**Realtime Cerebellum:**

Realtime Simulation of a Realistic Cerebellar Model using a GPU for Real-World Engineering Applications

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**Take-home message**

GPUs accelerate computer simulation of large-scale realistic brain models, and enable realtime sensory information processing and motor control by the models.

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**Abstract**

A graphics processing unit (GPU) has been used in the field of computational neuroscience to scale up models and to make computer simulations faster (sometimes in realtime) [1]. Specifically, realtime computing is a natural demand for sensory information processing and controlling physical objects in realtime. The cerebellum plays an essential role in fast and smooth motor control and on-line motor adaptation [2]. Once we build a cerebellar model running in realtime, the cerebellar model could be used as a neural controller of hardware composed of a number of sensors and actuators such as humanoid robots. We have built a large-scale spiking network model of the cerebellum [3, 4] composed of more than 100,000 neurons acting as a general-purpose supervised learning machine of spatiotemporal information. The previous model, however, runs in about 90 times slower than realtime.

In this study, we re-implemented our previous model on a GPU. We achieved realtime computer simulations of the present model. We also succeeded to control a humanoid robot to hit a ball thrown by a pitching machine through online learning of a proper timing to swing a bat.

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**Materials & Methods**

**Cerebellar model**

Our cerebellar model is composed of 102,400 granule cells, 1,054 Golgi cells, 16 Purkinje cells, 16 basket cells, 1 inferior olive, 1 inferior cerebellar nucleus (not shown). External inputs are fed by mossy fibers to granule cells and the nuclei. Granule cells excite Golgi cells, Purkinje cells and basket cells. Golgi cells and basket cells inhibit granule cells and Purkinje cells, respectively. Purkinje cells inhibit the nuclei. Another external inputs are fed by climbing fibers to Purkinje cells. The final output is given by the nucleus. Granule cell-Purkinje cell synapses undergo plastic change.

Neurons were modeled as conductance-based leaky integrate-and-fire units. The membrane potential \(V(t)\) is calculated by the convolution of a synaptic potential function \(e(t)\) and spikes \(\delta(t)\) exerted by presynaptic neuron. When \(V(t)\) exceeds a threshold, the neuron emits a spike.

**Parallel computing**

- **Parallel state update**
- **Parallel conductance calculation**

Schematics of updating states of neurons in CPU and GPU. In CPU version, for each time step and each neuron, the state is updated sequentially. In GPU version, multiple threads are assigned to neurons, and each thread updates the assigned neuron's state.

Schematics of calculation of conductances in CPU and GPU. In CPU version, a conductance value (Cond) is calculated by summing synaptic weight \(w(i)\) for all presynaptic neurons \(i\). In GPU version, multiple threads are assigned to presynaptic neurons and each thread adds the weight. Threads in the same thread block adds to a variable (Sh) in the shared memory. Atomic operation is used (Atom.). After sync, representative thread for each thread block adds the value of Sh to Cond to obtain the final conductance value.

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**Results**

**Comparison of simulation time**

Exposure time for simulation of 1 s. CPU version spends about 90 s, whereas GPU version less than 1 s, thereby achieving 100 times faster simulation. Also, the GPU version runs in realtime. Y-axis is plotted in log scale.

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**Robot experiments**

- **Overview**
- **Pitching machine**
- **Robot, bat, fence**

Also, experiments have reported that Purkinje cells tend to "pause" around the US onset by learning. Our model reproduced the pause successfully.

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**Experimental setup**

- **Computer spec**
- **Robot setup**

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Supporting information
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