NEUR0016
Neural computation: Models of brain function
draft 2022 timetable.

Module organisers: Prof. Caswell Barry & Prof. Neil Burgess

**Contact details**
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Prof. Neil Burgess: n.burgess@ucl.ac.uk

Further course information available on Moodle.
NEUR0016 – 15 credit
Module aims and objectives

Aims
1. To introduce the consideration of neurons and synapses in terms of their computational properties and interpretation of their action in terms of information processing.
2. To introduce the analysis of an animal’s ability to learn, remember or act in terms of the action of neurons and synapses within the animal’s nervous system.
3. To understand several examples of how the action of individual neurons and synapses in various parts of the central nervous system contribute to the learning, memory or behaviour of an organism.

Method of assessment
NEUR0016 is a 15 credit module

Undergraduate BSc and 4th year MSci students: Coursework essay analysing a research paper, max. 2000 words. Papers for your essay available on the Moodle site and listed at the end of this booklet. You will make a 5 min presentation about a paper to get feedback (not marked) in weeks 12, 13 or 14. The essay mark constitutes 10% of the final mark for the course.

Final assessment constitutes the remaining 90% of the mark for the course. This was a 3 hour exam (pre-covid) or an open book essay (2500 words) for 3rd year BSc or 4th year MSci students.

MSc students, and affiliate students (leaving before May): One 3,000 word essay, chosen from these titles:

- Can a mechanistic neuron-level understanding of some aspects of cognition be attained?

  Discuss the approximations made in computational approaches to understanding the functional properties of networks of neurons, including when and how they have proved to be useful.

  Describe examples where understanding of the electrophysiological behaviour of neurons allows increased understanding of the behaviour of the organism.

  The deadline for essays is 2:00pm Tuesday January 10th 2023.
# NEUR0016 Neural computation: Models of brain function

**Provisional Timetable Autumn 2022**

3 hours/week. 2 hrs on Weds 1hr on Friday. **For lecture locations please check:**
https://timetable.ucl.ac.uk/tt/moduleTimet.do?firstReq=Y&moduleId=NEUR0016

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Subject</th>
<th>Lecturer</th>
<th>Location</th>
<th>Week</th>
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</thead>
<tbody>
<tr>
<td>Wed 19</td>
<td>11:00–12:00</td>
<td>Intro to artificial neural networks &amp; unsupervised learning.</td>
<td>Prof Neil Burgess</td>
<td>Drayton House B20 Jevons LT</td>
<td>8</td>
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<tr>
<td>Oct</td>
<td>12:00–13:00</td>
<td></td>
<td>Prof Neil Burgess</td>
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<td></td>
<td></td>
<td>Intro to artificial neural networks &amp; unsupervised learning, cont.</td>
<td>Prof Neil Burgess</td>
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<tr>
<td>Fri 21</td>
<td>10:00–11:00</td>
<td>Intro to artificial neural networks &amp; unsupervised learning, cont 2.</td>
<td>Prof Neil Burgess</td>
<td>Chandler House G10</td>
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<td>Oct</td>
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<tr>
<td>Wed 26</td>
<td>11:00–12:00</td>
<td>Computational properties of individual neurons</td>
<td>Prof David Attwell</td>
<td>Drayton House B20 Jevons LT</td>
<td>9</td>
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<tr>
<td>Oct</td>
<td>12:00–13:00</td>
<td>Simple supervised learning in artificial neural networks</td>
<td>Prof Neil Burgess</td>
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<tr>
<td>Fri 28</td>
<td>10:00–11:00</td>
<td>More advanced learning algorithms in artificial neural networks.</td>
<td>Prof Neil Burgess</td>
<td>Chandler House G10</td>
<td>9</td>
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<td>Oct</td>
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<tr>
<td>Wed 2</td>
<td>11:00–12:00</td>
<td>More advanced learning algorithms in artificial neural networks, cont.</td>
<td>Prof Neil Burgess</td>
<td>Drayton House B20 Jevons LT</td>
<td>10</td>
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<tr>
<td>Nov</td>
<td>12:00–13:00</td>
<td>The hippocampus and spatial representation.</td>
<td>Prof Caswell Barry</td>
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<td>Fri 4</td>
<td>10:00–11:00</td>
<td>Model(s) of conscious awareness</td>
<td>Prof Neil Burgess</td>
<td>Chandler House G10</td>
<td>10</td>
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<tr>
<td>Nov</td>
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**Week 11 = Reading Week.**
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Topic</th>
<th>Speaker</th>
<th>Location</th>
<th>Room</th>
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<tbody>
<tr>
<td>Wed 16 Nov</td>
<td>11:00–12:00</td>
<td>Reinforcement learning.</td>
<td>Prof Neil Burgess</td>
<td>Drayton House B20 Jevons LT</td>
<td>12</td>
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<td></td>
<td>12:00–13:00</td>
<td>Reinforcement learning.</td>
<td>Prof Neil Burgess</td>
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<tr>
<td>Fri 18 Nov</td>
<td>10:00–11:00</td>
<td>Path integration, continuous attractors and grid cells.</td>
<td>Prof Caswell Barry</td>
<td>Chandler House G10</td>
<td>12</td>
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<tr>
<td>Wed 23 Nov</td>
<td>11:00–12:00</td>
<td>Hippocampus and associative memory.</td>
<td>Prof Caswell Barry</td>
<td>Drayton House B20 Jevons LT</td>
<td>13</td>
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<tr>
<td></td>
<td>12:00–13:00</td>
<td>Hippocampus and associative memory, cont.</td>
<td>Prof Caswell Barry</td>
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<td>Fri 25 Nov</td>
<td>10:00–11:00</td>
<td>STRIKE – FINAL LECTURE WILL NOW BE ON THE 16TH DEC</td>
<td>n/a</td>
<td>n/a</td>
<td>13</td>
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<tr>
<td>Wed 30 Nov</td>
<td>11:00–12:00</td>
<td>STRIKE – all presentations now on 7TH Dec</td>
<td>n/a</td>
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<td></td>
<td>12:00–13:00</td>
<td>STRIKE</td>
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<tr>
<td>Fri 2 Dec</td>
<td>10:00–11:00</td>
<td>Learning performing &amp; remembering serially ordered actions</td>
<td>Prof Caswell Barry</td>
<td>Chandler House G10</td>
<td>14</td>
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<tr>
<td>Wed 7 Dec</td>
<td>11:00–12:00</td>
<td>Student presentation of essay papers (small groups)</td>
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<td>various locations</td>
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<tr>
<td></td>
<td>12:00–13:00</td>
<td>Student presentation of essay papers (small groups)</td>
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<td>Fri 9 Dec</td>
<td>10:00–11:00</td>
<td>Hippocampal and striatal navigation.</td>
<td>Prof Caswell Barry</td>
<td>Chandler House G10</td>
<td>15</td>
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<tr>
<td>Wed 14 Dec</td>
<td>11:00–12:00</td>
<td>Spatial processing in the spine and motor cortex.</td>
<td>Prof Caswell Barry</td>
<td>Drayton House B20 Jevons LT</td>
<td>16</td>
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<td></td>
<td>12:00–13:00</td>
<td>Computing with spike timing and delays.</td>
<td>Prof Neil Burgess</td>
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<tr>
<td>Fri 16 Dec</td>
<td>10:00–11:00</td>
<td>Temporal processing in audition and olfaction.</td>
<td>Prof Caswell Barry</td>
<td>Chandler House G10</td>
<td>16</td>
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General reading list

General: Fundamentals of Computational Neuroscience by Thomas Trappenberg (OUP, 2002)

Artificial Neural Networks:
1. An Introduction to Neural Networks, James A. Anderson (MIT Press, 1995);
2. An Introduction to Neural Networks, Kevin Gurney (UCL Press, 1997);

Biological neural networks:

Models of brain systems/ systems neuroscience:

Computational Neuroscience (includes most things, but v. mathematical)
Specific reading lists

For students interested in the details of a particular lecture (lecturers may also give additional references during the lecture).

Introduction to artificial neural networks and unsupervised learning.
- Books 1,2,8.

Simple supervised learning in artificial neural networks
- Books 1,2,5.

More advanced learning algorithms in artificial neural networks
- Books 1,2,4,6

Computational properties of neurons
- Books 8,9,10.

Spatial processing in the spine and motor cortex

The hippocampus and spatial representation
- Book 13

Path integration, continuous attractors & grid cells

Hippocampal and striatal navigation


The hippocampus and associative memory


Reinforcement learning


Learning, performing and remembering serially ordered actions


Temporal processing: Models of audition and olfaction


Model(s) of conscious awareness


Computing with spike timing and delay


Objectives

By the end of the following lectures the students should be able to:

Introduction to artificial neural networks and unsupervised learning (3hrs)

- Understand simple mathematical models of how a neuron’s firing rate depends on the firing rates of the neurons with synaptic connections to it.
- Describe how Hebbian learning rules relate change in synaptic weights to the firing rates of the pre- and post-synaptic neurons.
- Describe how application of these rules can lead to self-organisation in artificial neural networks.
- Relate self-organisation in artificial neural networks to organisation of the brain, such as in topographic maps.
- Explain how Hebbian learning in recurrent connections between neurons can create an associative memory.

Artificial neural networks, simple supervised learning (1 hr)

- Describe how a set of examples of stimuli and correct responses can be used to train an artificial neural network to respond correctly via changes in synaptic weights governed by the firing rates of the pre- and post-synaptic neurons and the correct post-synaptic firing rate.
- Describe how this type of learning rule is used to perform pattern classification in a Perceptron.

More advanced learning algorithms in artificial neural networks (2 hrs)

- Discuss the limitation of simple supervised learning algorithms such as the Perceptron, and the use of multi-layered networks to overcome them.
- Explain the problems posed to learning by the credit assignment problems caused by correct responses not being provided for each neuron, or for each stimulus.
- Discuss how reinforcement learning and genetic algorithms overcome the problems of temporal credit assignment and how error back-propagation and the use of forward models can overcome the problem of credit assignment for neurons contributing indirectly to the network’s output.
- Discuss the relative biological plausibility of these learning algorithms

Computational properties of neurons (1 hr)

- Discuss how information can be coded by a neuron’s membrane potential as graded potentials or action potentials.
- Explain how processing of synaptic signals as graded potentials allows the operations of addition, subtraction, multiplication and division to be carried out by an individual neuron.

Spatial processing in the spine and motor cortex (1 hr)

- Explain the idea of a ‘convergent force field’ and how the combination of a small number of these could used to control limb movements to an arbitrary end point.
- Understand how a large number of broadly tuned neurons can provide an accurate code via their net ‘population vector’.
- Discuss how the spine and motor cortex together could control movement, with motor cortex providing a population vector of reaching direction and the spine solving the complex transformation to muscle tensions by producing convergent force fields.

The hippocampus and associative memory (2 hrs)

- Understand how an associative memory matrix stores information by switching synapses on
such that a pattern of activation in the output is reproduced by representation of the pattern of activation in the inputs.

- Explain what is meant by the terms content-addressable, pattern completion, error correction, interference, hetero-association and auto-association.
- Describe how the Chadwick of the hippocampal region CA3 is consistent with a role as an associative memory matrix.

The hippocampus and spatial representation (1 hr)

- Explain how unsupervised competitive learning could lead to the formation of location-specific firing in hippocampal ‘place cells’, and how the rat’s movement during learning would determine the effect the rat’s orientation has on their firing rates (Sharp, 1991).
- Discuss Sharp’s model & subsequent expts. Inputs sensitive to the distance of landmarks appear to be present (O’Keefe & Burgess, 1996), but place cell firing is probably non-directional to start with (not learned) & a fixed feed-forward model is sufficient to model the firing of cells (Hartley et al., 2000; Zipser, 1986). Synaptic plasticity may be required, but for stability and robustness of place cell representation (Kentros et al., 2000; Nakazawa wt al., 2002).

Path integration, continuous attractors & grid cells (1 hr)

- Understand the idea of path integration, and how it might contribute to navigation and place cell firing.
- Discuss the continuous attractor model of place cell firing
- Describe the firing pattern of grid cells in entorhinal cortex and why they might be suitable to produce the path integration input to place cells.

Hippocampal and striatal navigation (1 hr)

- Describe how place cells could be used as a spatial memory for the proximity of a goal by synaptic change at the goal location.
- Describe how routes to a goal could be learned by modifying connections between the hippocampus and nucleus accumbens (Brown & Sharp, 2000), including the relevance of the limitations of perceptrons to linearly-separable functions and the problem of temporal credit-assignment

Reinforcement learning (2 hrs)

- Discuss formal models of classical and instrumental conditioning in animals
- Describe how reinforcement learning (e.g. using the temporal difference learning rule) solves the ‘temporal credit assignment’ problem in learning to act from infrequent reward.
- Describe how the involvement of neuromodulators, such as dopamine, in reward and punishment learning is included in these models.

Learning, performing and remembering serially ordered actions (1 hr)

- Explain how asymmetric recurrent connections can be used to learn a chain of association.
- Discuss the limitation of associative chaining as a model for response selection.
- Describe the competitive queuing model of response selection, and how it applies to human short-term memory for serial order.

Temporal processing: Models of audition and olfaction (1 hr)

- Understand how delay lines and coincidence detection can be used to produce responses tuned to inputs with specific time differences.
- Explain how the auditory system of the Barn Owl can detect inter-aural time differences and use this information to determine the azimuthal angle of a sound
- Describe how the rat olfactory system solves the problem of detecting weak odours masked by the presence of strong odours.
Model(s) of conscious awareness (1 hr)

- Understand the different temporal durations required for stimuli to enter consciousness.
- Discuss some examples of the detection of information in the brain that is not available for conscious report (e.g. subliminal priming, skin conductance responses, blindsight).
- Explain how a model of modules with fast feed-forward processing and slower relaxation to attractor states could explain some of the differences between unconscious and conscious processing.

Using spike timing and delays (1 hr)

- Discuss the problems of the standard models using firing-rates and synaptic weights have encoding both absolute and relative sizes of stimuli.
- Describe the alternative model of using spike timing with respect to an oscillatory potential and delay lines to encode information.
- Discuss the biological plausibility and functional advantages and disadvantages of this model.
Essay subject matter:


Copies of these papers can be found here:
https://www.ucl.ac.uk/icn/neur0016-neural-computation-models-brain-function