DOI 10.18699/SBB-2022-665

# Towards artificial minds through computer simulation of natural ones, from simple to more complex

Palyanov A.
*A.P. Ershov Institute of Informatics Systems, SB RAS, Novosibirsk, Russia*
*palyanov@iis.nsk.su*

**Key words:** virtual organism, computational modelling, *C. elegans*, *Xenopus*, tadpole, computational neuroscience, biomechanics, hydrodynamics, Sibernetic software

*Motivation and Aim*: The problem of building an artificial mind (at least a simplest one capable of subjective experience) based on a computational system still remains a challenge. Even a fundamental possibility or impossibility of this remains unknown. There are approaches aimed at building artificial cognitive architectures and those which try to reproduce the natural ones at neuronal level in the form of a computer simulation. The advantage of the latter is the existence of biological prototypes which provide clues and guides for building their dynamical digital copies.
*Methods and Algorithms*: Modeling nervous systems requires the data about their neuronal connectivity and electrophysiological properties. However, it is highly preferable to provide them with meaningful sensory signals and ability to observe what actions correspond to the activity of their motor neurons. Being a part of two international projects working on investigation and computational modeling of nervous systems of simple multicellular creatures, we developed a software system named Sibernetic [1], which is capable of simulation and visualization of organism's bodies placed into virtual physical environment. Each virtual organism is provided with sensory and muscular systems connected with its simulated nervous system, so it can both move itself through contracting its muscles and receive the information about what is going on nearby as a result of this movement or for any other reason. In Sibernetic all simulated objects are represented by particles of different types (which are linked to each other in case of elastic objects) used to build organisms and environment. The latter includes incompressible liquid with density and viscosity of water at 20 °C, because both organisms use swimming for locomotion. The liquid is modeled via prediction-correction incompressible smoothed particle hydrodynamics (PCISPH) algorithm which we implemented in parallel form optimized for GPU computations using C++ and OpenCL.
*Results*: The organisms which we were attempting to simulate are invertebrate *Caenorhabditits elegans* nematode with 302 neurons (OpenWorm project) [2] and more complex one, vertebrate *Xenopus* tadpole, with thousands of neurons (2308 neurons of 12 types were included into the model) [3]. Nervous system of *C. elegans* appeared to be quite complicated to simulate, because its neurons are so specific that even lack action potentials and use passive electrotonic propagation of signals instead, so it is still far from being complete. However, virtual *Xenopus* tadpole driven by its nervous system, represented by a network of Hodgkin-Huxley type neurons, appeared to behave pretty natural – when touched in the middle of the body, it starts to swim (in nature it is

necessary to escape from predators) until the tadpole's head bumps into an obstacle and attaches to it with mucus from the cement gland. Even the swimming velocity of virtual tadpole turned out to be very close to the real one – 19.3 and 21 mm/s respectively.

*Conclusion*: Positive experience in modeling relatively simple organisms and their nervous systems together with the knowledge that human brain (86 billion neurons) and rat brain (0.2 billion neurons) are too complex to digitize them entirely at cellular level and simulate on a supercomputer, leads to the idea that the next object for modeling should be chosen thoughtfully so that the goal is achievable and useful. An adult frog has about 16 million neurons, but its cognitive abilities are not too impressive. *Drosophila*'s brain with its 200 thousands of neurons is already investigated quite well[4], and its neural circuits responsible for flying and navigation are of great interest. And, finally, ants with just 250 thousand of neurons are known to pass mirror test, i.e. distinguish between own reflection in a mirror and another ant seen through a glass [5], which is highly related to the origins of consciousness [6].

*Acknowledgements*: The study was performed according to the Russian Federation Government research assignment for A.P. Ershov Institute of Informatics Systems, SB RAS, project FWNU-2021-0005.

*References*

1. Palyanov A. et al. Three-dimensional simulation of the *Caenorhabditis elegans* body and muscle cells in liquid and gel environments for behavioural analysis. *Phil Trans R Soc B.* 2018;373:20170376.
2. Sarma G.P. et al. OpenWorm: overview and recent advances in integrative biological simulation of *Caenorhabditis elegans. Phil Trans R Soc B.* 2018;373:20170382.
3. Ferrario A., Palyanov A. et al. From decision to action: Detailed modelling of frog tadpoles reveals neuronal mechanisms of decision-making and reproduces unpredictable swimming movements in response to sensory signals. *PLoS Comput Biol.* 2021;17(12):e1009654.
4. Hulse B.K. et al. A connectome of the Drosophila central complex reveals network motifs suitable for flexible navigation and context-dependent action selection. *eLife.* 2021;10:e66039.
5. Cammaerts M.-C., Cammaerts R. Are Ants (Hymenoptera, Formicidae) Capable of Self Recognition? *J Sci.* 2015;5(7):521-532.
6. Barron B.B., Klein C. What insects can tell us about the origins of consciousness. *PNAS.* 2016;113(18):4900-4908.