontaneous nature of voluntary decision making it is hypothesized that they are an emergent property of brain function.

Methods

Computational modelling is the primary mode of investigation for this project. Building on the work of Garagnani 2013 The spontaneous ignition of cell assemblies must first be replicated in the extended spiking model from Garagnani et al 2017. Data can then be collected from the spontaneously igniting cell assembly circuits.

The measures of emergence are obtained using the techniques presented in Rosas et al 2020. The approximation technique, the “Practical Criteria”, will be used to collect initial results. Following this an exact information decomposition such as partial or integrated information decomposition (PID or ΦID) can be applied to the data. To analyse the significance of our results we will compare the collected data to a control group of randomly selected neurons in the population. Surrogate methods will also be applied to the collected data for further analysis and reducing bias.

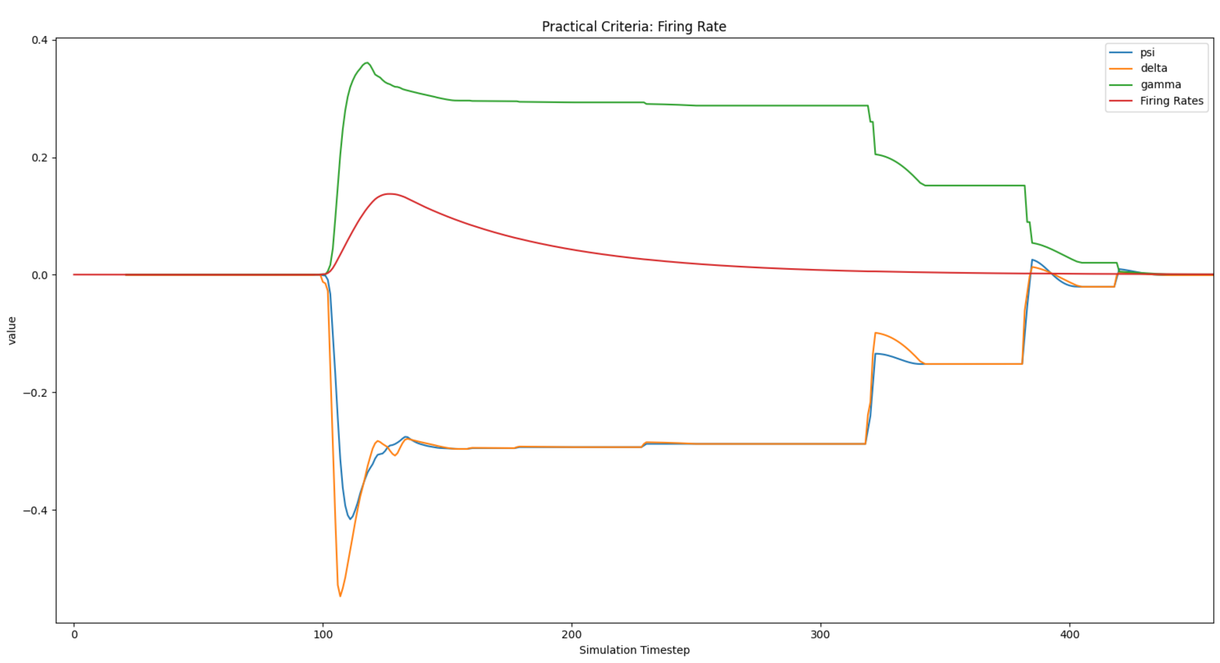

Figure 2: Emergence (psi), downward causation (delta) and causal decoupling (gamma) measured during the ignition of a single CA (estimated firing rates) using the Practical Criteria from Rosas et al 2020.

What is Emergence?

In this study emergence is considered as a property of physical systems that are capable of being more than the sum of their parts. In the brain this can mean that cortical function can be produced without the need for it being a priori hard wired into the system. Information theory has been used to detect and quantify emergence in complex systems. Here we apply these techniques to a model of voluntary action decisions.

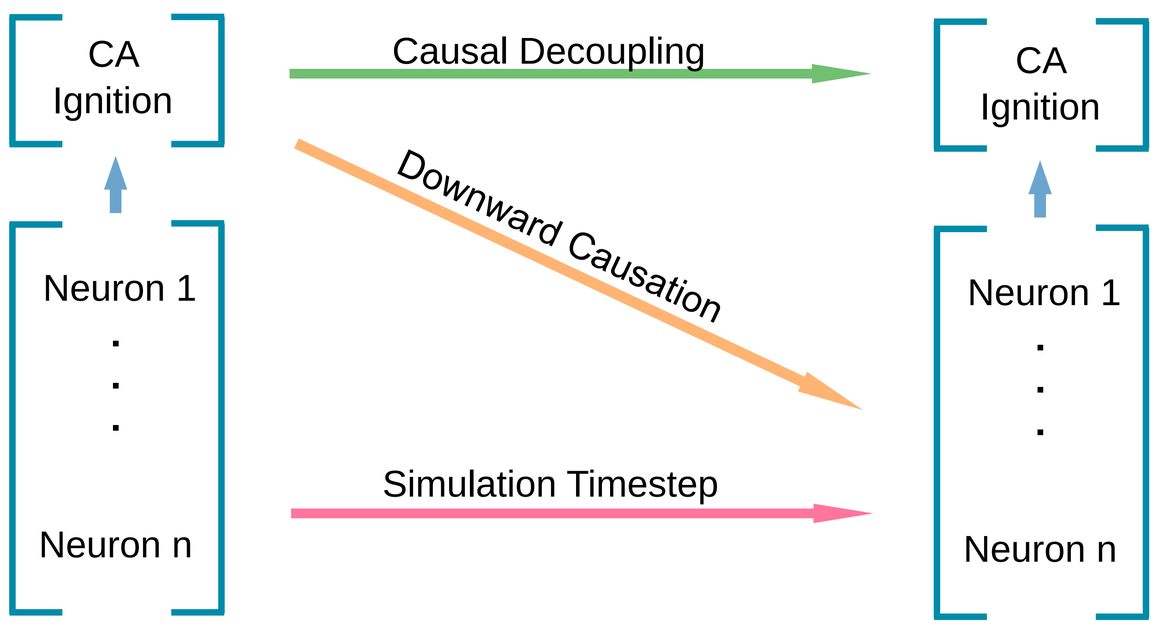

Figure 1: Causal decoupling shows how an emergent feature influencing itself without interaction with the micro elements. Downward causation shows the emergent property influencing micro elements but not itself.

Information Decomposition

Information decomposition takes Shannon information, specifically the measure of mutual information, and decomposes it into Redundant, unique and synergistic components. Synergistic information forms the basis of information theoretic measures of emergence as it captures the “extra” information produced by the interaction of a system that cannot be reduced to, or predicted by, any one of its parts.

Initial Findings and Summary

The figure 2 shows a typical example of the information dynamics associated with the ignition of a single CA (in this case 151 individual neurons). This behaviour was consistently observed in over 20 trails across different CAs and in additional trials with differing ignition conditions. These results indicate that an increase in information dynamics is associated with CA ignition and throughout the CA activation lifecycle. However, an exact information decomposition would be needed to confirm the specific type and levels of emergence. These initial findings would seem to suggest that causal decoupling i.e., a CAs ability to predict its own activity at subsequent timesteps is likely present and strongest upon ignition, fading over time with declining CA activity. In summary these findings appear to provide evidence in support of the hypothesis that CA activation, associated with voluntary action decisions, is an emergent phenomena.

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References

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