Imperial College London

A Cognitive System with a Neurally-Implemented Global Workspace

David Gamez, Zafeirios Fountas, Murray Shanahan and Andreas Fidjeland
Department of Computing, Imperial College London, SW7 2AZ, UK.

Introduction

Global workspace theory is a well established theory about conscious cognition in the brain that explains how a serial procession of conscious states can be produced by interactions between multiple parallel processes (see Figure 1). Our NeuroBot system implements the global workspace architecture using spiking neurons and controls an avatar in the Unreal Tournament 2004 computer game (UT2004). The human-like behaviour of NeuroBot within this environment was demonstrated in the 2011 Botprize competition (www.botprize.org), in which NeuroBot came a close second.

This poster briefly summarises the NeuroBot system and explains how an analysis based on graph theory was used to measure the structural properties of the network and identify its connective core.

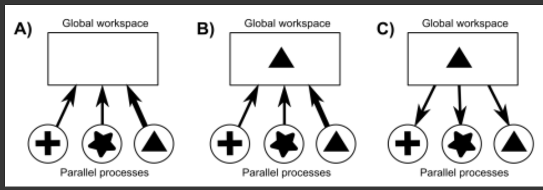


FIGURE 1. Generic operation of the global workspace architecture. A) Three parallel processes compete to place their information in the global workspace; B) The process on the right wins and its information is copied into the global workspace; C) Information in the global workspace is broadcast back to the parallel processes and the cycle of competition and broadcast begins again.

Module	Input	Controls
Moving	-	Moving desire
Navigator	Moving desire, range finder	Motion direction
Exploration	Range finder, health level	View direction
Firing	Enemy direction, enemy proximity, health level	Firing desire
Jumping	Moving desire, velocity, enemy proximity	Jumping desire
Chasing	Enemy direction, enemy proximity, health level	View direction, looking at an enemy desire
Fleeing	Enemy direction, enemy proximity, health level	Motion direction, fleeing desire
Recuperation	Health vial direction, health vial proximity, health level	View direction, Looking at a health vial desire
Looking Item	Item direction, item proximity	Look at an item desire, view direction
U-turn	Moving desire, motion direction, velocity, range finder	Motion direction

TABLE 1. Behaviour modules

NeuroBot (http://tinyurl.com/6puskpu)

The NeuroBot system is based around a modular spiking neural network with a global workspace architecture. This network contains approximately 20,000 neurons and it is structured as shown in Figure 2.

The **workspace modules** are 4 identical layers of neurons linked with topographic excitatory connections and diffuse inhibitory connections. These neurons operate as working memory that sustains the current information while different modules compete to broadcast their information. The workspace modules contain areas representing different types of globally broadcast information, such as the view direction or level of health.

The **sensory modules** are injected with spike encoded information received from the UT2004 environment (see Figure 3). NeuroBot interacts with the environment by decoding spiking activity in the **motor modules.**

The **behaviour modules** (see Table 1) are responsible for specific tasks corresponding to simple behaviours. These modules receive information from the workspace and compete to broadcast their information. These modules can also cooperate, so that a coalition of modules gains access together. Behaviour modules are coordinated by the **action selection module**, which prevents incompatible behaviours from being activated simultaneously.

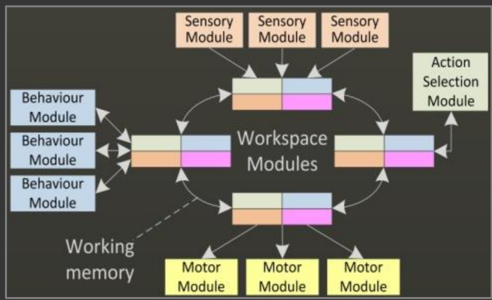


FIGURE 2. NeuroBot architecture

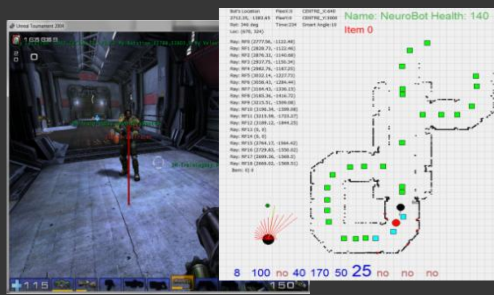


FIGURE 3. Left: UT2004 environment; Right: data available from this environment.

Structural Connectivity Analysis

A number of graph theory analyses were applied to the network to measure its structural connectivity properties. The results, given in figures 4-6, indicate that the excitatory workspace nodes W1-4 formed the network's core and W3 and W4 made the most important contribution to its information routing.

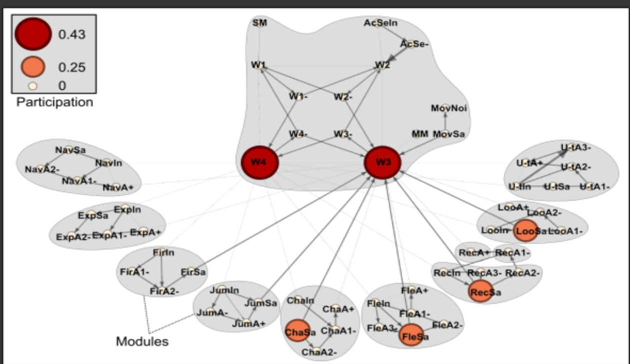


FIGURE 4. A **modularity** algorithm breaks the network down into non-overlapping groups of nodes, maximizing the number of within group edges and minimizing the number of between group edges. The grey areas in the figure show the 14 modules that were identified.

Participation expresses the distribution of intra- versus inter-module connections. The results indicate that two of the excitatory global workspace nodes, W3 and W4, played a key role in inter-module connectivity, with some of the salience nodes in the behaviour modules playing a subsidiary role.

FIGURE 5 (RIGHT). **K-core decomposition** successively removes nodes with a degree less than k until no nodes are left. The core number is the largest k such that the node is still contained in the k-core. The results of our analysis show that the excitatory workspace nodes, W1, W2, W3 and W4 form the network core, which is likely to play a key role in the information routing.

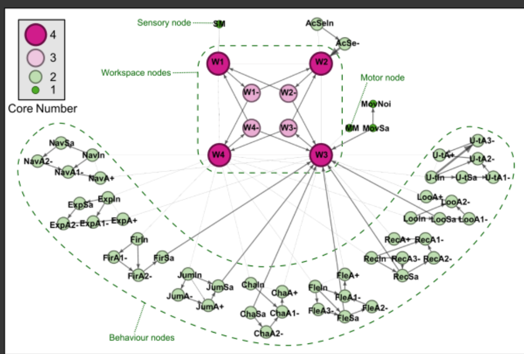
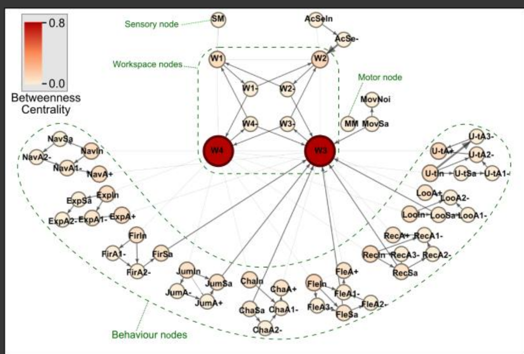


FIGURE 6 (RIGHT). **Betweenness centrality** measures the proportion of shortest paths between vertices that pass through a particular node. This provides an indication of the relative importance of the node in the connectivity of the network. The results show that the excitatory global workspace nodes W3 and W4 had the highest betweenness centrality of ~0.8, with the other nodes having ~0.1 or less.



Discussion and Future Work

This work has shown that a global workspace constructed out of spiking neurons can be used to control an avatar in real time in a human-like manner. The structural connectivity analysis indicated that two of the excitatory global workspace nodes formed the structural core of the network with the other workspace nodes playing a subsidiary role. In future work we are planning to measure how the effective connectivity between the nodes changes over time.

Acknowledgements

This work was supported by EPSRC grant EP/F033516/1.