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# Worm uploaded to a computer and trained to balance a pole

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The analogue, natural version of C.elegans. Credit: TU Wien

Is it a computer program or a living being? At TU Wien (Vienna), the boundaries have become blurred. The neural system of a nematode was translated into computer code – and then the virtual worm was taught amazing tricks.

It is not much to look at: the nematode C. elegans is about one millimetre in length and is a very simple organism. But for science, it is extremely interesting. C. elegans is the only living being whose neural system has been analysed completely. It can be drawn as a circuit diagram or reproduced by computer software, so that the neural activity of the worm is simulated by a computer program.

Such an artificial C. elegans has now been trained at TU Wien (Vienna) to perform a remarkable trick: The computer worm has learned to balance a pole at the tip of its tail.

C. elegans has to get by with only 300 neurons. But they are enough to make sure that the worm can find its way, eat bacteria and react to certain external stimuli. It can, for example, react to a touch on its body. A reflexive response is triggered and the worm squirms away.

This behaviour is determined by the worm's nerve cells and the strength of the connections between them. When this simple reflex network is recreated on a computer, the simulated worm reacts in exactly the same way to a virtual stimulation – not because anybody programmed it to do so, but because this kind of behaviour is hard-wired in its neural network.

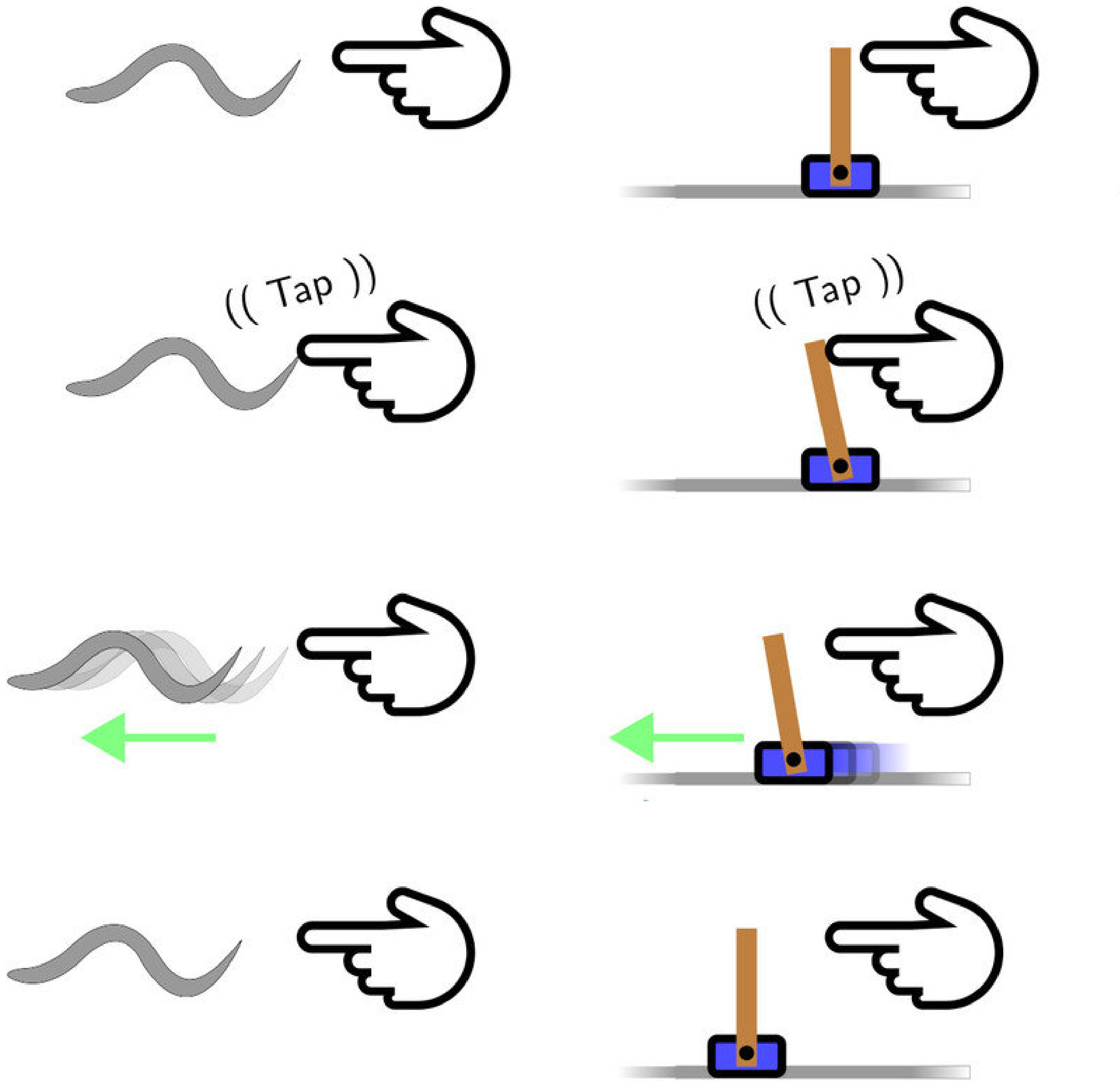
"This reflexive response of such a neural circuit, is very similar to the reaction of a control agent balancing a pole," says Ramin Hasani (Institute of Computer Engineering, TU Wien). This is a typical control problem that can be solved quite well by standard controllers. A pole is fixed on its lower end on a moving object, and it is supposed to stay in a vertical position. Whenever it starts tilting, the lower end has to move slightly to keep the pole from tipping over. Much like the worm has to change its direction whenever it is stimulated by a touch, the pole must be moved whenever it tilts.

Mathias Lechner, Radu Grosu and Ramin Hasani wanted to find out whether the neural system of C. elegans, uploaded to a computer, could solve this problem – without adding any nerve cells, just by tuning the strength of the synaptic connections. This basic idea (tuning the connections between nerve cells) is also the characteristic feature of any natural learning process.

## A Program without a Programmer

"With the help of reinforcement learning, a method also known as 'learning based on experiment and reward,' the artificial reflex network was trained and optimized on the computer," Mathias Lechner explains. The team succeeded in teaching the virtual nerve system to balance a pole. "The result is a controller, which can solve a standard technology problem – stabilizing a pole, balanced on its tip. But no human being has written even one line of code for this controller, it just emerged by training a biological nerve system," says Radu Grosu.

The team is going to explore the capabilities of such control circuits further. The project raises the question whether there is a fundamental difference between living nerve systems and computer code. Is machine learning and the activity of our brain the same on a fundamental level? At least we can be pretty sure that the simple nematode C. elegans does not care whether it lives as a worm in the ground or as a virtual worm on a computer hard drive.




In real life, the worm reacts to touch—and the same neural curcuits can perform tasks in the computer. Credit: TU Wien

**More information:** Worm-level Control through Search-based Reinforcement Learning: docs.google.com/viewer?a=v&pid …

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