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In this talk (and accompanying demo), we present a new visualisation of the anatomy and spiking activity in a tadpole spinal cord model. Scientific visualisation is an important technique that allows us to better understand large and/or complex datasets (McCormick et al., 1987). Modern visualisation approaches provide a natural way to demonstrate and highlight important details hidden in data, and to illustrate the interactions and interconnections present. Usually the data concerned have complex three (or higher) dimensional structure, but are typically shown as non-interactive two dimensional images or videos. Our approach to presenting the results of our models is based on virtual reality (VR). This provides a new perspective, bringing the viewer/user closer to the data and allowing them to interact with specific elements in order to access contextualised information in an intuitive and exciting way (Bryson, 1996).

The dataset that we are visualising consists of the axonal trajectories and physiological (spiking) activity of approximately 1,500 neurons from a model of the Xenopus tadpole spinal cord. In order to create the anatomical part of the data, we use a novel “developmental” approach (Borisyuk et al., 2014). For each neuron, properties such as soma position and dendrite extents are chosen randomly according to a distribution that matches experimental measurements for that particular neuron type. Following this, we simulate the growth of each neuron’s axon according to a set of equations that mimic the response of axon growth cones to chemical gradients. The sensitivities to chemical gradients were chosen using an optimization routine, such that the statistics of the generated axons match those of stained real axons. When the axon of one neuron crosses the dendritic area of another neuron, a synapse is created between the two with some probability. By mapping approximately 80,000 synapses that this process generates onto a network of single compartment Hodgkin-Huxley neurons (with parameters chosen to fit available electrophysiological data (Sautois et al., 2007)), we are able to simulate the spiking activity in the entire spinal cord. This model can produce various physiological behaviours, such as robust swimming in response to sensory input (Roberts et al.,

2014) and transient synchronous activity (Li et al., 2014). Our visualisation maintains the integrity of the original data while providing a novel approach to studying them.

The demonstration consists of two sections: the first is used to provide context and scale, and the second actually visualises the axonal and spiking data. The first section shows the typical swimming behaviour of a tadpole in a natural environment (a rockpool within a lush forest). An important element in VR is the sense of scale (Steuer, 1992) and we take advantage of this in the first section by shrinking the user to a fifth of the size of an average human. This gives the user a different perspective, allowing them to better relate to the tadpole and its size within the environment. The second section takes place inside a “virtual lab” where the user’s scale is reduced even further, to allow them to relate and understand the neurobiological data. The spinal cord is dynamically constructed around the user in order to display the contextualised information in an immersive way (Figure 1). The user is able to play back the results of the physiological simulation, showing how the different neurons interact with each other to produce swimming behaviour. The rendered environment is fully interactive and provides information within context for the user, including labels showing neuron types, their axonal connections, and spiking activity.

We chose to develop the software with a dedicated game engine (Unity Game Engine, 2016) because of its platform versatility and VR support, although other similar engines are available (see e.g. Unreal Game Engine, 2016). A number of innovative techniques were used, from photogrammetry (Baltsavias, 1999) for building the natural environment, to developing a custom chunking system for optimised rendering (Ebert et al., 2000), which is required due to the size and complexity of the data. At runtime the axonal data are converted into meshes that are optimised for rendering without compromising the integrity of the raw data. All the metadata sits in separate memory structures to the rendering data, allowing for the future possibility of implementing a more dynamic system with adaptable mesh generation and a separate representation of connections between different data chunks.

We believe that this visualisation approach is general and suitable for many applications beyond our model of the tadpole spinal cord. It could easily be adapted to visualise similar spiking neuron models, either using existing information about the spatial structure of the network or algorithmic techniques to select the clearest possible arrangement of cells. Alternatively, it could also be used to visualise the anatomy of real neural circuits, using anatomical data from experiments. We see significant value in broader application of this visualisation approach both within the neuroscience community and more generally, to provide new tools designed for complex data analysis in virtual reality.

Keywords: Virtual Reality, VR, Visualisation, Scientific Visualisation, Education

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