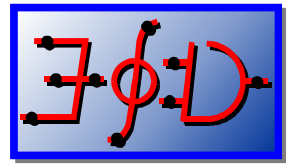

Behavioral Simulation of Biological Neuron Systems in SystemC

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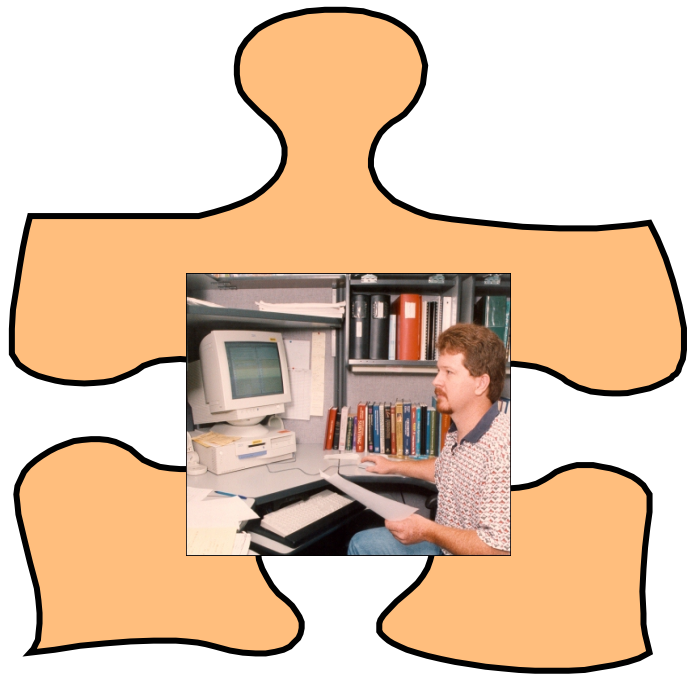
There is a disconnect between….

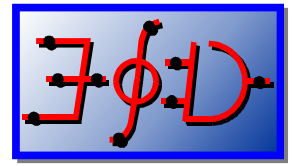
Neurobiologists

- working in labs & using software

Engineers

- developing software





Why is there is a disconnect ?

You cannot do full analogue simulation on systems with > 1000 nodes practically

- Simulation Time is long
- Accuracy is an issue

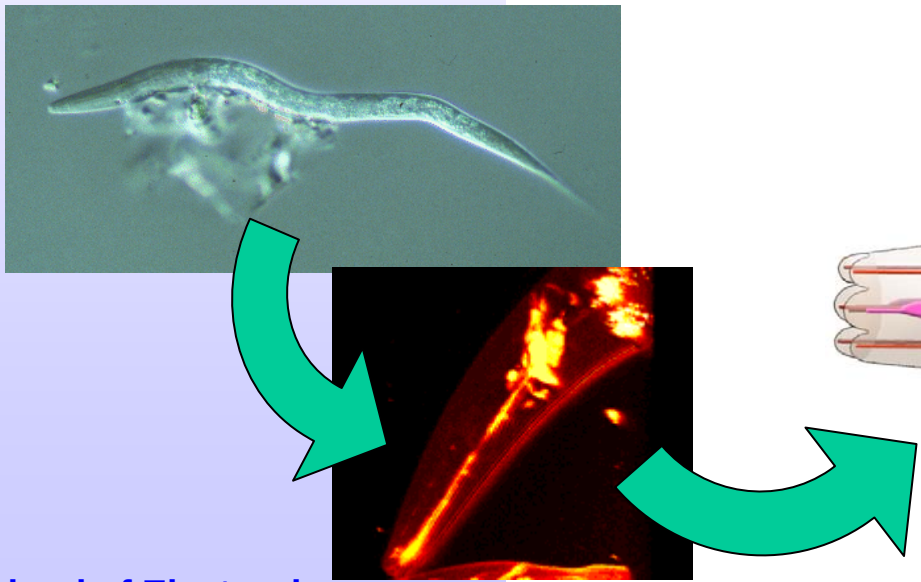
You cannot do meaningful system modelling on neural networks with < 10000 nodes

- What is the point of small systems – do experiments instead

Take a simple example: C. elegans

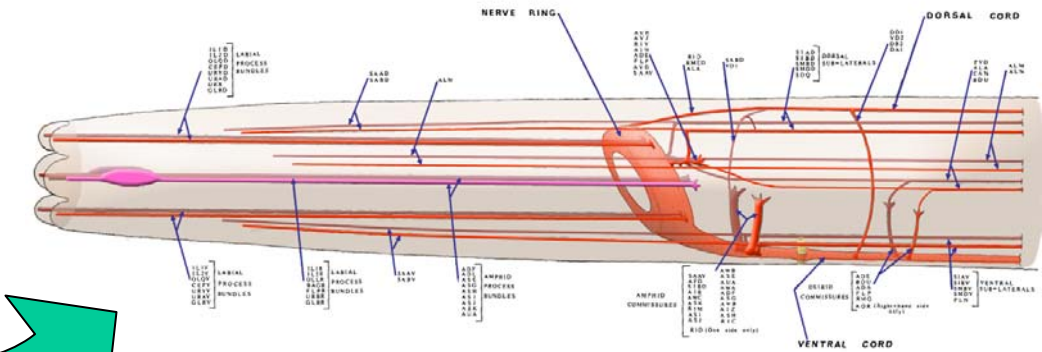
Should be simulatable

- Has only 302 neurones
- Topology known



But….

- Everything is connected to everything else
- Connection 'strengths' are not known

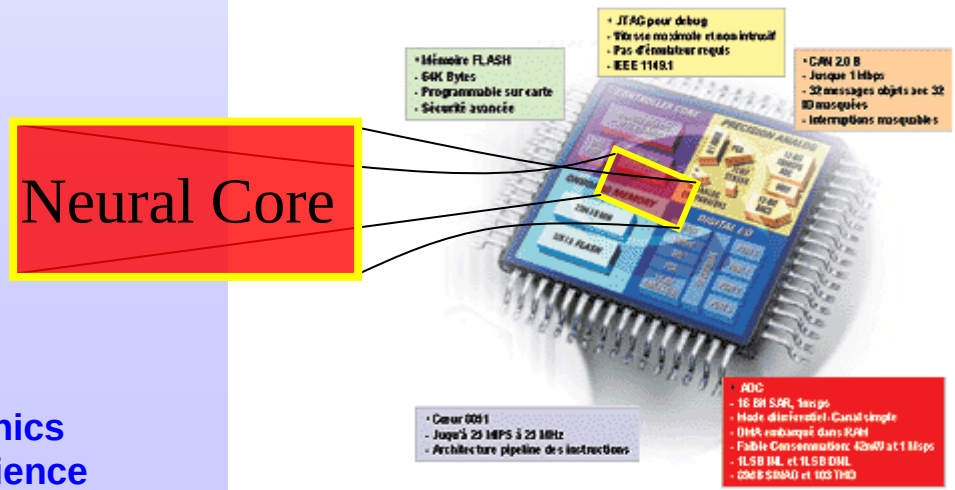


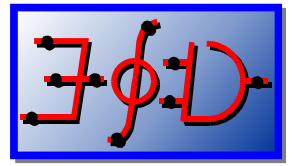
Further Motivation

Emergence of new class of Neural Architectures based on Neuroscience

- Pulsed Neural Network with Spatial-temporal coding and Spike Trains
- Novel Analogue and Digital Architectures with radically different type of information processing

Future sophisticated SOCs will contain such neural cores





Bringing it all together…

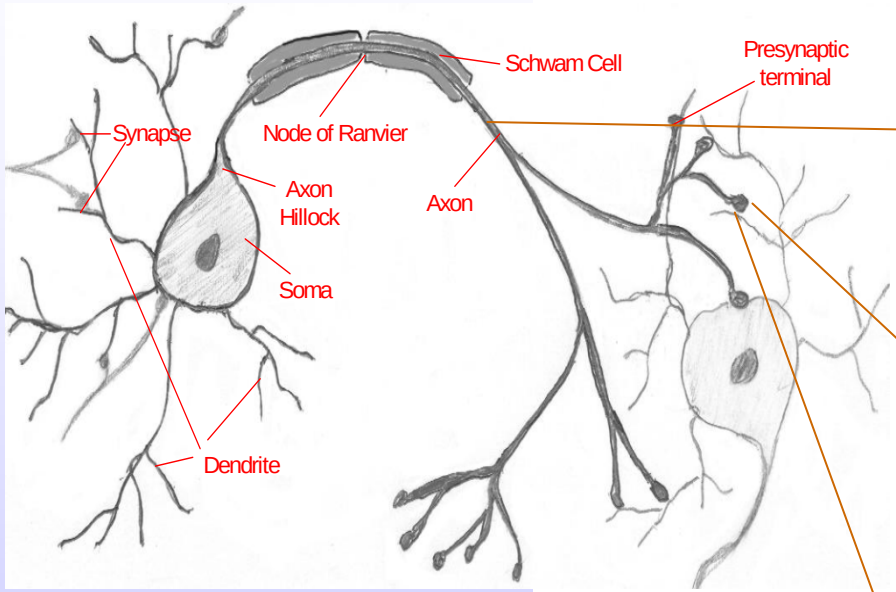
We need biologically realistic modelling and simulation of Biological Neuron Systems (BNS) :

- To gain insight of the Information Processing of BNS
- To perform “Virtual experiments” on BNS
- Verification of behaviour of neural SOC core

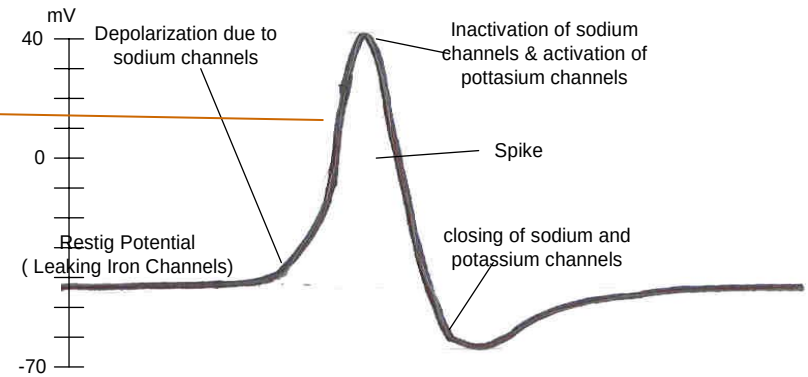
Desired characteristics for the modelling framework:

- Efficient, fast simulation of large neuron aggregates
- Effective visualization of results for meaningful interpretation
- Extensible and flexible framework, working on various level of abstraction
- Easy integration in SOC design environment

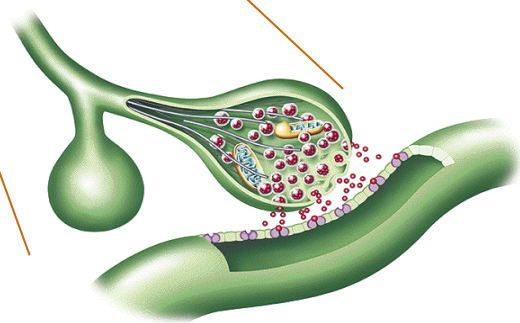
Biological Neurons



Generic neuron



Action potential Spike



Synapse

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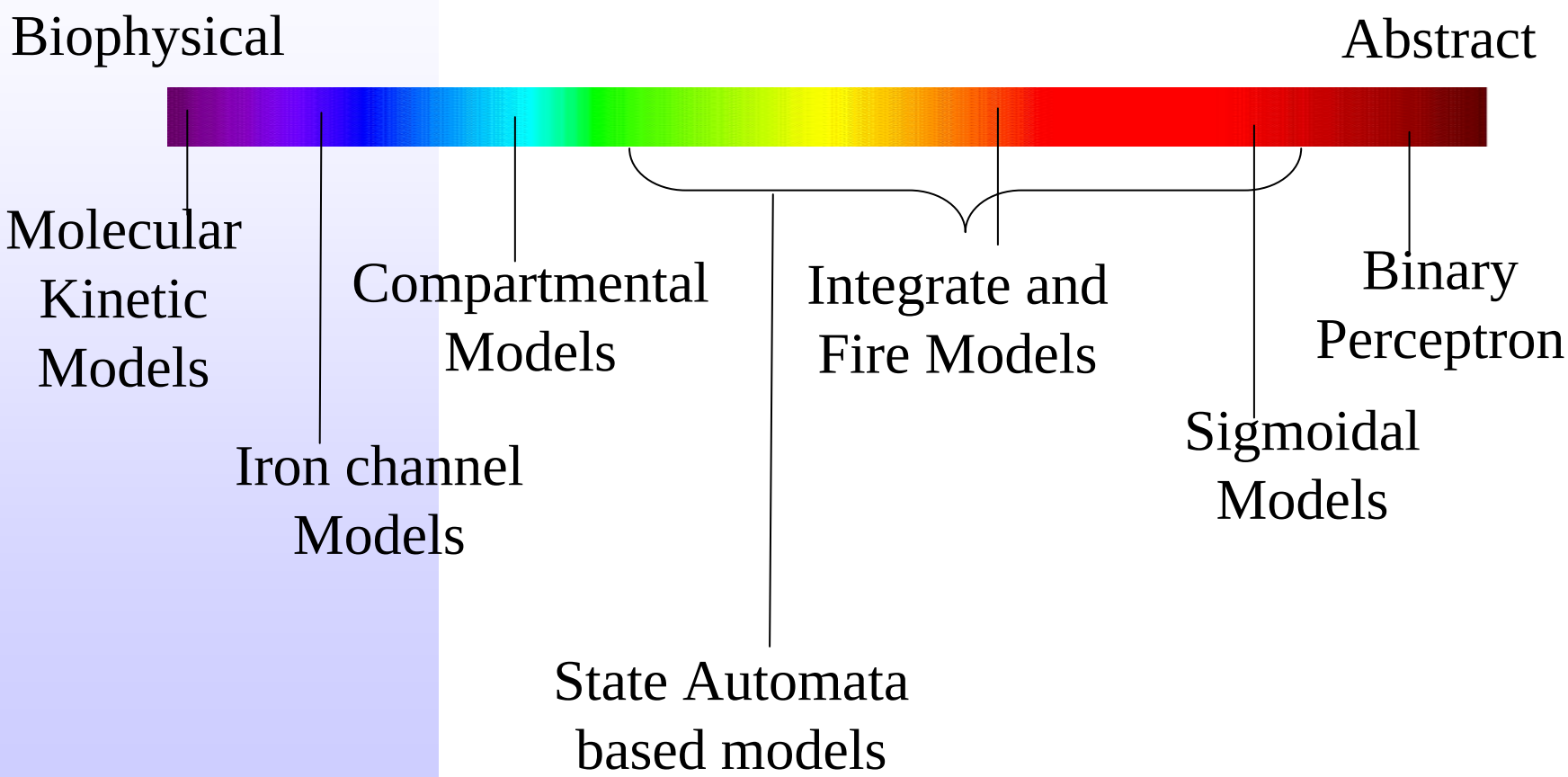
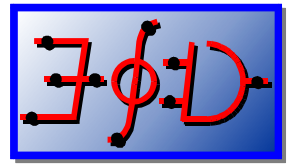
Neuron Modelling





Simulators

The current simulators:

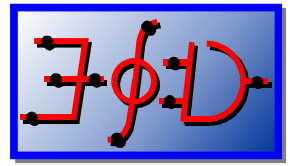
- **Bio-physical Models**
- **Analogue Simulation**

} *Low efficiency, restricted to small neural aggregates*

- **No standard, reusable and flexible platform**
- **Do not use OOP and component library approach**
- **Not very suitable for integrating in SOC design environment**

Previous work developed a bespoke simulator

- **can we be more general/standard?**



Previous important work

***Behaviour* of neural aggregates *implies* statistical connectivity**

- **Not contentious**

Initial results indicate *random* networks (with the right statistics) exhibit the *same* behaviour

- **Health warning – single source so far**

•*E.T. Claverol, A.D. Brown and J.E. Chad 2002 'Scalable cortical simulations on Beowulf architectures', Neurocomputing, 43, pp 307-315, Mar 2002.*

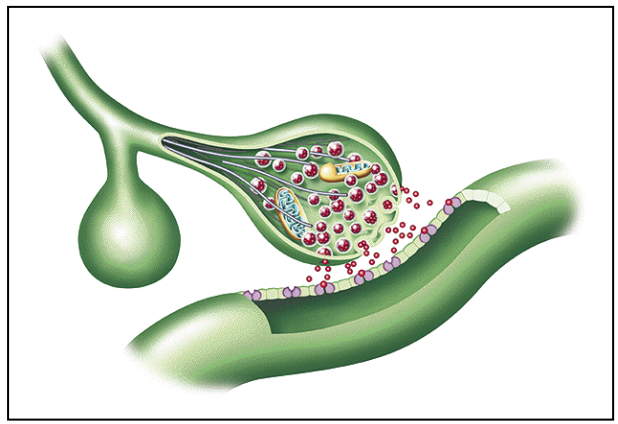
•*E.T. Claverol, A.D. Brown and J.E. Chad, 'Discrete simulation of large aggregates of neurons', Neurocomputing. 47, pp 277-297 Oct 2002*

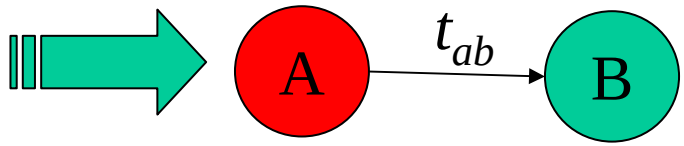
•*E.T. Claverol, A.D. Brown and J.E. Chad, 'A large scale simulation of the piriform cortex by a cell automaton based network model', IEEE Transactions on Biomedical Engineering. 49, no 9, Sept 2002 pp 921-935*

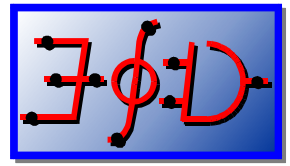
What would we like to do?

The development of a computational model of:

- a single mammalian neurone
- that *concisely* characterizes the information processing capabilities.







How do we accomplish this?

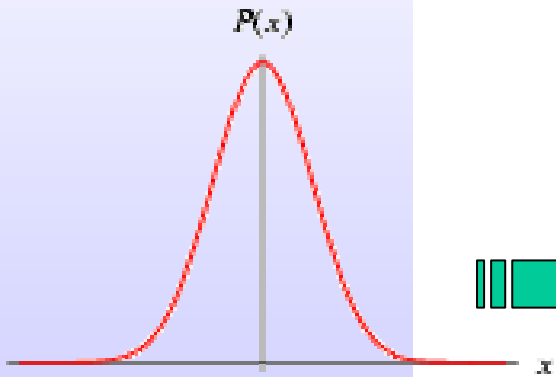
The development of a specialised (extremely fast) simulator that can

- **Handle the simulation of extremely large networks of the model.**
- **The system will allow topological changes to be made to the network**
  - Predicated dynamically on the simulation results themselves (plasticity).
- **Use a standard modeling and simulation platform for**
  - Interoperability
  - Portability
  - Efficiency
  - Reliability
  - Development of libraries of standard elements

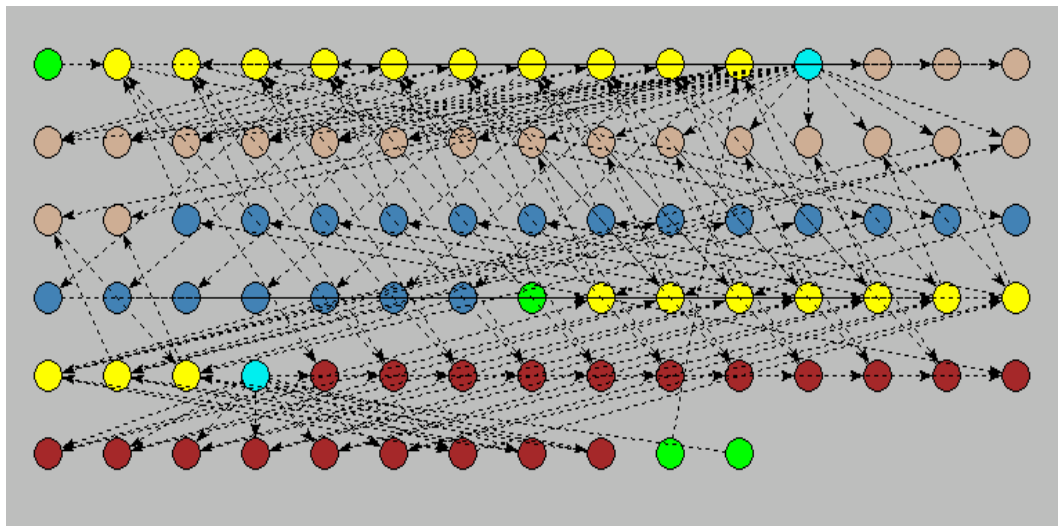
What else would we like to do?

The development of a 'statistical assembler'

- Will automatically assemble large bodies of neurone models, such that the gross connectivity properties of the collection can be manipulated by the researcher.



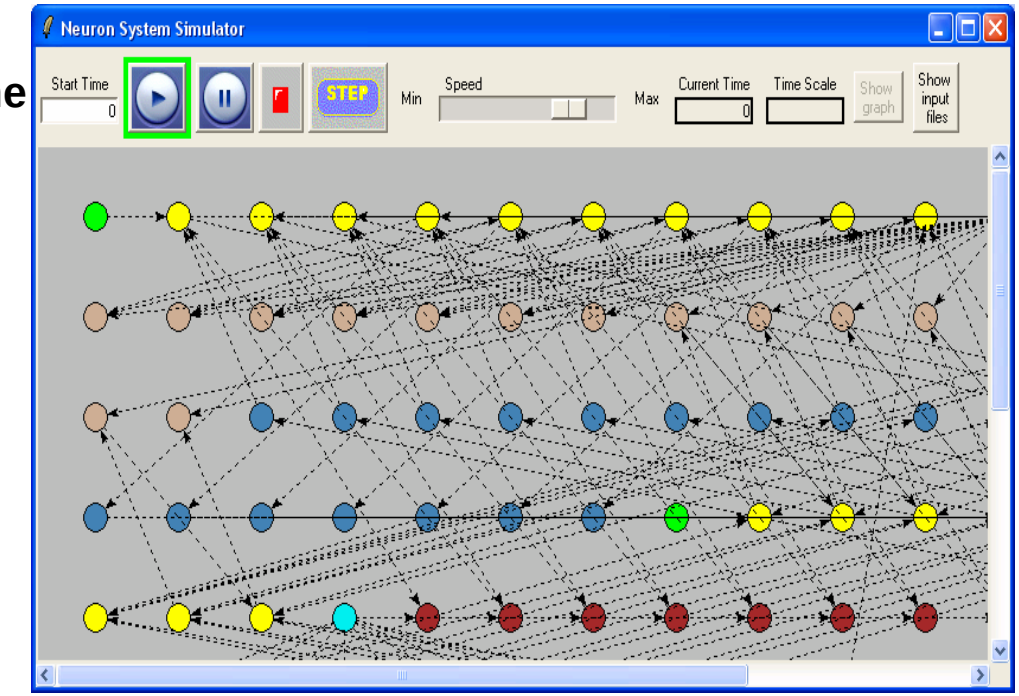
$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/(2\sigma^2)}$$

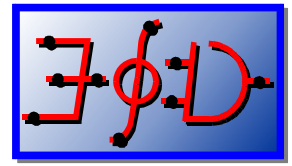


Can we develop a design technique?

The development of an 'activity browser'

- **Allows the investigator to study the macroscopic behaviour of the assembled system in a manner sympathetic to the aims of the research.**
- **Simple user interface**
  - Decouple main user from the complex programming required



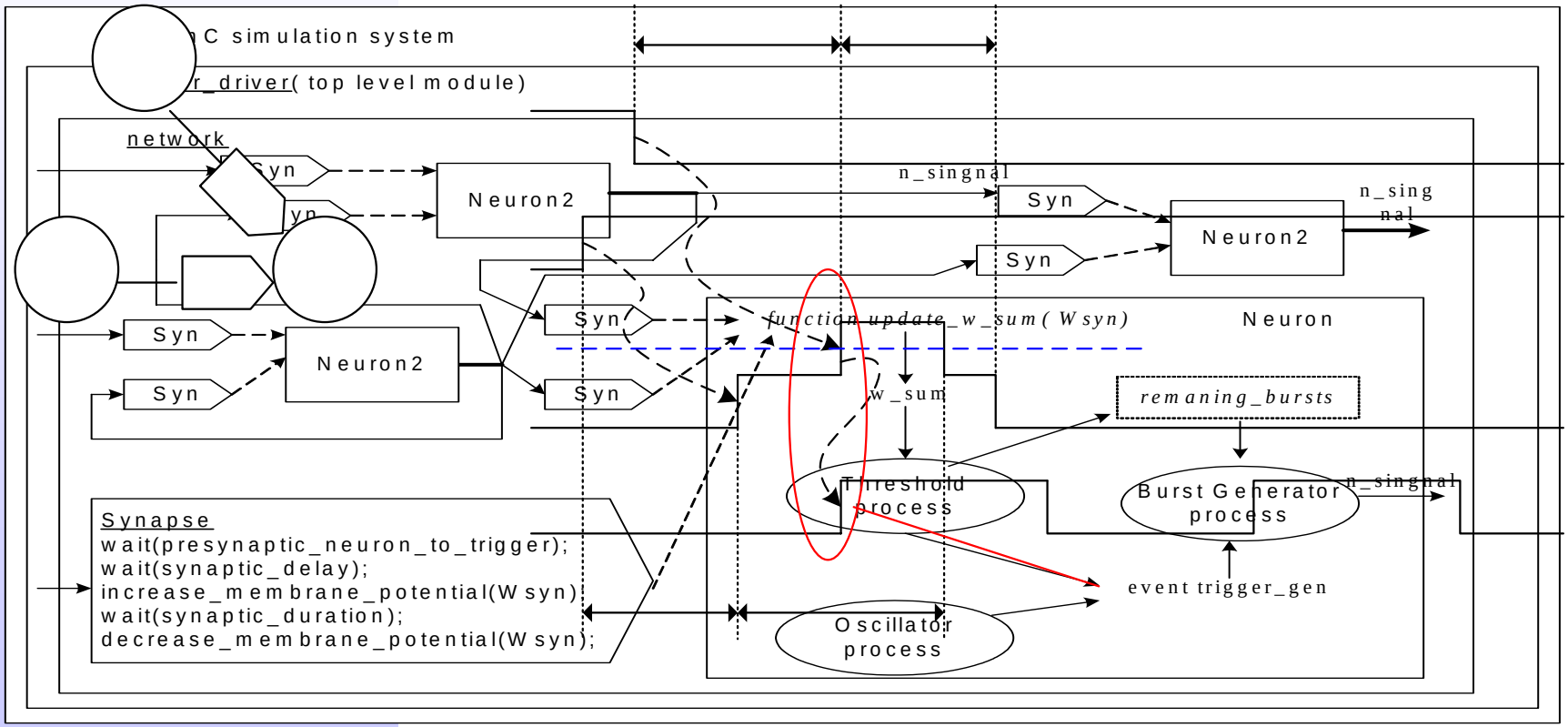


Basic platform: Choice of SystemC

- A natural candidate: an HDL with inbuilt concurrency and time
- Built on the general purpose C++ programming language
- Designed to handle simulation of very large system
- Efficient and fast event driven kernel
- Open source and uses standard compilers
- Object oriented, promotes libraries with Plug-and-play components
- Scalable designs, small executables specifications
- C/C++ is pervasive in the scientific/ engineering community
- Designed for SOC design and verification, enables seamless integration of BNS modelling and simulation in SOC environment

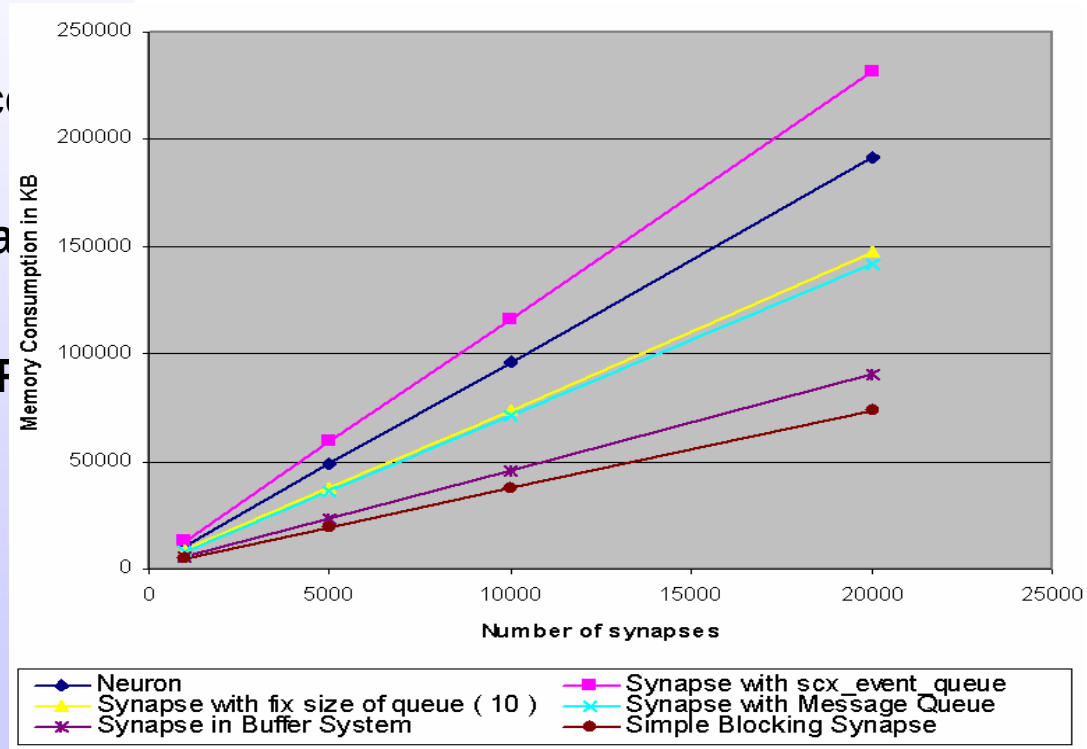
SystemC Framework

Structure

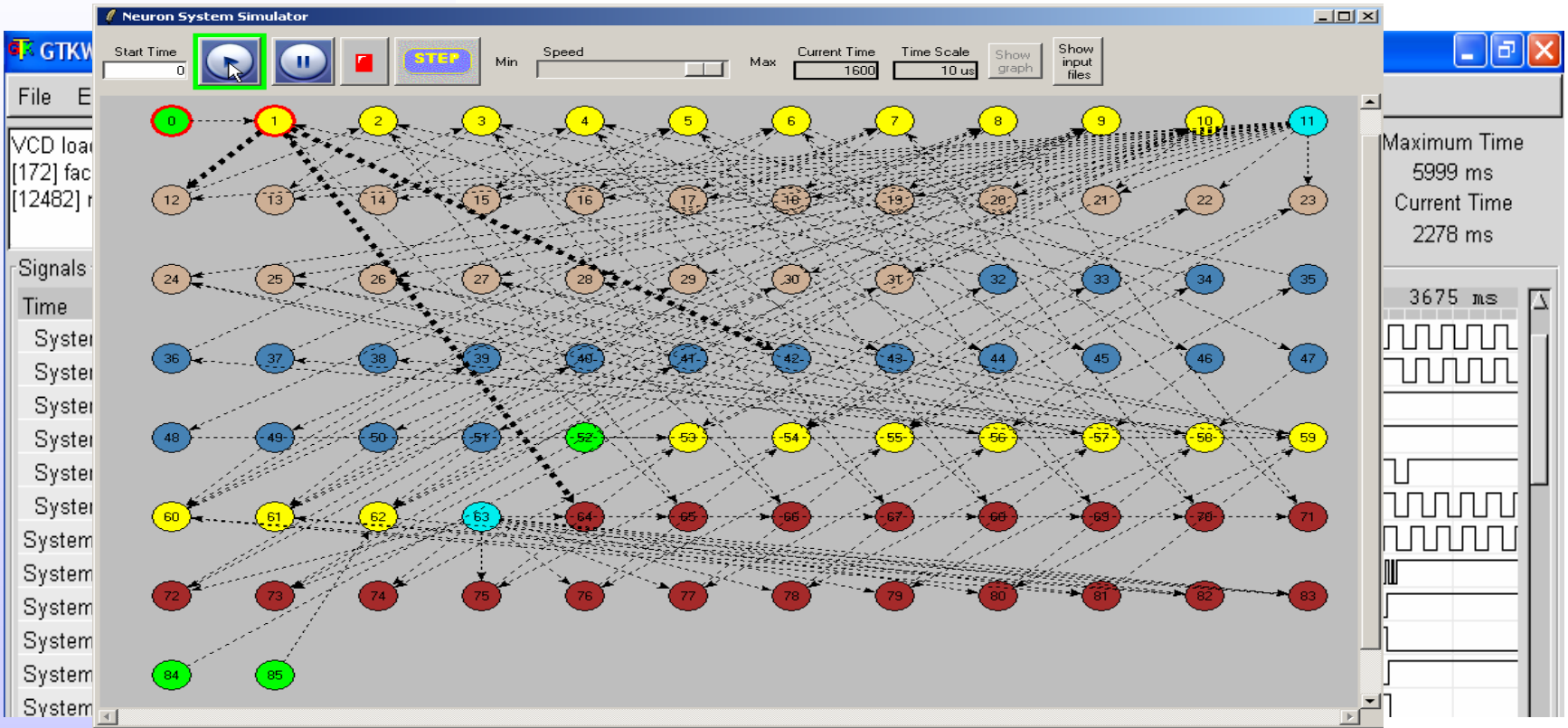


Some Design and Performance Issues

- Modelling of Transport delay
- Pointer ac
- Use of sha
- Run-time F



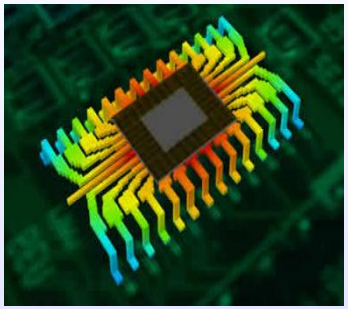
Some Results: Visualization

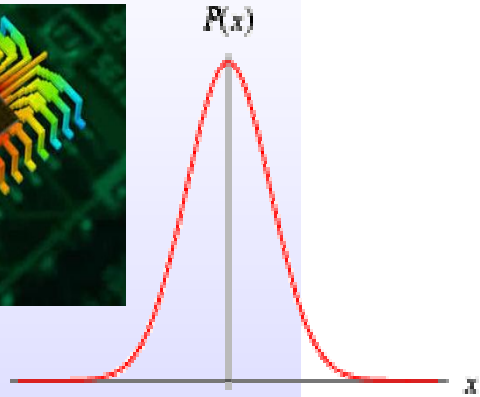


Waveform viewer

Activity Browser

Animated Visualization





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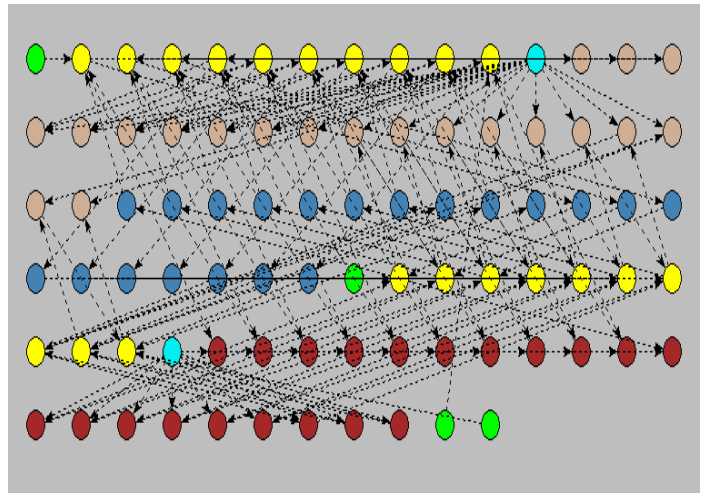

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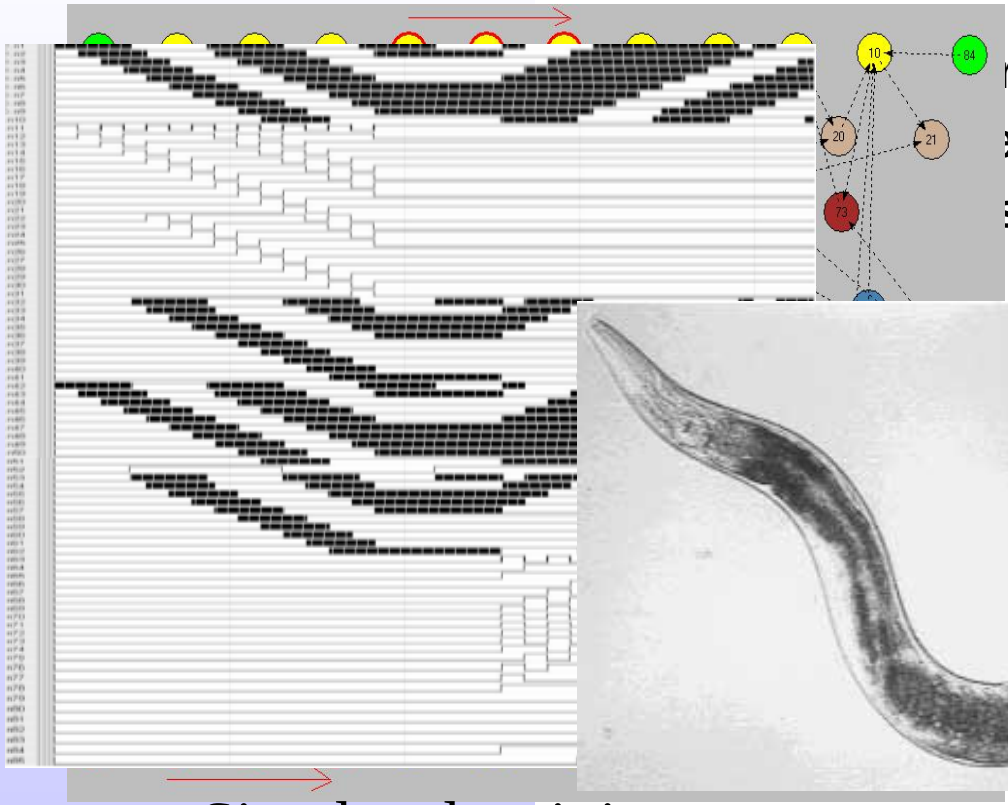
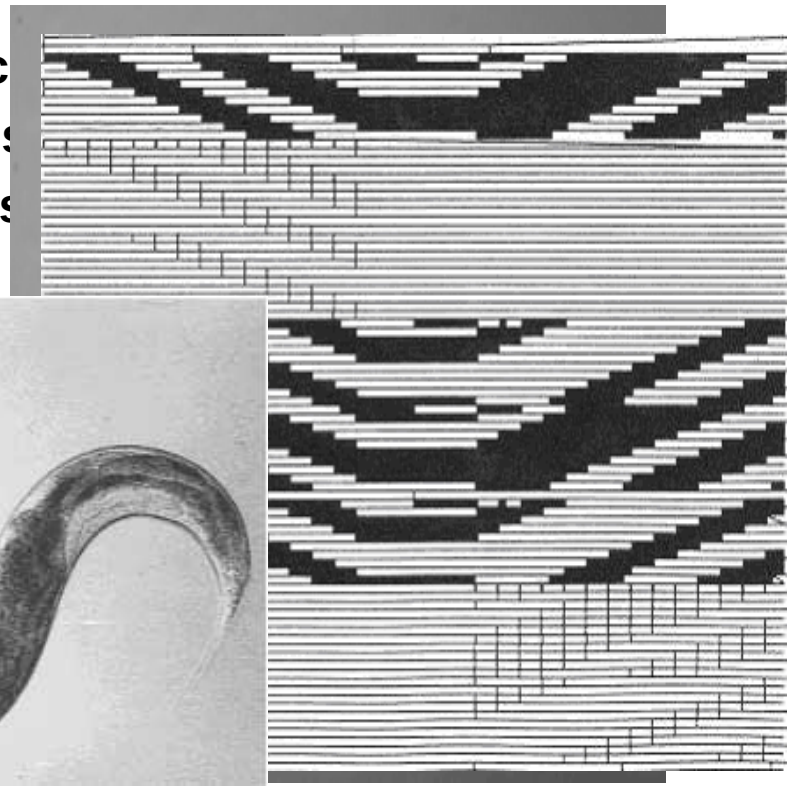
Modelling of C.Elegans Nervous System





Simulated activity

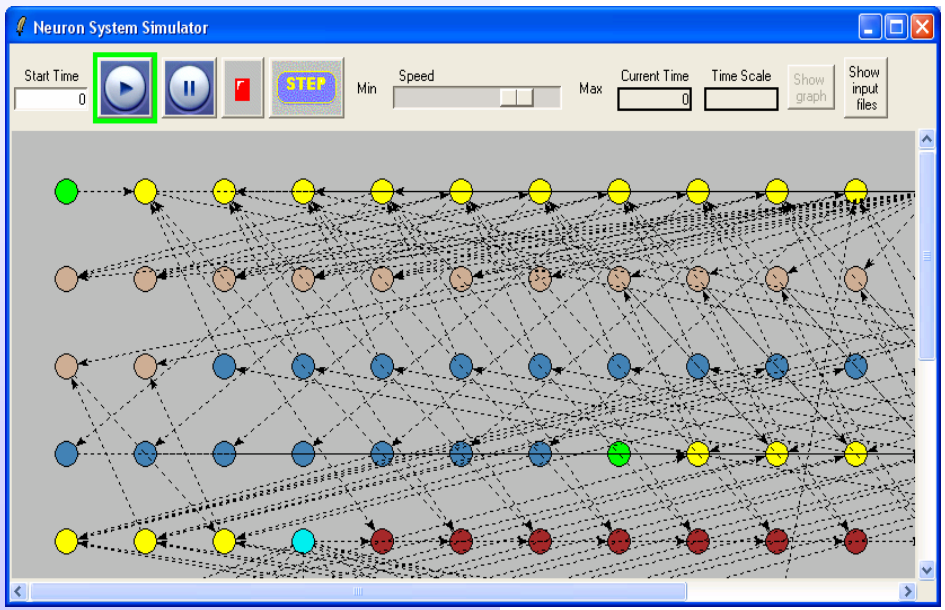
Animated visualization

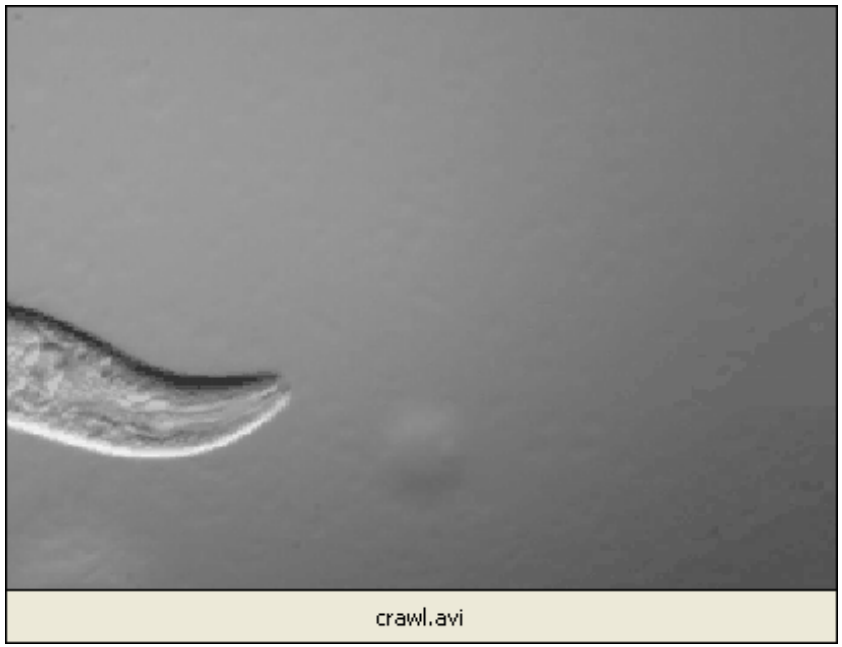
Animal Movement

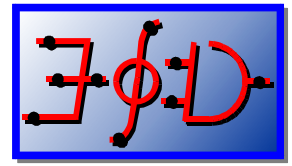
Reference results

Calibration of the model…

Wet experiments to ‘calibrate’ the model/simulator







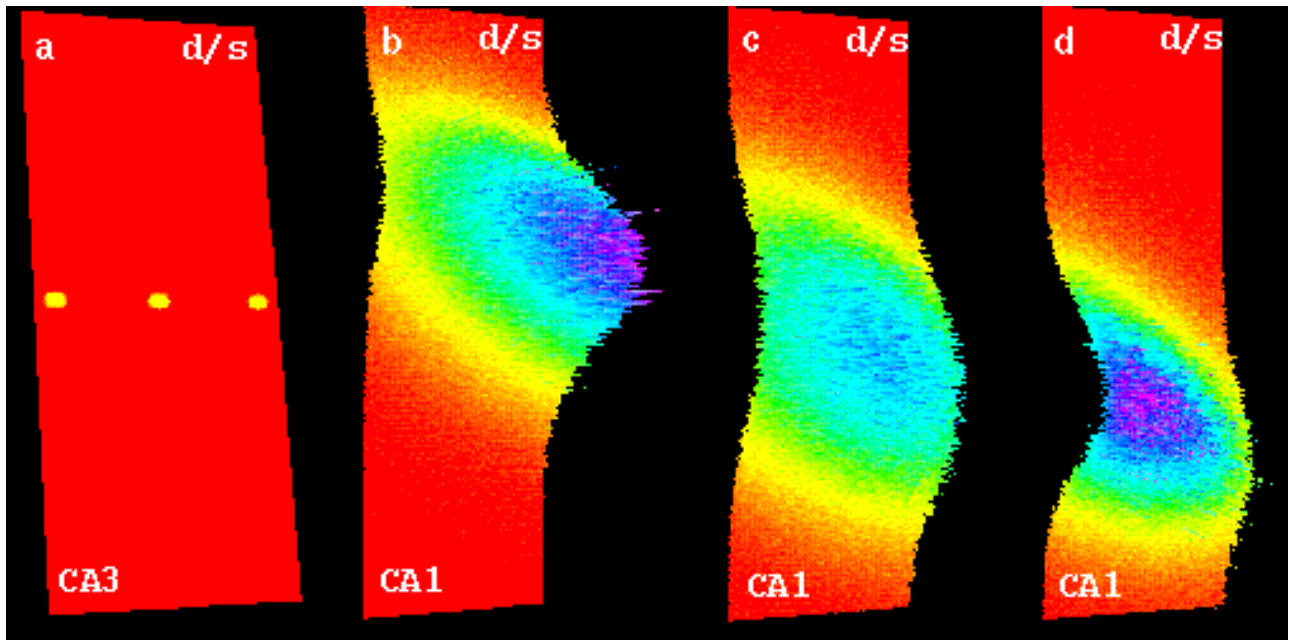
Outcomes

Outcomes:

- **Use of SystemC for Biological Neuron System simulation**
  - Effective
  - Fast
  - Efficient
- **Flexible, modular and extensible framework in very short design time**
- **Tcl/ Tk activity browser**
- **Results consistent with previous work**
  - NB 3 years modeling work condensed to 3 months using a standard platform
  - Users can develop and use these models with a minimal learning curve

Short Term Goals

Large scale statistical experiments on emergent behaviour of artificial neural aggregates



Long Term Goals

Interaction with the chemical ambient

- How the models behaviour changes depending on the ambient chemistry

The bottom line….

This approach allows Neuroscientists to leverage the power of advanced simulation techniques to analyse neuron structures

Engineers delivering a practical usable platform, and also learning from how nature deals with complexity