RICC Usage Report for Fiscal Year 2010

Project Title:

Multi-scale neural simulation of visual-oculomotor systems

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Description of the project

1. Background and purpose of the project, relationship of the project with other projects

Our overall goal is a system-scale spiking neuron-level model of the early mammalian visual system. This system comprises the retina, the superior colliculus and the brainstem eye motoneuron systems. In primates it is primarily engaged in generating saccades and fast attention processing.

With a system-scale model that encompasses the entire visual-perception loop, from the retinal input to motoneuron output, we can close the perception action loop. That will enable us to compare model output with that of behaving animal models. It also lets us take whole-system dynamics into account when modeling individual areas; as individual areas never operate in isolation, it is important to consider the behavior of related areas. Such added considerations help us restrict the model design to make it stronger.

Modeling at multiple scales – here, both at system level and neuron level – we can use data from neurophysiology as well as anatomy and behavioral data to restrict our model.

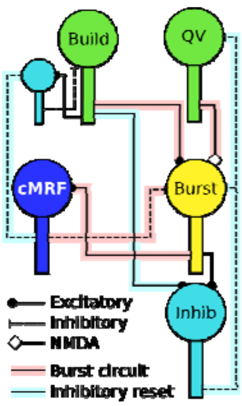
We cooperate with the Laboratory for Neuroinformatics at RIKEN where they are developing a spiking neuron-level model of the retina. Our current work focus on the superior colliculus, the next step in the processing chain; and we have done work on the brainstem horizontal and vertical gaze motoneuron systems at OIST in Okinawa.

2. Specific usage status of the system and calculation method

Usage

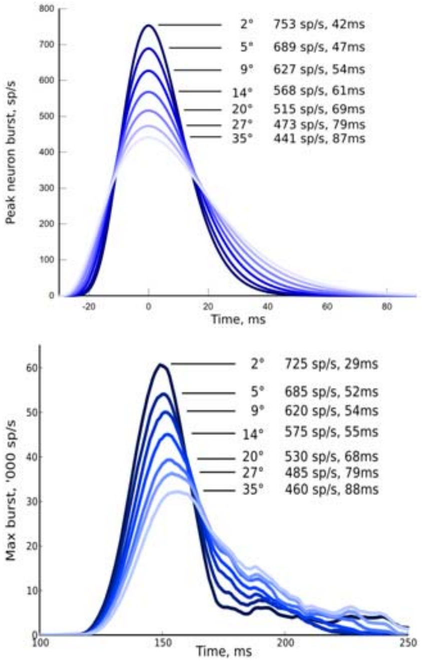
3. Result

We have developed a model of the intermediate superior colliculus. We use a conductance-based leaky-integrate and fire neuron model (by Brette and Gerstner) and have augmented it with a NMDA-receptor synaptic input to generate membrane potential-dependent bursting in accordance with physiological data. The neuron model uses measured superior colliculus neuron parameters mostly from the rat (Saito and Isa; Isa).



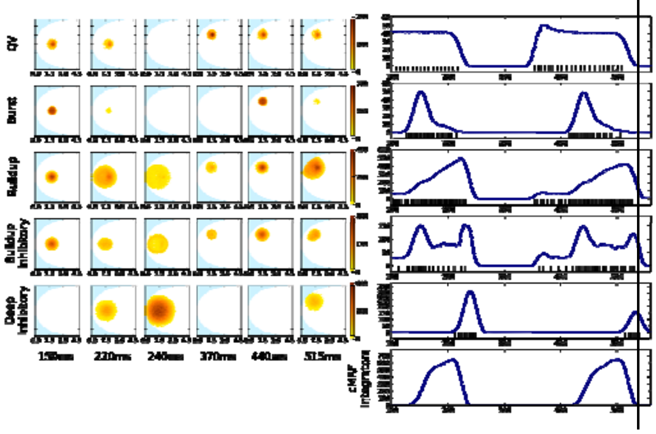
Our model uses on the order of 100k neurons in five major layers connected according to currently known neurophysiology, and augmented by a simple integrator model of the central Mesencephalic Reticular Formation.

The model can generate correct bursting output to the brainstem motor systems to get the correct eye movement profile for different saccade distances – the "main sequence" – and it generates the lower peak speed and longer saccade duration for oblique saccades, needed to generate straight saccades.



Top: Monkey superior colliculus neuron output as function of saccade angle. Parameterized data from Goossens and van Opstal (2008)
Bottom: Output from our model for the same saccade angles. Averages of ten simulations.

Our model is also able to account for the characteristic and significant spread of buildup neuron activity shortly before and during a saccade. There are a number of conflicting theories of the functional significance of this spread (and it may be that the function differ by animal model). We hypothesize that the spreading activation acts as an activity monitor and triggers a reset of the saccadic system once it has finished. In this formulation the direction of the spread is not seen as significant, but only the amount of activity.



Above: system behavior during two consecutive saccades. First target is a 9 degrees horizontal saccade, and the second target is 8 degrees, at 45 degree angle. The burst neuron layer is the primary output of the superior colliculus, generated by the reciprocal inhibition from the cMRF. Buildup neuron layer spreading activation eventually triggers the deep inhibitory neurons that inhibit other areas and resets the system.

4. Conclusion

At this point the model of the intermediate superior colliculus is largely complete. We are able to create the correct system-level behavior using a model built at the spiking neuron level, using neurophysiological data to guide connection patterns and model neuron parameters. We also have a novel interpretation of the hitherto poorly understood phenomenon of buildup neuron spreading activation, and show that it can act as a well-timed shutdown mechanism for saccade burst output generation.

5. Schedule and prospect for the futureThis is described in our new RIKEN Supercomputer System Grant Request Form

The model is not yet complete. The intermediate superior colliculus is well covered, but we have not yet addressed the superficial division, which is responsible for fast, bottom-up saliency estimation and for holding and conditioning the inputs to the intermediate system. We also have not yet implemented the intercollicular connections needed to achieve bi-directional saccades.

Our coming work will focus on completing these areas in order to create a complete action-perception loop. The plan is to connect the aforementioned retinal model, our intermediate and superficial collicular model and a fairly simple motoneuron system model with a humanoid robot at ATR. The robot would act as the physical input-output system for a fully embodied real-time saccade-generation system as described above. We expect two kinds of results from this:

- The full-system approach should guide us to a physiologically reasonable, working superficial collicular model in the same way that this approach is already doing for the intermediate superior colliculus. As the superficial areas are at least as complex as the intermediate ones, we need all the restrctions we can muster in order to narrow down the model. This should help the group doing the retinal model in the same way.
- A real-time embodied perception-action system is at least potentially amenable to directly comparative experiments, where we can give the simulated system and experimental subjects the same test inputs and compare the generated movements in some detail.

6. **If you wish to extend your account, provide usage situation (how far you have achieved, what calculation you have completed and what is yet to be done) and what you will do specifically in the next usage term**

To achieve the planned results, we need to:

- develop a superficial superior colliculus;
- implement intercollicular connections;
- create the correct retino-tectal and tecto-spinal connection patterns, and investigate the need for some form of cerebellar adjustment;
- create the software needed to connect the RICC in Wako with the CB-I robot at ATR.

To run this in anything near real time we need to scale down the collicular model; even then we estimate that we will need upwards of 800 nodes at RICC for the real-time simulations (development, which is not real-time, will of course need much less).

We have already discussed the technical and other issues around using the RICC with representatives, and investigated the requirements for the connection software, and it seems quite doable. We are also already working on the software on the robot side, and again, work is progressing well.

What we will need as far as RICC is concerned is normal Quick Use access in order to develop the remaining parts of the model. The parameter tuning process especially is fairly computationally heavy and we can make good use of the RICC facilities for such simulations,

For most of the model interconnectivity and robot-model connection development the Quick Use resources are also sufficient. The saccade generation system is feed-forward open-loop so we can develop and test off-line as needed. Only when we want to actually run the physical system online will we need additional resources, and we have been assured we can get those resources through the weekend special operations process.

Fiscal Year 2010 List of Publications Resulting from the Use of RICC

[Publication]

[Proceedings, etc.]

[Oral presentation at an international symposium]

Moren, J., Shibata, T., Doya, K. (2010). Toward a spiking neuron model of the oculomotor system. In Doncieux, S.; Girard, B.; Guillot, A.; Hallam, J.; Meyer, J.-A.; Mouret, J.-B. (Eds.), *From Animals To Animats: The 11th International Conference on Simulation of Adaptive Behavior (SAB)*, 25-28 Aug., Paris, France, pp. 104-113.

[Others]

Moren J, Shibata T, Yoshimoto J, Doya K (2011). A spiking-neuron model of superior colliculus reproduces saccade movement profiles through NMDAR-mediated burst activity. 11th Winter Workshop on the Mechanism of Brain and Mind. Rusutsu, Japan, January 11-13, 2011

Moren J, Shibata T, Cassagnes A, Yoshimoto J, Doya K (2010) Modeling saccades through NMDAR-mediated bursting with reciprocal inhibition in the Superior Colliculus. *Neuro 2010*. Kobe, Japan, September 2-4, 2010.