Basal Ganglia Models for Autonomous Behavior Learning

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Abstract. We propose two basal ganglia (BG) models for autonomous behavior learning: the BG system model and the BG spiking neural network model. These models were developed on the basis of reinforcement learning (RL) theories and neuroscience principals of behavioral learning. The BG system model focuses on problems with RL input selection and reward setting. This model assumes that parallel BG modules receive a variety of inputs. We also propose an automatic setting method of internal reward for this model. The BG spiking neural network model focuses on problems with biological neural network architecture, ambiguous inputs and the mechanism of timing. This model accounts for the neurophysiological characteristics of neurons and differential functions of the direct and indirect pathways. We demonstrate that the BG system model achieves goals in fewer trials by learning the internal state representation, whereas the BG spiking neural network model has the capacity for probabilistic selection of action. Our results suggest that these two models are a step toward developing an autonomous learning system.

Keywords: System architecture, basal ganglia, reinforcement learning, modular learning system, reward, spiking neuron, input space selection, execution timing.

1 Introduction

The objective of our research is to develop an autonomous behavior learning system for machines. Flexible operation of the output of a system is essential for future intelligent machines to work and interact with people under real world situations. The most advanced flexible operation in animal behavior is autonomous selection of behaviors in a dynamically changing environment. In the future, people will demand that the machine selects the best option by assessing the situation. However, the current level of machine intelligence lags far behind that of animals.

A prominent feature in animal intelligence is the ability to learn to select a relevant behavior autonomously, whereas current machine learning systems typically require supervisory support from a human in designing the system, selecting the training data, choosing the algorithm, setting the parameters and determining the goal of learning. To explore the secrets of animal learning systems, we have investigated the learning mechanism underlying behavior selection in the animal brain, in the basal ganglia (BG) in particular. We have focused on the BG because of its functional and evolutional importance.
The BG function in learning and selection of behaviors. The association of cognitive and affective components can be observed in primate BG disorders, including Parkinson’s disease, Huntington’s chorea, schizophrenia, attention deficit disorder, Tourette’s syndrome and various addictive behaviors. Although there are other brain regions that perform learning and selection of behaviors, the BG are phylogenetically old. The basic neural circuit architecture of the BG begins phylogenetically at the level of fish and it persists up to the level of human [1]. This not only proves its evolutionary importance but also provides us with a new methodology for developing a computational model: investigation of several evolutionary levels of the circuits in animals. The primate brain is a very complex system in which many part of the brain interact with one another. However, it is based on the brain system of reptiles and rodents. Thus, we can extract the essence of the animal learning system by selecting and combining evidence from animal brains ranging from reptile to human. For this reason, we think the BG provide stronger support for exploration of animal learning systems than other parts of the brain.

Animal learning can be seen as the process through which animals are able to use past and current events/states to predict the future state. In classical Pavlovian conditioning, animals learn to predict what outcomes are contingent on which events/states. In instrumental conditioning, animals learn to predict the consequences of their actions and use this prediction to maximize the likelihood of rewards, minimize the occurrence of punishment, or achieve goals. Barto’s [2] reinforcement learning (RL) research led to the proposal of a temporal difference (TD) learning model to explain both Pavlovian and instrumental conditioning. The recently identified phasic activity of dopamine neurons in the BG [3][4][5][6][7][8] enhances the link between RL and the BG, has contributed to the evolution of RL models, and has opened new questions [9][10].

In this chapter, we introduce our BG model of an autonomous behavior learning system. We briefly review related studies in RL and BG models in section 2 and then describe our models in section 3. Finally, a discussion regarding open questions is presented in section 4.

2 Related Works

Recent active interaction between machine learning (reinforcement learning, RL) research and neuroscience (basal ganglia, BG) research clarify both consistency and difference between them. In this section, we firstly review the RL research, secondly pick up the findings in neuroscience that relate to the RL, and lastly list up the open problems to develop the autonomous behavior learning system by referring both RL research and neuroscience research.

2.1 Reinforcement Learning Research

Although RL was originally born out of mathematical psychology as just trial-and-error reward learning, current RL research is actively progressing with evidence from the neuroscience field. Current RL models can be divided into two broad classes, model-based and model-free [11].