Electronics & Computer Science

University of Southampton

Behavioural Simulation of Biological Neuron Systems using VHDL and VHDL-AMS

J.A. Bailey[1], P.R. Wilson[1], A.D. Brown[1] and J.E. Chad[2]
School of Electronics and Computer Science[1] &
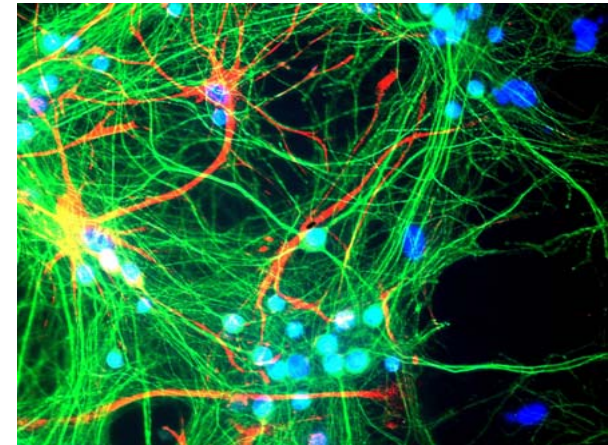**School of Biological Sciences[2]**
University of Southampton,
SO17 1BJ, U.K.

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Presentation Outline

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Introduction

→ **Biologists & Engineers**

→ **Characterising**
  - → Single Neurons
  - → Network Behaviour

→ **Biological experiments**
  - → Live Tissue
  - → Electrodes

→ **Modelling**
  - → Test Hypotheses

Stained Rat Cortical Neurons [1]

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[1] -   EnCor Biotechnology 2003, http://www.encorbio.com/Album/pages/ChkMAP2-GFAP-Hoe-40X-1.htm

Motivation

→ **Modelling Neuronal Systems**
  → Look at whole animals

→ **Virtual Experiments**
  → More than neurons

→ **Translate to hardware**
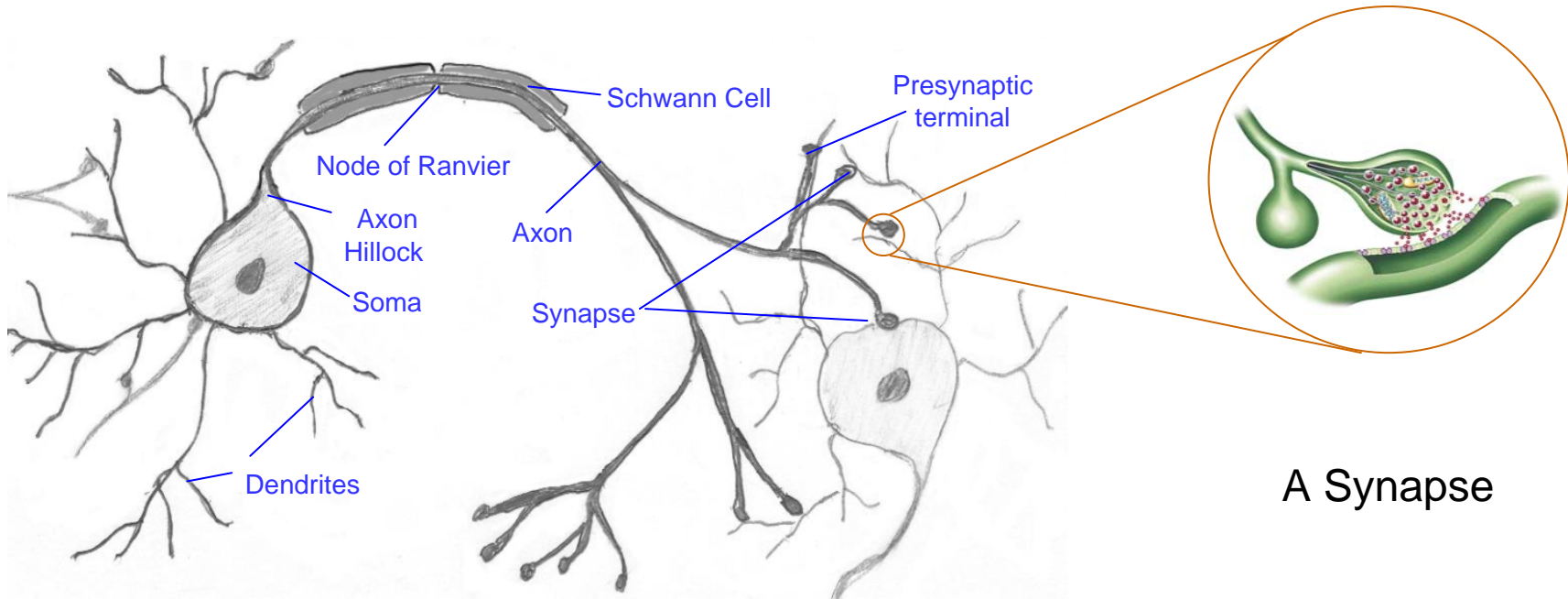 → Real-Time Simulation!

→ Introduction

→

→ Modelling Neurons

→ Simulation Methods & Simulation Results

→ Current & Future Work

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A Typical Neuron

A Synapse

Neuron Signalling

Axon

Synapse

Dendrite

Action Potential

Pre-Synaptic
Neuron

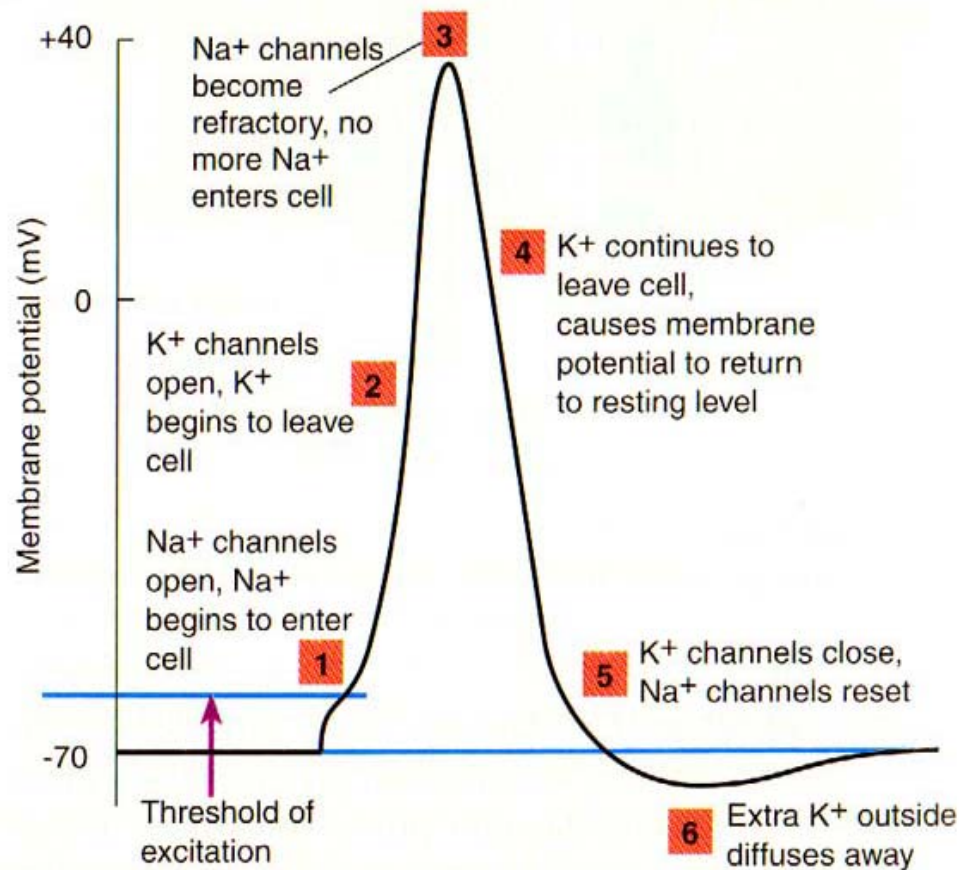Post-Synaptic
Neuron

Neurotransmitter

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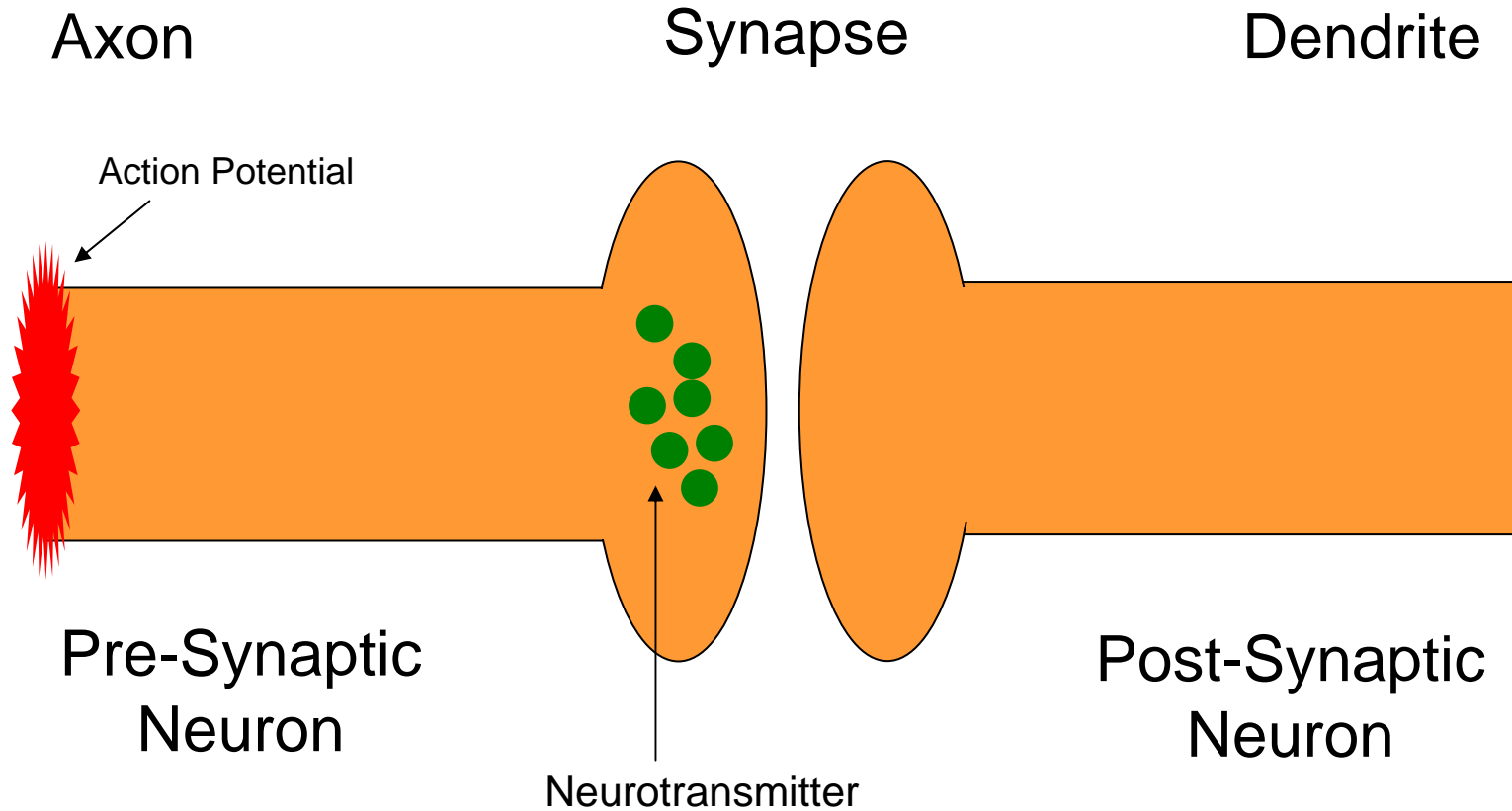
Neuron Function

→ Receives signals simultaneously

→ Makes "Decisions"

→ Modulates activity

→ Information
  → Action Potentials

Phases of an Action Potential [1]

[1] – R. McCready, "Anatomy & Physiology Review: NEUROLOGICAL SYSTEM", London Health Sciences Centre, January 2007.
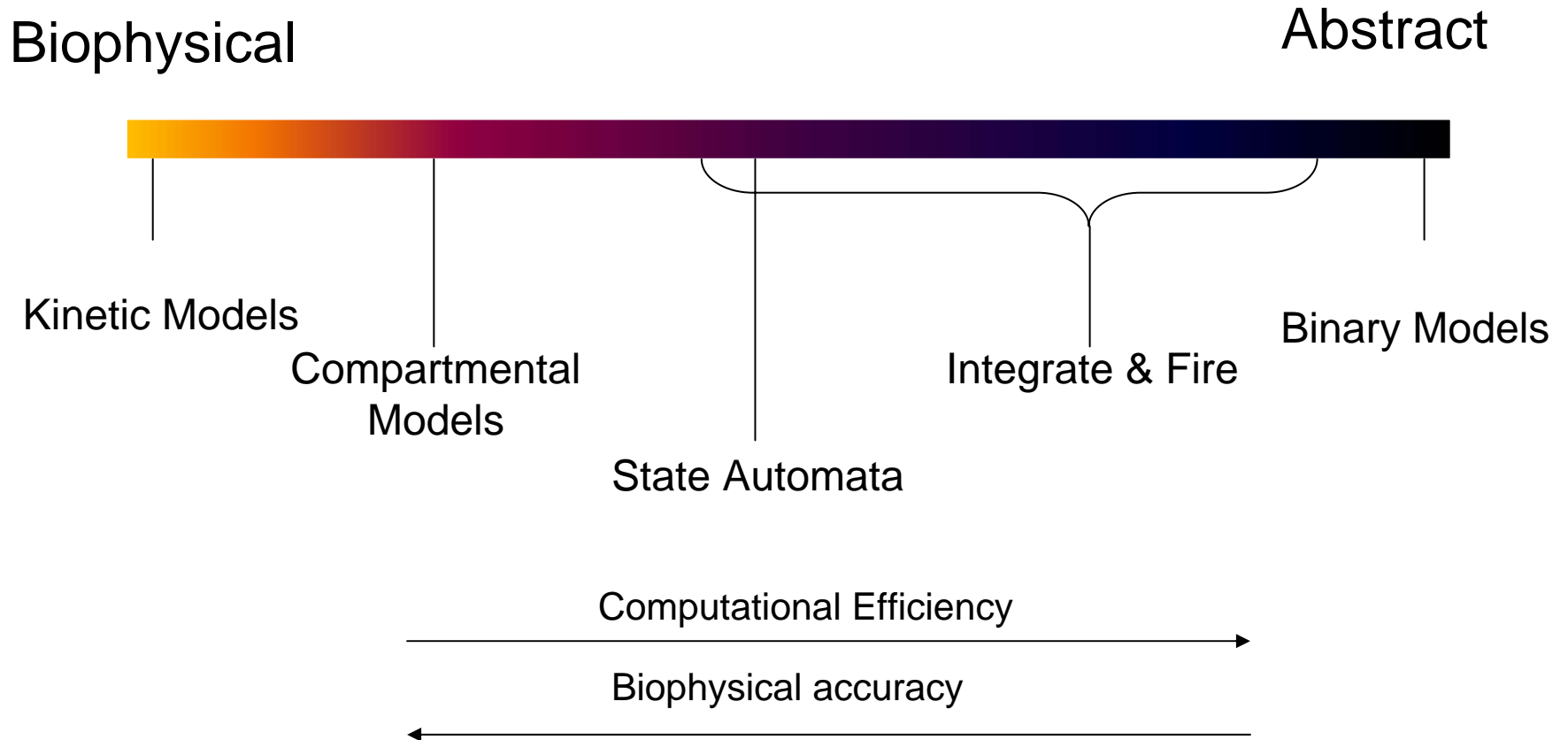   http://gargoyle.arcadia.edu/psychology/blustein/neuro/Lecture_Notes/Week_1/Week_2/Action_Potential.jpg

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→ Introduction

→ The Nervous System

→ [Modelling Neurons](#)

→ Model Verification & Simulation Results

→ Current & Future Work

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Scale of Modelling

Biophysical

Abstract

Kinetic Models

Compartmental
Models

State Automata

Integrate & Fire

Binary Models

Computational Efficiency →

Biophysical accuracy ←

State Automata Models

➔ Good Balance

➔ Translation into Hardware

➔ Previous Experience

➔ Past Work
- ➔ E.T. Claverol, A.D. Brown & J.E. Chad, "Scalable Cortical Simulations on Beowulf Architectures", Neurocomputing, 43, pp 307 – 3-15, Mar 2002.

- ➔ E.T. Claverol, A.D. Brown & J.E. Chad, "Discrete Simulation of large aggregates of neurons", Neurocomputing, 47, pp 277-297, Oct 2002.

- ➔ E.T. Claverol, A.D. Brown & J.E. Chad, "A Large Scale Simulation by a cell automaton based network model", IEEE Trans. Biomed. Eng., 49(9), pp 921-935, Sept 2002.

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The Model
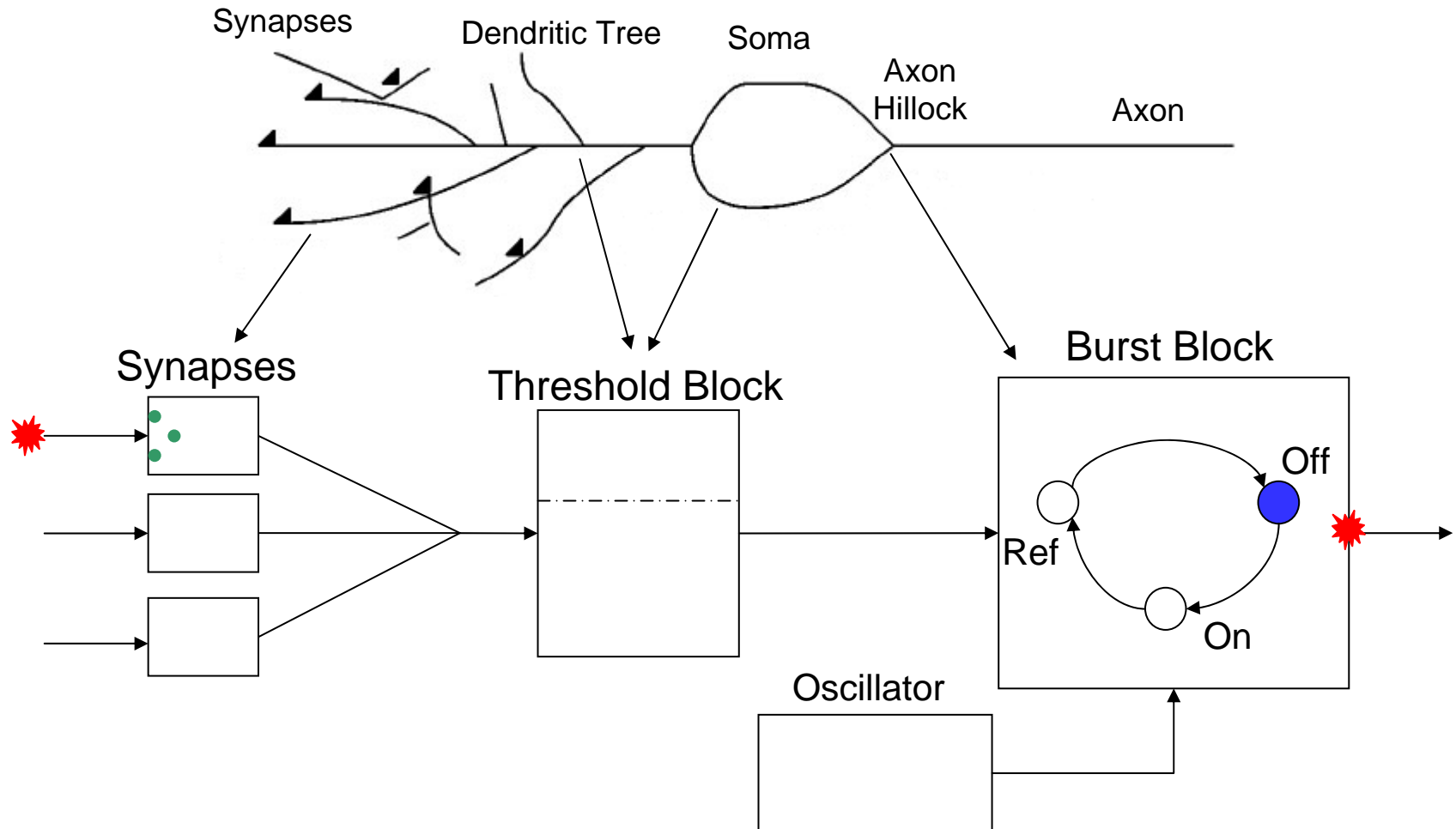
Choosing a Platform

➔ ## System C
 ➔ Based on C/C++
  ➔ Open-Source (Free)

➔ ## VHDL
  ➔ Mature Platform
  ➔ AMS extensions
  ➔ Simulating Hardware
  ➔ Potential for Hardware Implementation

➔ Previous Work
  ➔ S.S. Modi, P.R. Wilson, A.D. Brown & J.E. Chad, "Behavioural Simulation of Biological Neuron Systems in System C", *Proc. IEEE Workshop on Behavioural Modelling and Simulation (BMAS),* pp 31-36, 2004
  ➔ D. Sotiriou, "Implementation of Neuron Models in VHDL", MSc Report 2003

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VHDL Implementation

→ **Standard Components Library**

→ **Top Level Entities**
  - → Neuron
  - → Synapse

→ **Configurable**

→ **Nervous System Components**

Library: LibNeuron

Threshold Block,
Burst Block,
Oscillator Block,
Counters, etc.
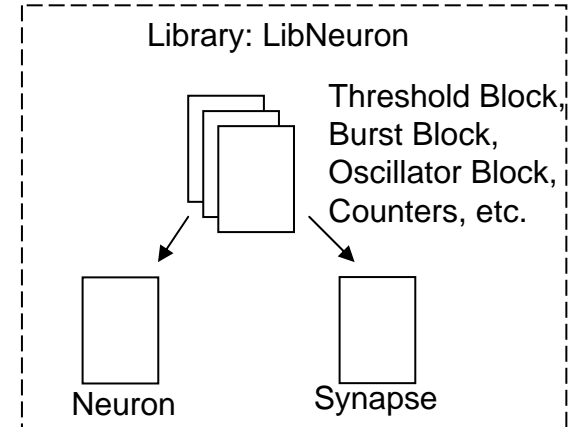
Neuron   Synapse

```
generic(NumberSynapses : Positive;
        THe         : Real;
        THi         : Real;
        Nburst      : Real;
        Tap          : Time;
        Tref         : Time
        );
```
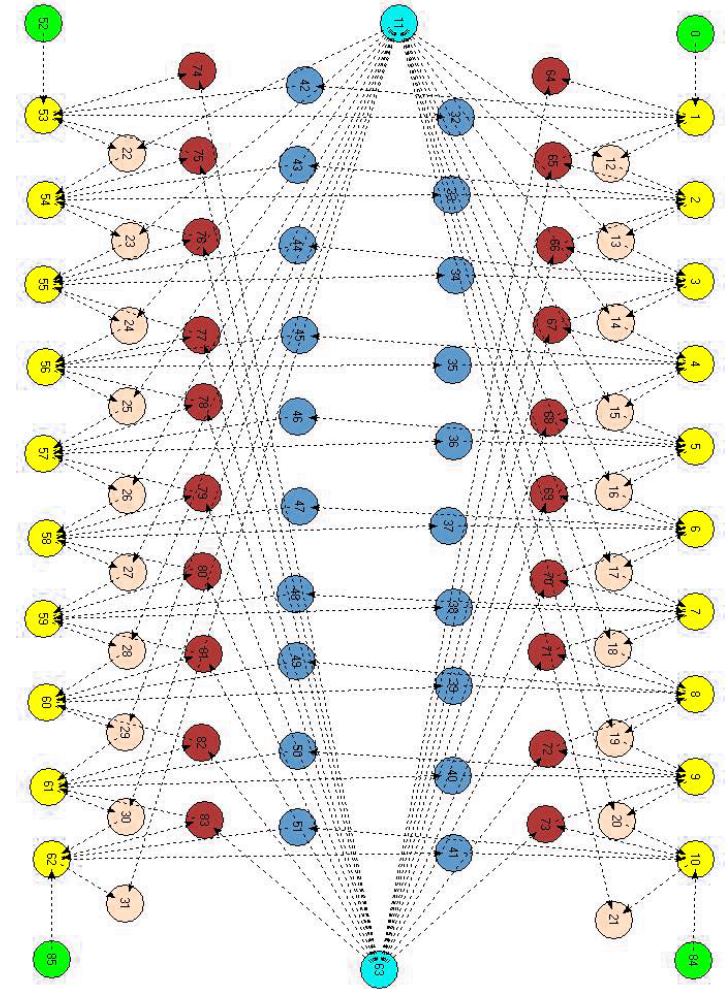
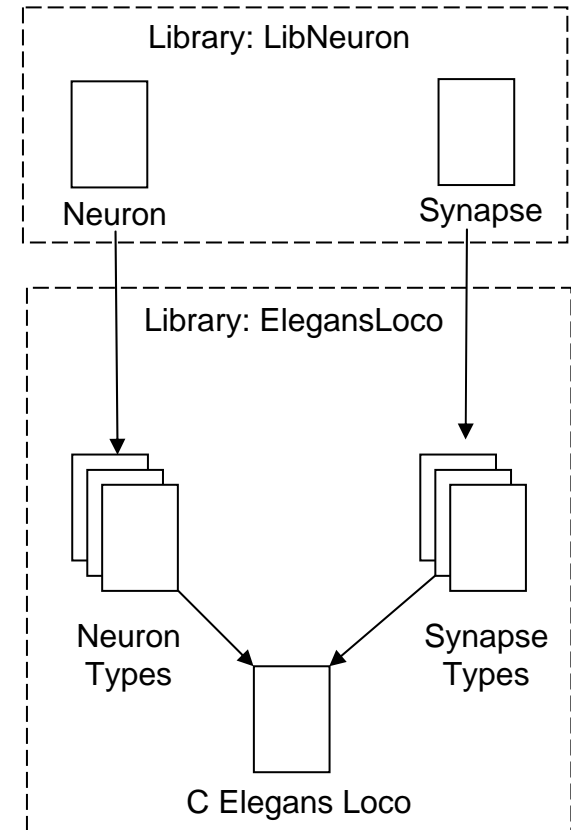**University of Southampton**

Model Verification

→ ## Nematode, C Elegans

→ 1 mm long, 80 microns wide

→ 302 Neurons

→ Extensively studied

→ Connections partially known

→ Locomotion system
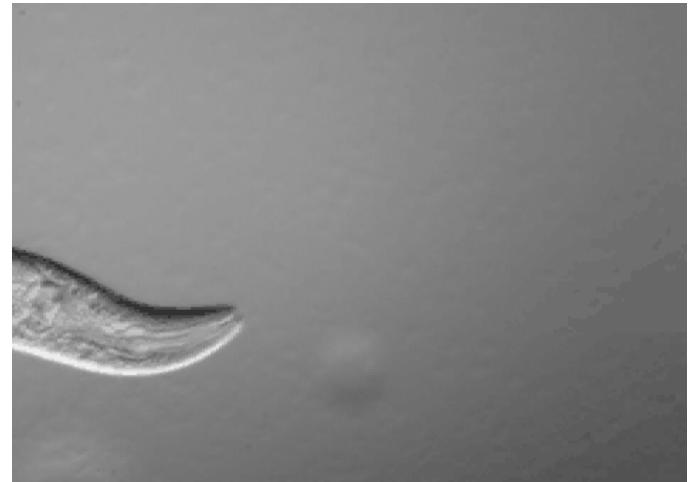 → 85 neurons, approx 164 Synapses
  → Regular connection pattern

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C Elegans VHDL

→ **Animal Library**
  → ElegansLoco

→ **Specifies Generics**
  → Creates Types

→ **Complexity Hidden**

Library: LibNeuron

Neuron   Synapse

Library: ElegansLoco

Neuron   Synapse
Types   Types

C Elegans Loco

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Previous results

→ Previous results
  → System C

→ C Elegans Videos
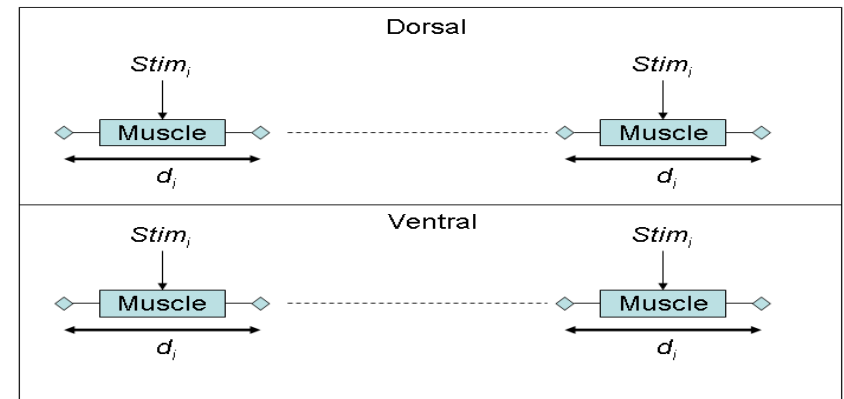
→ Verification VHDL
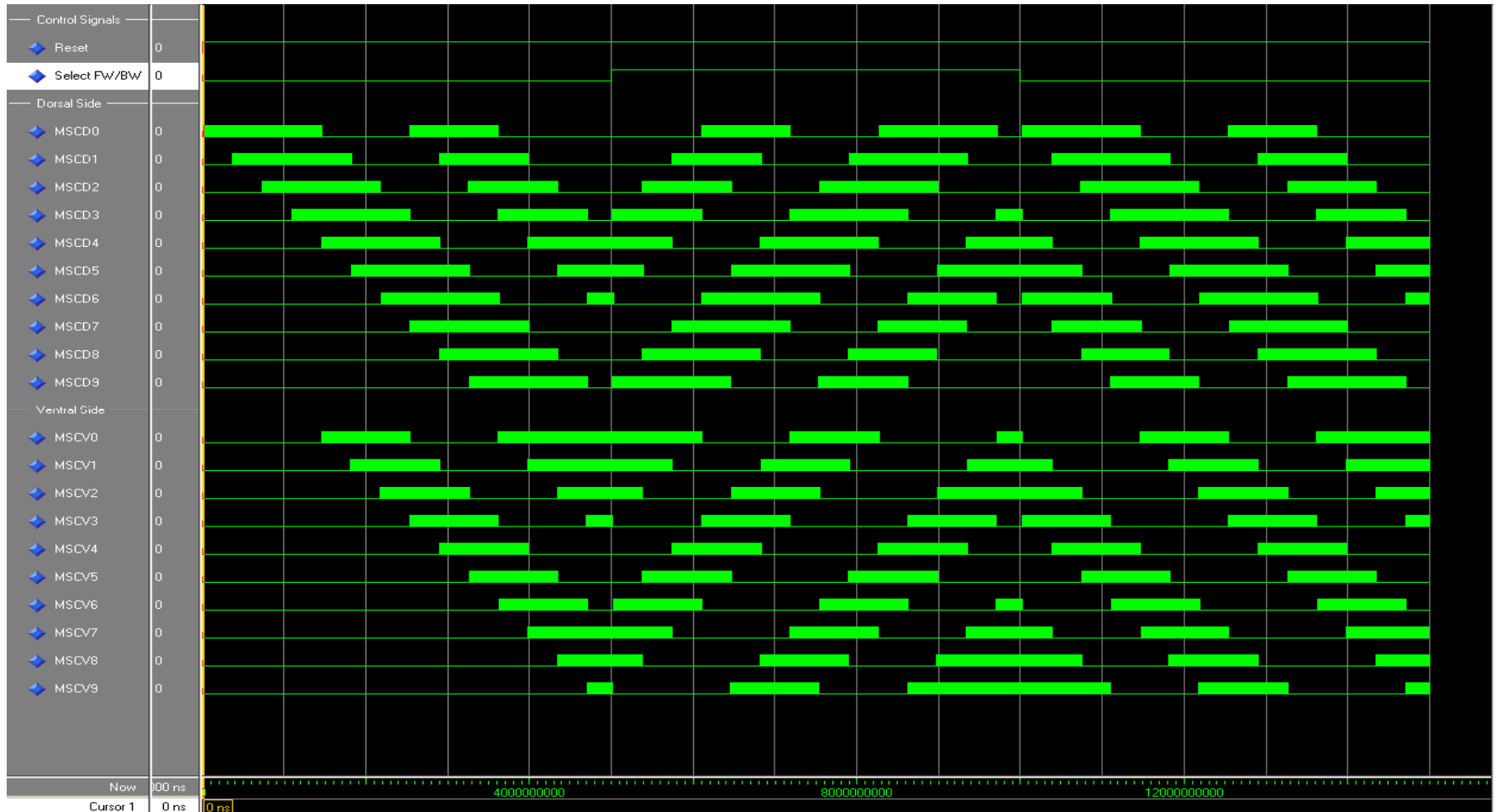
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Simulation Results
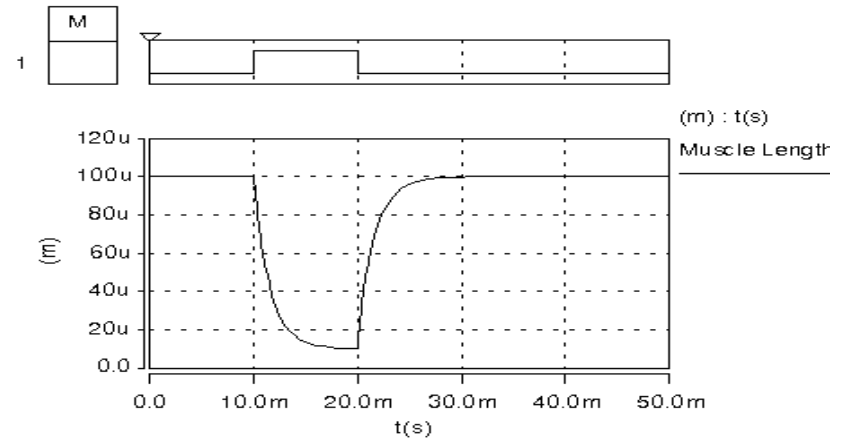
→ Introduction

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VHDL-AMS

→ Muscles
  → Complex Entities
  → Model Behaviour

→ C Elegans Body Model

→ Sensory Information
  → Chemical Gradients

→ Virtual Experiments

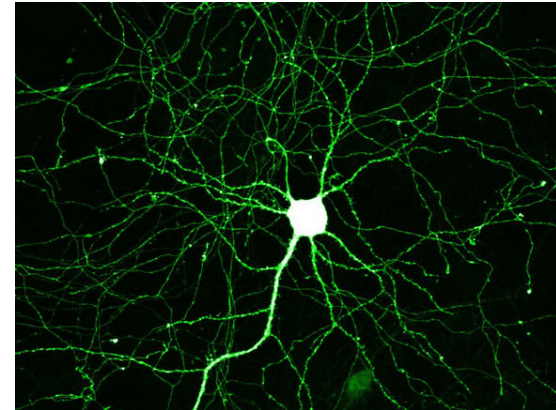# Synthesis

➜ **Synthesis to Hardware**

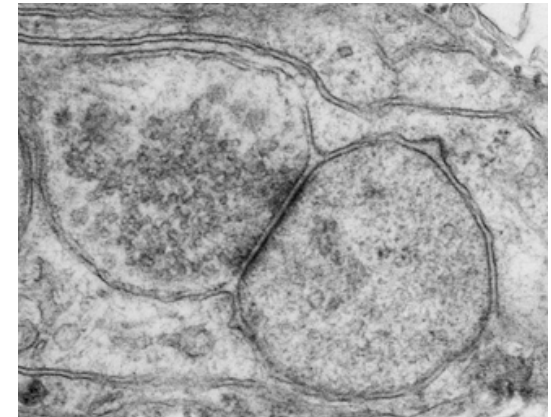   ➜ Single Neuron
        ➜ 330 - 411 Function Generators
        ➜ 143 - 116 D-Type Flip-Flops

    ➜ Single Synapse
        ➜ 1053 Function Generators
        ➜ 446 D-Type Flip-Flops

Stained Hippocampal Neuron [1]


SEM image of a Synapse [2]

[1] - EnCor Biotechnology 2003, http://strangepaths.com/wp-content/uploads/2006/10/neuron.jpg
[2] - City of Hope National Medical Center and Beckman Research Institute,
http://www.cityofhope.org/NR/rdonlyres/6683468D-846E-470F-8732-31AA8841673C/0/NeuronalSynapse.jpg

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Synthesis

➔ **C Elegans Locomotion Design**
  ➔ Very Large (Approx. 201,558 FGs, 85,280 DFFs)

➔ **What happens after synthesis?**

  ➔ Watch activity on oscilloscope
    ➔ Easily Compare to Simulations

  ➔ Interface to PC
    ➔ Real-Time Simulation
    ➔ Hardware Accelerator
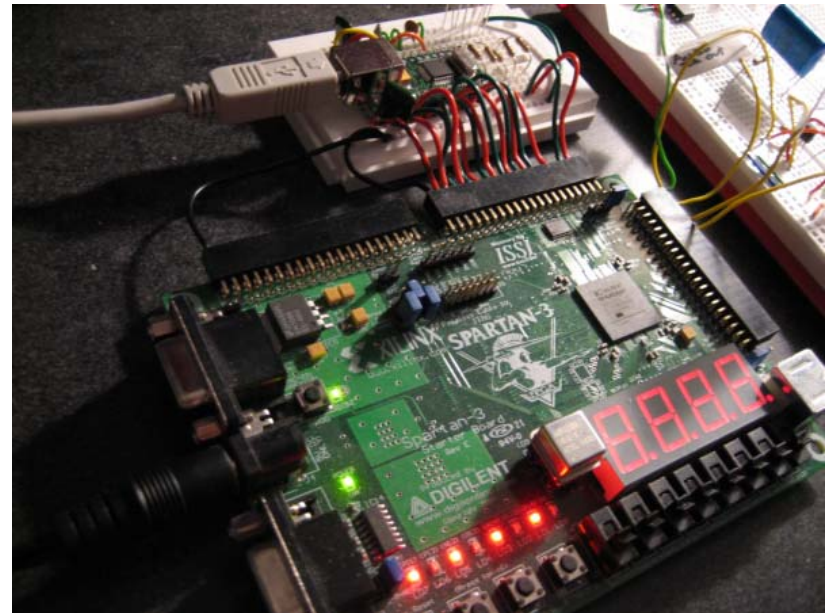
→ Mechanical Body Model – C Elegans

→ Synthesis to Hardware
  → Interface to PC
  → Hardware Acceleration

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Summary

→ **State Automata Model**

   → VHDL Library – LibNeuron

→ **C Elegans Locomotion System**

   → Verified against previous work

→ **VHDL-AMS Behavioural Muscle Model**

   → Verified against Experiments

   → Mechanical Body Model

→ **Synthesis to Hardware**

   → Hardware Acceleration of Simulations

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Thanks For Listening!

→ Any Questions ?

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