Engineering Tripos Part IIB, 4G3: Computational Neuroscience, 2017-18

Leader
Prof M Lengyel [1]

Lecturer
Prof M Lengyel and Dr G Hennequin

Timing and Structure
Lent term. 16 lectures. Assessment: 100% coursework

Prerequisites
3G2 and 3G3 is useful.

Aims
The aims of the course are to:

- introduce alternative ways of modelling single neurons, and the way these single neuron models can be integrated into models of neural networks.
- describe the challenges posed by neural coding and decoding, and the computational methods that can be applied to study them.
- demonstrate case studies of computational functions that neural networks can implement.
- describe models of plasticity and learning and how they apply to the basic paradigms of machine learning (supervised, unsupervised, reinforcement) as well as pattern formation in the nervous system.
- consider control tasks (sensorimotor and other) faced and solved by the nervous system.
- examine the energy efficiency of neural computations.

Objectives
As specific objectives, by the end of the course students should be able to:

- understand how neurons, and networks of neurons can be modelled in a biomimetic way, and how a systematic simplification of these models can be used to gain deeper insight into them.
- develop an overview of how certain computational problems can be mapped onto neural architectures that solve them.
- recognise the essential role of learning is the organisation of biological nervous systems.
- appreciate the ways in which the nervous system is different from man-made intelligent systems, and their implications for engineering as well as neuroscience.

Content
Note that for the 2016-17 academic year, this module is running in DAMTP and so the information below may not be accurate.
The course covers basic topics in computational neuroscience, and demonstrates how mathematical analysis and ideas from dynamical systems, machine learning, optimal control, and probabilistic inference can be applied to gain insight into the workings of biological nervous systems. The course also highlights a number of real-world computational problems that need to be tackled by any ‘intelligent’ system, as well as the solutions that biology offers to some of these problems.

**Principles of Computational Neuroscience (7L, M Lengyel, CUED)**

- how is neural activity generated? mechanistic neuron models
- how to predict neural activity? descriptive neuron models
- what should neurons do? normative neuron models
- how to read neural activity? neural decoding
- what happens when many neurons are connected? neural networks
- how to tell a neural network what to do? supervised learning
- how can neuronal networks learn without being told what to do? unsupervised learning
- how do neural networks remember? auto-associative memory
- how can our brains achieve the goal of life? reinforcement learning

**Network dynamics (2L, D Barrett, Engineering)**

- linear and non-linear network dynamics

**Representational learning (3L, Dr R Turner)**

- Bayesian inference and learning
- generative models and receptive fields

**Synaptic plasticity and unsupervised learning (2L, H Sprekeler, CUED)**

- Hebbian plasticity
- spike timing-dependant plasticity
- learning receptive fields

**Energy aspects of neural computation (2L, S Laughlin, Zoology)**

- energetics of information processing
- the energetic cost of spikes and synapses

**Further notes**

For more information, see the course web page [2].

**Examples papers**

N/A

**Coursework**

For information on coursework, see the course web page [2].
Coursework

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<th>Format</th>
<th>Due date &amp; marks</th>
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<td>Individual/group Report / Presentation</td>
<td>Thu week 3 [xx/60]</td>
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Coursework 1 brief description

Learning objective:

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<td>Individual Report</td>
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Coursework 2 brief description

Learning objective:

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Booklists

Please see the Booklist for Group G Courses [3] for references for this module.

For more information, see the course web page [2].

Examination Guidelines

Please refer to Form & conduct of the examinations [4].

UK-SPEC

The UK Standard for Professional Engineering Competence (UK-SPEC) [5] describes the requirements that have to be met in order to become a Chartered Engineer, and gives examples of ways of doing this.

UK-SPEC is published by the Engineering Council on behalf of the UK engineering profession. The standard has been developed, and is regularly updated, by panels representing professional engineering institutions, employers and engineering educators. Of particular relevance here is the 'Accreditation of Higher Education Programmes' (AHEP) document [6] which sets out the standard for degree accreditation.

The Output Standards Matrices [7] indicate where each of the Output Criteria as specified in the AHEP 3rd edition document is addressed within the Engineering and Manufacturing Engineering Triposes.

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