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RESEARCH ARTICLE

A machine consciousness approach to urban traffic control

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Abstract
In this work, we present a distributed cognitive architecture used to control the traffic in an urban network. This architecture relies on a machine consciousness approach – Global Workspace Theory – in order to use competition and broadcast, allowing a group of local traffic controllers to interact, resulting in a better group performance. The main idea is that the local controllers usually perform a purely reactive behavior, defining the times of red and green lights, according just to local information. These local controllers compete in order to define which of them is experiencing the most critical traffic situation. The controller in the worst condition gains access to the global workspace, further broadcasting its condition (and its location) to all other controllers, asking for their help in dealing with its situation. This call from the controller accessing the global workspace will cause an interference in the reactive local behavior, for those local controllers with some chance in helping the controller in a critical condition, by containing traffic in its direction. This group behavior, coordinated by the global workspace strategy, turns the once reactive behavior into a kind of deliberative one. We show that this strategy is capable of improving the overall mean travel time of vehicles flowing through the urban network. A consistent gain in performance with the ''Artificial Consciousness'' traffic signal controller during all simulation time, throughout different simulated scenarios, could be observed, ranging from around 13.8% to more than 21%.
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Introduction

Traffic is one of the biggest problems faced by many big cities. One approach to reduce this problem is the use of adaptive traffic light controllers, able to change its control policy based on local information. Even in the case when they are not able to completely solve traffic problems, they produce significant improvements without the need to change current infrastructure or transportation models.

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In this scenario, the control and optimization of traffic lights phases is a key topic in improving cities traffic conditions (Brockfeld, Barlovic, Schadschneider, & Schreckenberg, 2001; Sánchez-Medina, Galán-Moreno, & Rubio-Royo, 2010; Srinivasan, Choy, & Cheu, 2006). For large urban networks, though, there is a prohibitive number of variables, states, stochastic aspects, uncertainty, interactions between subsystems, mutually exclusive goals, and other issues (Guberinic, Senborn, & Lazic, 2008), which make scenarios like these nearly impossible to be solved with conventional strategies.

Some approaches consider the problem only locally, restricted only to a small number of traffic lights (Sik, Soo, Kwang, & Kug, 1999). However, when dealing with the whole urban network, because of the non linear and stochastic events which happen in the network and their inter-dependencies, the actual state of traffic becomes hard to assess and the effects of changes in traffic control becomes almost impossible to forecast (Srinivasan et al., 2006). Recent works investigated different approaches to this problem, such as dynamic programming (Heung, Ho, & Fung, 2005; Heydecker, Cai, & Wong,2007), neuro-fuzzy networks (Choy, Srinivasan, & Cheu, 2003) and reinforcement learning (Cai, Wong, & Heydecker, 2009). Box and Waterson (2013) developed one traffic light controller which learns strategies based on previous experience. They used human experts to control a single microscopic traffic simulation of an area in Southampton's urban road network. The researchers used the experts' decisions to train a neural network, which was later used to control the simulation and achieved better results than earlier applied algorithms and benchmarks.

This paper is organized as follows. In Section ''Background'' we include some background about Global Workspace Theory, and the CST — the Cognitive System Toolkit — which is being developed by our research group, and is used as the main basis for the construction of the cognitive architecture which will be controlling our traffic lights. In Section ''Materials and method'' we present the materials and methods for our experiments, describing the traffic simulation tool we used and some details about how it models urban traffic networks. In this section, we also start the description of the cognitive architecture controlling the traffic lights by using Global Workspace Theory. In Section ''Results'', we present the main results we obtained with our simulations, and in Section ''Discussion'' we provide a discussion for these results and the main conclusions.

Background

Global Workspace Theory

Global Workspace Theory (GWT) (Baars, 1988) is a cognitive theory which tries to explain the phenomena of consciousness in the human brain, and is largely inspired by the ''blackboard model'' from the beginning of artificial intelligence (Nii, 1986). Due to its computational origins, it is, among other consciousness theories, one which is particularly interesting for deriving computational models, being very popular in the field of ''machine consciousness''. GWT suggests that only one integrated sensory content can be dominant in the brain in a given moment. Potentially conscious content compete for access to the limited capacity of this workspace. This dominant content is then broadcasted to other regions of the brain, in a nervous system seen as a set of massive distributed small networks with specialized purpose. In such a system, coordination, control and resolution of new problems take place with the exchange of central information. This theory tries to conciliate the limited capacity of conscious content with the vast repertoire of long term memories. It states that the limited capacity of conscious content brings advantages to animal survival, because it helps the animal to focus in what is most important in a given critical situation. The concept of a dynamic core provides a mechanism for events in the Global Workspace, as it projects brain signals in the cortex in a reentrant manner (Edelman, Gally, & Baars, 2011).

In vertebrate mammals consciousness is a dynamic, integrated, multimodal mental process (Fabbro, Aglioti, Bergamasco, Clarici, & Panksepp, 2015). The scientific hypothesis for neural correlates sufficient for this process is that they were naturally selected during animal evolution because they permitted animals to plan for future events and deal with unexpected situations they had never experienced before, in a complex and ever changing environment (Baars & Franklin, 2009; Crick & Koch, 2003; Edelman et al., 2011). The main advantages brought by such a mechanism are twofold. First, there is an executive summary of perceptions, generating a unique and integrated content from all perceptual information at a given moment. The most relevant information for the animal survival becomes conscious, enabling it to better deal with unexpected and novel situations that differ from an original plan. Second, there is automation and deautomation of behaviours. In automation, as novel situations become more and more frequent, conscious content is stored in long term memory, becoming accessible for planning and making predictions. Once automated, action selection can happen without conscious interference. However, if an automated behaviour produces unexpected results, consciousness regains control of action selection and information processing, which might result in the deautomatization of this previous behavior. This mechanism makes animal behavior extremely adaptive to changing environments.

Traffic lights control in an urban network can be seen as a set of subsystems operating in parallel, where each subsystem is a single junction composed of n traffic lights influencing and being influenced by its neighbor subsystems. In most cases, each subsystem is operated in isolation. However, for the network to function properly, it would be interesting to have these subsystems interacting in a way that critical situations might be avoided, such as in deadlocks and big traffic jams. This scenario is similar to what is found in the animal body, where different isolated subsystems are coordinated by an executive control nervous system. In this central executive mechanism, consciousness can be viewed as a supervisor process that takes care of many semi-autonomous subsystems.

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