Computational Cognitive Neuroscience (CCN)

Peggy Seriès,

Institute for Adaptive and Neural Computation,
University of Edinburgh, UK

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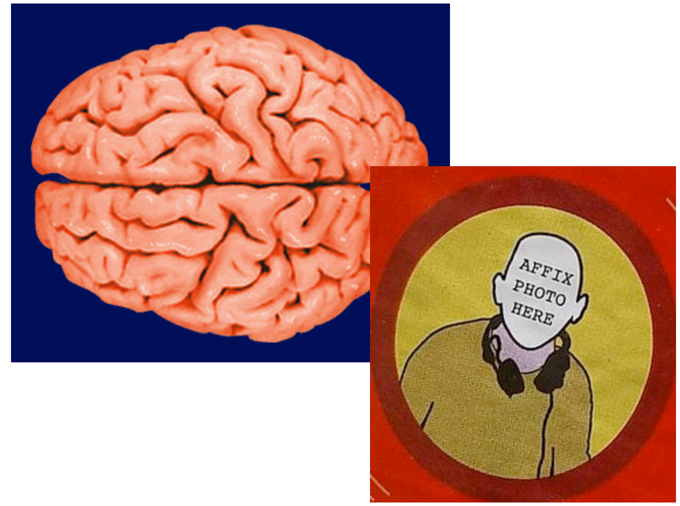
How are we ever going to understand this ?



Practical things

- **Lecturer**: Peggy Series
pseries@inf.ed.ac.uk
course materials: http://homepages.inf.ed.ac.uk/pseries

- **Tutor**: Hannes Saal

- 2 **Lectures** / week:
Monday 11 am, Thursday 11 am -- DHT 4.01.

- **Labs**: one week/2 (5 labs in total).
Fridays 12 pm AT 5.08 - starting Jan 22nd.
Matlab implementation of simple models.

- **Office hour**. Thursday 12 - 1 am (after class) in my office IF 2.47.

Practical things

- **Assessments:**

- 2 reports / Matlab implementation of simple models. (50%)
- 1 paper on an article (or 2) of your choice. See 'tips'. If unsure, ask me. (50%)

- **no textbook**, useful references:

- Dayan & Abbott, Theoretical Neuroscience, MIT press (online)
- O Reilly, Computational explorations in cognitive neuroscience, MIT press (online)
review papers that i will provide.

- Textbooks in Cognitive Science will help, e.g. the student's guide to cognitive neuroscience, J. Ward, Psychology Press. (basic).

what is Computational Cognitive Neuroscience ?

The tools of computational neuroscience + The questions (and data) of cognitive neuroscience

1) Cognitive Neuroscience: Questions

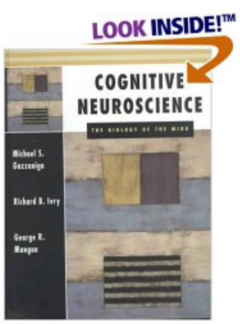
- How does the brain create our mental world?

How does the physical substance (body) give rise to our sensations, feelings, thoughts and emotions? (our mind)

- physical reductionism
- = psychology meeting neuroscience
- perception, action, language, attention and memory

1) Cognitive Neuroscience: Questions

perception, action, language, attention and memory



Gazzaniga

1- A Brief History of Cognitive Neuroscience
2- The Substrates of Cognition
3- The Methods of Cognitive Neuroscience
4- Perception and Encoding (vision, audition)
5- Higher Perceptual Functions (object & shape recognition)
6- Attention and Selective Perception
7- Memory Systems (short term memory, long term, amnesia..)
8 - Language in the brain
9- Cerebral Lateralization and Specialization
10- Motor Control
11- Executive Functions and Frontal Lobes
12- Development and Plasticity
13- Evolutionary Perspectives
14 - The Problem of Consciousness

1) Cognitive Neuroscience: Methods

- a diversity of methods,

- psychophysics
- EEG/ERP
- MEG
- PET
- MRI/fMRI
- single neuron recordings, multiple neuron recordings.

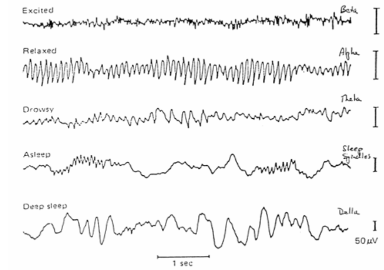
- invasive / non-invasive
- different spatial and temporal resolutions.

- recent explosion of the field due to development of new methods.

Psychophysics

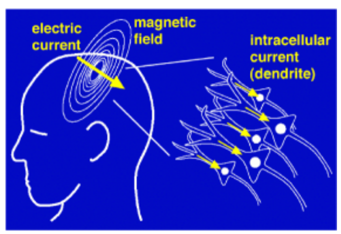
• A sub-discipline of psychology dealing with the relationship between physical stimuli and their perception (Fechner, 1860)
• uses tools from signal detection theory.
• interested in measuring thresholds of perception (just noticeable differences) in detection, discrimination.
• measuring illusions, reaction times, effects of training, group differences, effect of substance intake etc..
• non invasive: a human (or monkey) + joystick.

EEG/ERP



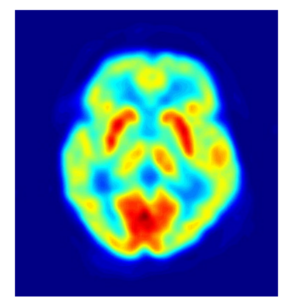
• records electrical (postsynaptic dendritic) signals generated by the brain, through electrodes placed on different points of the scalp.
• Event Related Potential (ERP): EEG waves of many trials are averaged and linked to the onset of a stimulus
• non invasive
• good temporal resolution: msec; low spatial resolution

Magneto-encephalography : MEG



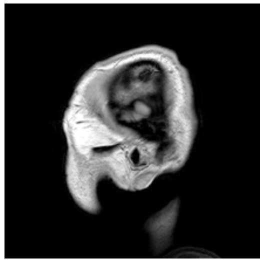
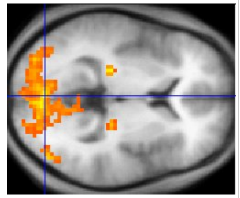
• measure magnetic fields produced by electrical activity in the brain (1968)
• good temporal resolution: msec
• better spatial resolution than EEG.

Positron Emission Tomography PET



• 1979
• uses a radioactive tracer injected in the bloodstream
• measures blood consumption.
• spatial (10 mm) and temporal resolution (30 sec) worse than fMRI.

structural MRI and fMRI

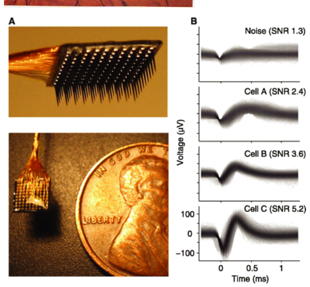
- structural MRI (1973) - detailed visualisation of differences in types of body tissue.
- functional MRI - blood oxygen level dependent (BOLD) fMRI (1990) measures magnetic signal variations related to oxygen consumption in the blood which is related to neural activity
- precise relationship with neural signals under study.
- spatial resolution : 1mm -- low temporal resolution: 1-4 sec.
- explosion of the field.

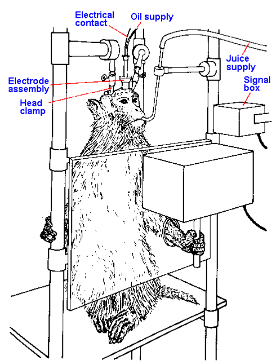
TMS: transcranial magnetic stimulation

- stimulation of the brain via a strong, transient magnetic field
- 1985
- non invasive
- spatial resolution 1 cm^2 - immediately behind the skull.
- 'virtual lesion' - brief and reversible

Single and Multi-unit neural recordings

- recording of electrical activity of single neurons
- msec time resolution
- invasive
- animal studies in anesthetized and awake.
- electrical stimulation





2) Computational Neuroscience

❖ A tool of neuroscience, use mathematical and computer models to understand how the brain works / the principles of computation and representation and their neural implementation

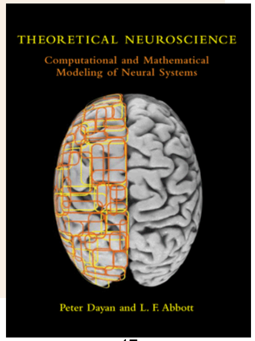
❖ Aims:
- what? description: unify data in a single framework.
- how? understand mechanisms.
- why? understand principles underlying functions (optimality for eg).
- make predictions - guide experiments. better data analysis.

❖ Many different levels of modeling (synapses, neuron, networks), levels of abstraction (computational, algorithmic, implementation) and set of tools.

❖A relatively recent field that is growing fast while its grounds / techniques are getting more solid

❖ Textbook : Dayan and Abbott (2001)

Contents



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Neuron
Perspective

Theoretical Neuroscience Rising

L.F. Abbott[1,*]
[1]Department of Neuroscience and Department of Physiology and Cellular Biophysics, Columbia University Medical Center, New York, NY 10032, USA
*Correspondence: lfabbott@columbia.edu

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Theoretical neuroscience has experienced explosive growth over the past 20 years. In addition to bringing new researchers into the field with backgrounds in physics, mathematics, computer science, and engineering, theoretical approaches have helped to introduce new ideas and shape directions of neuroscience research. This review presents some of the developments that have occurred and the lessons they have taught us.

Introduction

Twenty years ago, when *Neuron* got its start, theoretical neuroscience was experiencing a start of its own. Of course, there were important theoretical contributions to neuroscience long before 1988, most notably: the development of what we now call the integrate-and-fire model by Lapicque in 1907; the modeling of the action potential by Hodgkin and Huxley, a brilliant theoretical offshoot of their experimental work; the development of dendritic and axonal cable theory by Wilfred Rall; and the broad insights of David Marr. Nevertheless, over the past 20 years, theoretical neuroscience has changed from a field practiced by a few multitalented experimentalists and dedicated theorists (Jack Cowan,

be inconsistent and unworkable. Mathematical formulation of a model forces it to be self-consistent and, although self-consistency is not necessarily truth, self-inconsistency is certainly falsehood.

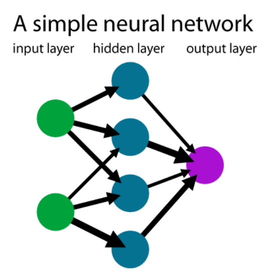
A skillful theoretician can formulate, explore, and often reject models at a pace that no experimental program can match. This is a major role of theory—to generate and vet ideas prior to full experimental testing. Having active theoretical contributors in the field allows us collectively to contemplate a vastly greater number of solutions to the many problems we face in neuroscience. Both theorists and experimentalists generate and test ideas, but due to the more rapid turnover time in mathematical

3) Computational Cognitive Neuroscience

❖ A very recent field, still in infancy

❖ Previously: Connectionism
80s, Mc Clelland, Rumelhart et al, 1986. PDP
(O Reilly's book)

Connectionism



❖ a reaction against the computer metaphor of the brain (serial computation, symbolic, if-then rules)
❖ explain how the brain works using neural networks. Mental phenomena = emergent processes of interconnected networks of simpler units.
❖ Distributed, graded representation.
❖ Showed that such networks can learn any arbitrary mapping by changing strength of connections; developed sophisticated learning rules (e.g. backpropagation).

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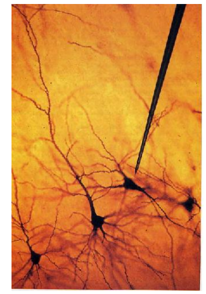
❖ New approaches. Closer to Biology. (this course)
- New data: e.g. development of electrophysiology in awake behaving monkey.
- new models: simulations of physiological data, Bayesian models

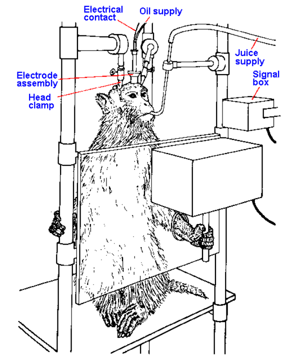
❖ a new conference -- reflects progress of the field.
http://www.ccnconference.org/

❖ Very exciting times !

Focus of this course



activity of individual neurons



response of animal / performances

Rough Schedule of the Course

• Perception: linking physiology and behavior (psychophysics)
- encoding
- decoding
• Models of neurons and networks
• Attention
• Learning: methods: supervised, unsupervised, reinforcement, and models of perceptual learning
• models of Memory
• models of Decision Making
• Bayesian Cognition
• Mental disorder (schizophrenia)

Survey

- Background
- NC, NIP, CNV (PMR)
- Matlab. (checkout primer on website).