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ARTICLE

Cartoon Network Update: New Features for Exploring of Neural Circuits

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Cartoon Network is an open-source simulator for neural circuits. It allows students to playfully explore the remarkable complexity that emerges from networks of interacting neurons. This brief report describes four new features that have been added to Cartoon Network: 1) the ability to save and load different networks, 2) the addition of bursting neurons, and 3) new accelerometer inputs for the Finch robot. In addition, new data from the National Institute of Teaching Psychology is reported showing that psychology faculty report strong interest in using Cartoon Network as a pedagogical tool. The updated version of Cartoon Network is available at: https://github.com/rcalinjageman/cartoon_network.

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Cartoon Network is a neural network simulator designed for the playful exploration of how neural circuits produce complex outputs and behaviors (Calin-Jageman, 2017). The simulator features a simple user interface that is suitable for young students, but is also complex enough to foster meaningful exploration for undergraduate students. Neurons are represented in a cartoon-like fashion: action potentials are illustrated as an electrical spark traveling along the axon and neurotransmitter is then animated as it is expelled from the neuron, activates neighboring neurons, and is broken down and reabsorbed.

By physically positioning neurons next to each other students can easily build circuits with complex properties, including feed-forward excitation, lateral inhibition, and oscillatory behavior. Basic neural properties can be adjusted to then see how these influence the operation of the network as a whole; editable properties include excitability, amount of transmitter released per action potential, type of transmitter released (glutamate or GABA), and type of neuronal activity (silent, spontaneously active, or bursting).

To make the connection between brain and behavior concrete, Cartoon Network can also be connected to a Finch robot from Birdbrain Technologies (https://www.finchrobot.com). With a Finch connected, sensory neurons can be added that fire based on the inputs active to the robot (light sensors, touch sensors, temperature sensor, accelerometers) and motor neurons can be added that activate the Finch actuators (left and right motors, lights, sound card). Thus, students can literally build the 'brains' for a robot and experiment with how different circuit motifs convey different behavioral repertoires. Cartoon Network is especially useful for posing open-ended challenges to students (e.g., "Can you make a circuit that enables the Finch to follow a light source"); this helps students use their natural creativity to solve authentic challenges and build deep intuitions about the dynamics of neural communications.

During the Summer 2018 Faculty for Undergraduate Neuroscience meeting at Domincian University (http://www.conference.funfaculty.org/) a workshop on Cartoon Network was conducted. Faculty spent about 20 minutes learning the basic functions of the simulator and how to connect a Finch robot. From there, faculty spent time collaboratively working on different challenges (e.g., making an oscillating circuit; making the Finch dance). At the conclusion of the workshop faculty were invited to give feedback on the simulator, both through open-ended comments and by rating its perceived pedagogical value. As reported previously, faculty rated the pedagogical potential of Cartoon Network as strong (Calin-Jageman, 2017). The open-ended feedback, though, was also extensive and helpful. Faculty identified several key features that the simulator lacked but that would be helpful for student use.

Based on feedback during the FUN conference I developed an updated version of Cartoon Network. The new version is available for free download on github, where additional new releases will also be posted: https://github.com/rcalinjageman/cartoon_network. This paper reports on the new features and additional feedback collected from another sample of educators.

This primary new feature in Cartoon Network is the ability to save and then re-load networks. This includes networks that are designed to connect to a Finch robot. The functions are straight-forward: users select "Save Network" from the menu system to save the current network with a user-specified filename; selecting "Load Network" brings up a file-finder to select an existing network file. The file system used is OS-independent, meaning that networks created in one system (e.g., Windows) may be shared with users using a different operating system (e.g., OsX).

The ability to save and load networks means that instructors can build demonstration networks to show in class, students can continue their work across multiple lab sections, and interesting networks can be posted/shared publicly. For example, on the Github site for Cartoon Network I have posted a sample network (tritonia_swim_network.nwk) the loosely recreates the central pattern generator that underlies swimming behavior in *Tritonia diomedia* (Calin-Jageman et al., 2007; Sakurai et al., 2007). The circuit features a spontaneously active excitatory neuron that excites an interneuron that then excites an inhibitory neuron which silences the entire circuit. This simple 3-neuron motif produces oscillatory behavior with almost perfectly alternating behavior between the excitatory and inhibitory neurons. In the *Tritonia* this circuit is activated by contact with a predator; it then drives alternating dorsal and ventral flexion that produces 'swimming' behavior that helps the animal escape from the predator (really, more of a coordinated thrashing). After loading this network, students can connect a Finch robot and set the excitatory and inhibitory neurons to drive the left and right motors, respectively. This produces alternating bursts of left and right spinning, a kind of 'waggle dance' that is highly entertaining. Even better than the entertainment value, students can then explore how the individual neuronal properties relate to the oscillatory behavior (e.g., they can be asked to determine what changes bias left spinning over right spinning).

One drawback of the file system is that it is release-specific, meaning that files made in the current version of Cartoon Network may not be compatible with updated versions (compatibility depends on the extent to which the underlying code for neurons is altered; updates that don't alter the code for the neuron object will not break compatibility).

A second feature added to Cartoon Network is a bursting neuron feature: neurons that endogenously switch between spontaneously activity and silence. This was implemented with a simple spike-counting system; bursting neurons fire 10 spikes and then are silent for the same period of time it took to generate the burst (50% duty cycle). Specifically, the threshold for activity is set as a non-linear function of the recent spike history: the threshold starts out below the resting potential, causing spontaneous activity, but then temporarily rises above rest after a sufficient number of spikes have been fired. Users can set the activity level of a bursting neuron to determine the time it takes for each burst to complete (duty cycle stays at 50%, but rate for each cycle to complete can be altered). Endogenous bursting activity is common in neural circuits (e.g., Selverston and Moulins, 1985). Bursting neurons enable students to generate circuits with periodic outputs and to examine entrainment between different oscillators. In general, students tend to under-appreciate the degree to which neuronal activity is intrinsic and self-organized, so adding this feature provides additional opportunities to help students expand their thinking beyond simple reflex models of the nervous system.

A third change made to Cartoon Network is the introduction of new accelerometer inputs when connected to a Finch robot. Users can now define sensory neurons that fire action potentials based on the degree to which the Finch is tipped forward, backward, to the left, and to the right. This can enable networks that provide proprioceptive feedback to control Finch motor outputs (e.g., to avoid ramps).

Two other minor tweaks have been introduced. First, there was a problem in the first version that prevented those using OS X from successfully connecting a Finch robot. This problem has now been resolved; there is a specific package for Mac users posted to GitHub (cartoon_network_max.zip) that contains the additional files necessary for using the simulator with a Finch. Second, the interface now automatically scales to the screen resolution available on the user's computer.

One of the most useful features of Cartoon Network is that it can serve as the "brains" for a Finch Robot (https://www.finchrobot.com/). Acquiring a set of Finch robots can be expensive. To help with this issue, I have acquired a set of 9 which can be loaned out for the price of shipping. If interested in borrowing a set for a week for a lab activity, please email rcalinjageman@dom.edu. Work is underway to also make this a regular part of the FUN equipment loan program.

In addition to these new features, I have continued to solicit feedback from educators to help improve the pedagogical value of Cartoon Network. To that end I presented the simulator at the 2018 National Institute for the Teaching of Psychology (St. Petersburg, Florida) during the "Demo Demo" session for quick demonstrations of useful classroom tools. Audience members were asked to complete a short online survey to provide their feedback on the simulator. Twenty-four responses were provided. Of these, 17 strongly agreed with the statement "Cartoon Network is a useful tool for helping students understand neural communication" (an additional 6 agreed and 1 strongly disagreed). In addition, 12 strongly agreed with the statement "I am likely to utilize Cartoon Network as a classroom demonstration or student lab" (an additional 10 agreed and 2 somewhat agreed).

With these new features Cartoon Network becomes even more attractive to use for classroom explorations and student activities. The real power of the simulator is that it is simple enough that students can quickly begin 'playing' with neural networks, enabling their natural curiosity to lead them into gaining deep insight into the remarkable complexities of neural networks.

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Thank you to the many users who have provided useful feedback on this simulation.

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