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# Adaptive traffic signal control based on bio-neural network

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**Abstract**

Urban traffic management is one of the major concerns for big cities around the world, due to its negative impacts on society. Several approaches of traffic signal control based on artificial intelligence techniques or on control theory were proposed as alternatives to mitigate this problem. However, it is a challenge to reach a good solution, as the urban traffic is a complex and dynamic ecosystem. On this scenario, this paper proposes an adaptive biologically-inspired neural network that receives the system state and is able to change the behavior of the control scheme as well as the order of semaphore phases, instead of prefixed cycle-based ones. Proposed adaptive control was evaluated on a single intersection scenario. Despite analyzing the control of a single intersection, the model proposed is modular, allowing the control of multiple intersections. The analyses conducted herein showed that the model is robust to different initial conditions and has fast adaptation between system equilibrium states. Simulations with SUMO showed a better performance than a cycle-based traffic responsive control method regarding reactivity and capacity tests, in which the relevance of the constant monitoring and acting became evident.


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*Keywords:* Biologically-inspired neural network, complex dynamic systems, traffic signal control.

## 1. Introduction

The increase of traffic volume causes even more traffic jam due to the slow-paced and, the non-existent improvements in the urban traffic infrastructure. Traffic jam is a direct result of higher vehicle traffic over the city capacity and also unpredictive events like traffic accidents and climate effects. Healey and Picard[1] analyzed the

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impacts of urban traffic on human health, showing increased stress in situations of traffic jam. Furthermore, Grillo and Laperrouze[2] discussed the effects of traffic jam on the Gross Domestic Product (GDP) and on the environment, attributing its main causes to the cost of fuel, the opportunity cost of the time citizens spend in traffic, and CO2 emission. Traffic signal control is a cost-efficient alternative to improve the system efficiency, i.e., to increase the city capacity with the same urban infrastructure. Optimized vehicle flows reduce vehicle stops at traffic signals as well as their average travel times, preventing traffic jams. Different approaches have been proposed to control the traffic signals of urban networks, like ones based on the optimal control theory and on artificial intelligence techniques. However, it is challenging to find out a good solution for traffic signal control, because of the intrinsic complexity of the system. The urban traffic is dynamic and has uncertain nature, interdependent subsystems, nonlinearities, and great amount of variables, such as vehicle flows, vehicle queues and semaphore phase times.

On this context, Castro[3] investigated a model for traffic signal control based on the positive results of biologically-inspired neural networks for the control of complex systems, presenting its mathematical formalism, analyzing its behavior as well as the complex dynamic system, and evaluating its control performance. In contrast to other approaches, the proposed model does not have a prefixed order of semaphore phases, and thus is able to change control behavior in accordance to urban traffic state.

## 2. Related works

Initial solutions for traffic signal control were based on optimization methods that uses fixed green times for semaphores in order to reduce the average travel time of vehicles. As the urban traffic is a dynamic environment, adaptive approaches were then proposed to further decrease average travel time, readjusting semaphore green times during their operation. These control methods are also called vehicle actuated or traffic responsive, among which the most applied are LHOVRA[4] and others. However, they have a centralized structure, having restricted control efficiencies due to the long time required to exchange information of all intersections and to make a global decision.

Timotheou[5] et al. adopted linearized macroscopic models of the urban traffic as a basis for model predictive control (MPC) methods that focused on the distribution of the prediction and control capacities. Zhao[6] et al. stated that the use of macroscopic models to simplify urban traffic control limits its control efficiency, disregarding the complete dynamics of vehicles and semaphores. In addition, Gokulan and Srinivasan[7] claim that macroscopic urban traffic models that consider system uncertainties or try to predict its behavior are inaccurate and computational intensive. Regarding artificial intelligence techniques, Srinivasan[8] et al. proposed an artificial neural network for traffic signal control. The main advantage of control methods based on learning is that they do not require a model of the system. However, according to Gokulan and Srinivasan[7] these methods demand an infeasible amount of data and training time to adequately represent the behavior of stochastic systems with many variables, such as the urban traffic. A common disadvantage of the aforementioned control methods is that they are cycle-based, i.e., they only adjust semaphore green times after each cycle, which limits the system reactivity and, thus, its efficiency. Hamilton[9] et al. proposed a more flexible approach, which is based on a linear model but does not establish a fixed phase order or cycle length and is able to change semaphore phases at any moment, obtaining an increase in control performance in comparison to a cycle-based control method.

On the other hand, biologically-inspired neural networks differ from artificial neural networks as it explores more biological characteristics of real neurons in order to improve the overall dynamic behavior of the model, whereas one that focuses on the learning aspect of neural networks. Thereby, biologically-inspired neural networks do not usually have a training stage, choosing instead their synaptic weights to achieve a desired behavior. A variety of biologically-inspired neural networks were proposed for controlling dynamic systems, mainly in robotics. Robot control is similar to the control of complex dynamic systems, such as the urban traffic, because of the number of variables, nonlinearities, and environment uncertainties involved. Besides the unique structure of each neural network, these works adopt different types of neuron models, synapses and long and short term plasticity. Nichols[10] et al. proposed a pulsating neural network for robot control and adopted the leaky-integrator neuron model due to its low computational cost. Castro[3] et al. proposed a biologically-inspired neural network for traffic signal control and validated it with comparative simulations. The proposed neural network adopts the same neuron model adopted by Yang[10] et al. which represents the behavior of real neurons with low computational cost and is conventionally present in artificial neural networks. The proposed model has an adaptation mechanism, or short term plasticity. The proposed neural network has excitatory and inhibitory neurons and is more realistic concerning biological neurons.