3041
Neural computation: Models of brain function
2009 provisional timetable.

Course organiser: Prof. Neil Burgess

- Contact details

  Prof. Neil Burgess:   Tel: 020 7679 1147 (x21147 within UCL)
  e-mail: n.burgess@ucl.ac.uk
  office: rm 203 Alexandra House, 17 Queen Square.
3041 – Half unit.

Course 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.

Structure of the course

½ unit course (for intercalating and 3rd year neuroscience BSc students; + G041 for MSc students)

There is one course essay and a 3 hour exam (undergraduates) and a long essay (MSc students).

The essay consists of analysing a research paper (these will be distributed during the course), max. 2000 words. The essay constitutes 10% of the final mark for the course, and should be e-mailed to NB by deadline provided. The exam constitutes the remaining 90% of the final mark for the course.

3041 Neural computation: Models of brain function

Provisional Timetable Autumn 2009.

Lectures: Wednesday 11-1 in room B15, Anatomy Dept. (in basement; entrance on Gower St.); Friday 10-11 in room B10, Institute of Cognitive Neuroscience (17 Queen Sq.). NB the order/topic of lectures may change.
<table>
<thead>
<tr>
<th>Week</th>
<th>Day</th>
<th>Time</th>
<th>Subject</th>
<th>Lecturer</th>
<th>Venue</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Wed</td>
<td>14 Oct 11:00 – 13:00</td>
<td>Introduction to artificial neural networks and unsupervised learning.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building, Room B15</td>
</tr>
<tr>
<td>8</td>
<td>Wed</td>
<td>16 Oct 10:00 – 11:00</td>
<td>Introduction to artificial neural networks and unsupervised learning, cont.</td>
<td>Prof. Neil Burgess</td>
<td>Room 105a, Roberts Bldg</td>
</tr>
<tr>
<td>8</td>
<td>Wed</td>
<td>21 Oct 11:00 – 12:00</td>
<td>Artificial neural networks, feedback and simple supervised learning.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building, Room B15</td>
</tr>
<tr>
<td>8</td>
<td>Wed</td>
<td>23 Oct 12:00 – 13:00</td>
<td>Computational properties of neurons.</td>
<td>Prof. David Attwell</td>
<td>Anatomy Building, Room B15</td>
</tr>
<tr>
<td>8</td>
<td>Fri</td>
<td>25 Oct 10:00 – 11:00</td>
<td>Introduction to more advanced learning algorithms in artificial neural networks.</td>
<td>Prof. Neil Burgess</td>
<td>Room B10, ICN 17 Queen Sq.</td>
</tr>
<tr>
<td>9</td>
<td>Wed</td>
<td>28 Oct 11:00 – 12:00</td>
<td>Introduction to more advanced learning algorithms in artificial neural networks, cont.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building, Room B15</td>
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<tr>
<td>9</td>
<td>Wed</td>
<td>30 Oct 12:00 – 13:00</td>
<td>The hippocampus and spatial representation.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building, Room B15</td>
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<tr>
<td>9</td>
<td>Fri</td>
<td>30 Oct 10:00 – 11:00</td>
<td>Path integration, continuous attractors and grid cells.</td>
<td>Dr Caswell Barry</td>
<td>Room B10, ICN 17 Queen Sq.</td>
</tr>
<tr>
<td>10</td>
<td>Wed</td>
<td>4 Nov 11:00 – 12:00</td>
<td>Hippocampal and striatal navigation.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building, Room B15</td>
</tr>
<tr>
<td>10</td>
<td>Wed</td>
<td>4 Nov 12:00 – 13:00</td>
<td>Reinforcement learning.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building, Room B15</td>
</tr>
<tr>
<td>10</td>
<td>Fri</td>
<td>6 Nov 10:00 – 11:00</td>
<td>Reinforcement learning, cont.</td>
<td>Prof. Neil Burgess</td>
<td>Room B10, ICN 17 Queen Sq.</td>
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Reading Week: Monday 9 to Friday 13 November 2009
<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Wed</td>
<td>11:00</td>
<td>Neural bases of sensory decision making.</td>
<td>Dr Peter Latham</td>
<td>Anatomy Building Room, B15</td>
</tr>
<tr>
<td>12</td>
<td>Wed</td>
<td>12:00</td>
<td>Theories of the cerebellum.</td>
<td>Dr Peter Gilbert</td>
<td>Anatomy Building Room, B15</td>
</tr>
<tr>
<td>12</td>
<td>Fri</td>
<td>10:00</td>
<td>Models of prefrontal cortex.</td>
<td>Dr Sam Gilbert</td>
<td>Room B10, ICN 17 Queen Sq.</td>
</tr>
<tr>
<td>13</td>
<td>Wed</td>
<td>11:00</td>
<td>The hippocampus and associative memory.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building Room, B15</td>
</tr>
<tr>
<td>13</td>
<td>Wed</td>
<td>12:00</td>
<td>Image processing in the early visual system.</td>
<td>Prof. Matteo Carandini</td>
<td>Anatomy Building Room, B15</td>
</tr>
<tr>
<td>13</td>
<td>Fri</td>
<td>10:00</td>
<td>Associative memory, cont.</td>
<td>Prof. Neil Burgess</td>
<td>Room B10, ICN 17 Queen Sq.</td>
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<tr>
<td>14</td>
<td>Wed</td>
<td>11:00</td>
<td>Spatial processing in the spine and motor cortex.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building Room, B15</td>
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<tr>
<td>14</td>
<td>Wed</td>
<td>12:00</td>
<td>Spatial processing in the parietal cortex.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building Room, B15</td>
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<tr>
<td>14</td>
<td>Wed</td>
<td>12:00</td>
<td>Spatial processing in the parietal cortex, cont.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building Room, B15</td>
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<tr>
<td>14</td>
<td>Fri</td>
<td>10:00</td>
<td>Short-term memory and serial order.</td>
<td>Prof. Neil Burgess</td>
<td>Room B10, ICN 17 Queen Sq.</td>
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<tr>
<td>15</td>
<td>Wed</td>
<td>11:00</td>
<td>Models of conscious awareness.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building Room, B15</td>
</tr>
<tr>
<td>15</td>
<td>Wed</td>
<td>12:00</td>
<td>Temporal processing in audition and olfaction.</td>
<td>Prof. Neil Burgess</td>
<td>Anatomy Building Room, B15</td>
</tr>
<tr>
<td>15</td>
<td>Fri</td>
<td>10:00</td>
<td>Computing with spike timing and delays + Course review.</td>
<td>Prof. Neil Burgess</td>
<td>Room B10, ICN 17 Queen Sq.</td>
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</table>
**General reading list**

**Artificial Neural Networks:**
1. An Introduction to Neural Networks, James A. Anderson (MIT Press, 1995);

**Biological neural networks:**

**Models of brain systems/ systems neuroscience:**

**Computational Neuroscience** (includes most things, but v. 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.

**Artificial neural networks, feedback & simple supervised learning**
- Books 1,2,5.

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

**Introduction to more advanced learning algorithms in artificial neural networks**
- Books 1,2,4,6

**Spatial processing in the spine and motor cortex**

**Spatial processing in the parietal cortex**
- Book 13

**The hippocampus and spatial representation**
- Book 13
Path integration, continuous attractors & grid cells


Hippocampal and striatal navigation


The hippocampus and associative memory


Short-term memory and serial order


Models of conscious awarness


Reinforcement learning

- See also Book 14, chapter 9.

Models of prefrontal cortex

cortex, cognitive control and schizophrenia: recent developments and current challenges. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 351(1346):1515-27.

(This is also reprinted as chapter 14 of: Roberts, A.C., Robbins, T.W., & Weiskrantz, L. (1998). The Prefrontal Cortex: Executive and Cognitive Functions. OUP.)

**Theories of the cerebellum**


**Temporal processing: Models of audition and olfaction**


**Image processing in the early visual system**


**Computing with spike timing and delay**


**Neural bases of sensory decision making**

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.

Artificial neural networks, feedback & simple supervised learning (1 hr)

- Explain how Hebbian learning in recurrent connections between neurons can create an associative memory.
- 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 recognition in a perceptron.

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.

Introduction to advanced learning algorithms in artificial neural networks (2hrs)

- 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

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

- 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.

Spatial processing in the parietal cortex (1hr)

- Understand how spatial information can be represented in different reference frames, e.g. retinal, head-centred etc.
• Describe how posterior parietal neurons encode stimulus location in more than one reference frame using ‘gain fields’.
• Explain how neurons with gain field responses might enable translation from one reference frame to another.
• Describe how damage to a gain field representation of location might be the cause of hemi-neglect shown by patients with lesions to parietal cortex.

The hippocampus and associative memory (1hr)
• 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 anatomy 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

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

Models of prefrontal cortex (1 hr)
• Discuss computational and behavioral studies of contextual control deficits in Schizophrenia and frontal lobe patients, e.g. in the Stroop task.
• Explain a computational hypothesis for the impairment of Schizophrenics and frontal lobe patients in override automatic but inappropriate response tendencies.
Models of consciousness (1 hr)

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

Theories of the cerebellum (1 hr)

- **Cerebellar circuitry**: Parallel and climbing fibre inputs to Purkinje cells. Influence on movement via cerebellar nuclei.
- **Marr’s theory and motor learning**: Purkinje cells receive cerebral teaching signals for movements via climbing fibres; contexts via parallel fibres. Parallel fibre synapses on P-cells modifiable when climbing fibre fires. Memory capacity of P-cells.
- **Albus**: LTD at parallel fibre synapses on P-cells, basket cells and stellate cells.
- **Gilbert**: Group of P-cells as the memorizing unit. Variable frequencies learned by P-cells (as opposed to binary outputs of Marr and Albus). How muscular actions are coordinated. Potential second teaching input to P-cells via the noradrenergic input.
- **D’Angelo and De Zeeuw**: Granular layer plasticity: potential role in cerebellar learning.
- **Rhythmic activity in the cerebellum**: possible role in “binding” of complex contexts and in temporal sequencing of movements.
- **Experimental testing of the theories**: LTD in cerebellum. Output of P-cells during learning of movements. On-beam synchrony in parallel fibres of cerebellum.

Reinforcement learning (2 hrs)

- Discuss formal models of classical and instrumental conditioning in animals
- Describe how the involvement of neuromodulators, such as dopamine, in reward and punishment learning is included in these models.

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.

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.

Image processing in the early visual system (1 hr)

- Describe the concept of receptive field from retina to visual cortex and its elaborations.
- Describe the linear and nonlinear operations that lead to visual responses from retina to visual cortex.
- Describe the strengths and limitations of using simple laboratory visual stimuli vs. complex natural-like visual stimuli to study vision.

Neural bases of sensory decision making (1 hr)
• Describe the experiment of Shadlen and Newsome (2001) and how it sheds light on sensory decision making such as the direction of motion of a visual stimulus.
• Understand how the neural responses in the lateral intraparietal area (LIP) appear to be weighing the evidence behind a decision about sensory stimuli.

**Student presentations and review (2 hrs)**
• Brief presentation of a research paper by each student.
• Questions regarding the presentations and other aspects of the course.

**Essay subject matter:**


