Computational Cognitive Neuroscience (CCN)

Peggy Seriès, PhD

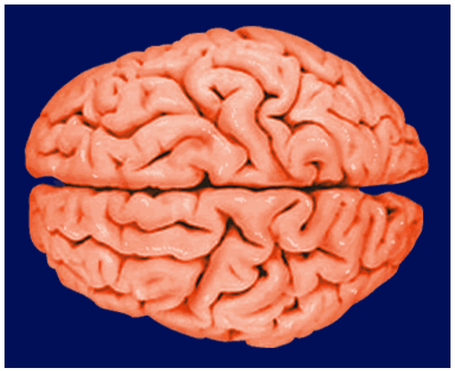
Institute for Adaptive and Neural Computation,
University of Edinburgh, UK

Autumn Term 2017

Survey

- UG4/MSc
- Informatics / others?
- Background
- NC, NIP, PMR
- Matlab. (checkout primer on website). Tutorial ?

How are we ever going to understand this ?



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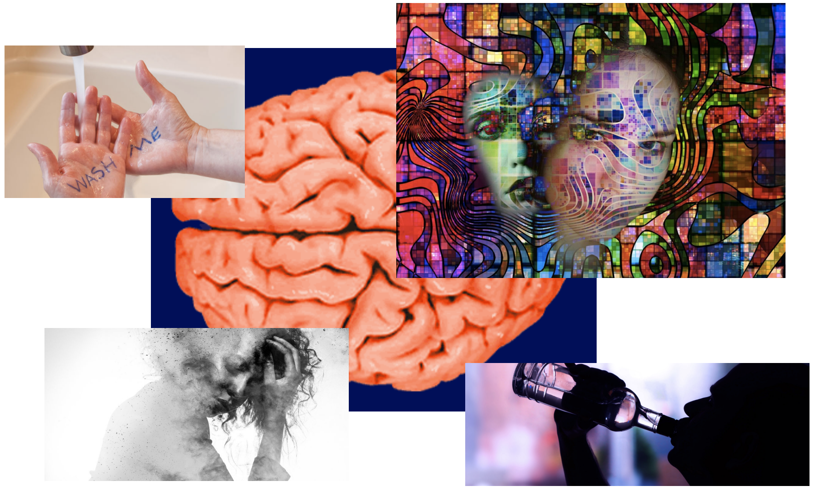


Practical things

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

- **TA:** Sam Rupprechter
- **Tutor**: Frank Karvelis

- 2 **Lectures**/ week: Monday 11.10 am, Thursday 11.10 am, 2.12 AT .

- **Labs**: week 2,4,6,8 (4 labs in total).

Location :15.10-17.00 on Tuesdays (5.05 West Lab AT) and Wednesdays (4.12 AT)

Matlab implementation of simple models.

- **Office hour**. After class, or email me or Sam.

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)
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).

Background/ what you can do this week

- Brain Facts. The SFN primer on the brain and neural system.
http://homepages.inf.ed.ac.uk/pseries/CCN/brain_facts.pdf

- for next class: read up about how neurons work, and the concept of tuning curves, basic visual perception.

- Matlab review.

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?

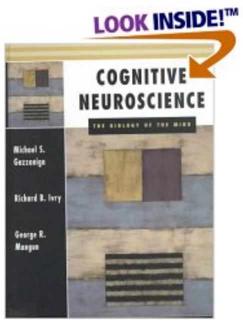
How does the physical substance (body) give rise to our sensations, feelings, thoughts and emotions? (our mind)

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

+ what goes wrong in mental disorders ?

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.

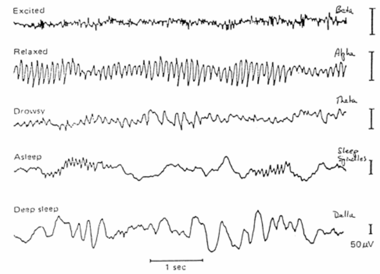
- invasive / non-invasive
- different spatial and temporal resolutions.

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

Psychophysics

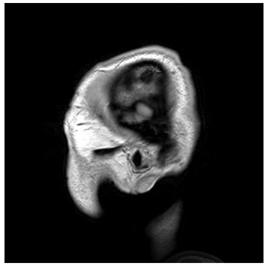
- A sub-discipline of psychology dealing with the relationship between physical stimuli and their perception (Fechner, 1860)
- uses tools from signal detection theory.
- interested in measuring thresholds of perception (just noticeable differences) in detection, discrimination.
- measuring illusions,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

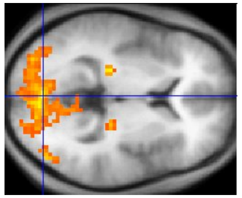
EEG/ERP



- 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

structural MRI and fMRI





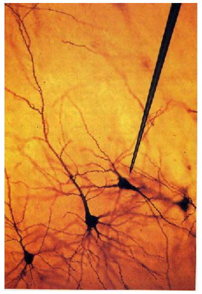
- Structural MRI (1973) - detailed visualisation of differences in types of body tissue. [http://www.youtube.com/watch?v=tD97Vhna-ic]
- Functional MRI - blood oxygen level dependent (BOLD) fMRI (1990) measures magnetic signal variations related to oxygen consumption in the blood which is related to neural activity
- precise relationship with neural signals under study (inputs to neurons).
- spatial resolution : 1mm -- low temporal resolution: 1-4 sec.
- explosion of the field. [https://www.youtube.com/watch?

TMS: transcranial magnetic stimulation

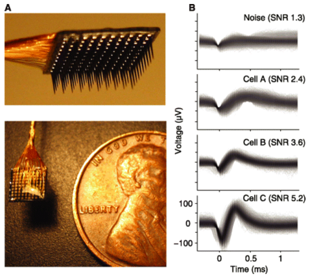
- 1985
- stimulation of the brain via a strong, transient magnetic field
- e.g. motor cortex --> activation; visual cortex --> phosphenes.
- non invasive
- spatial resolution 1 cm^2 - immediately behind the skull.
- repetitive TMS (rTMS) can lead to long term changes.
- 'virtual lesion' - brief and reversible

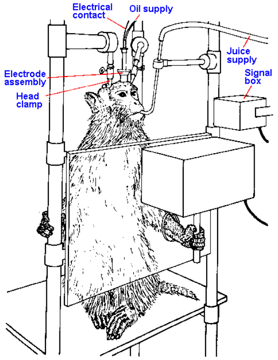
http://www.youtube.com/watch?v=XJtNPqCj-iA

Single and Multi-unit neural recordings

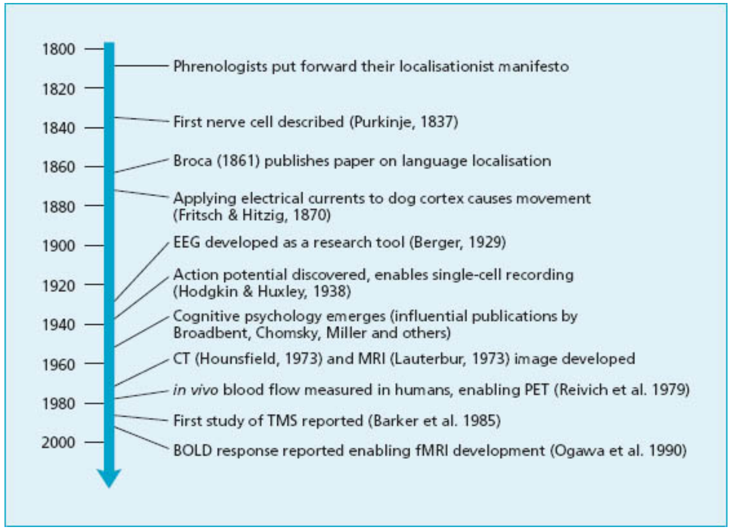


- recording of electrical activity of single neurons
- msec time resolution
- invasive
- animal studies in anesthetized and awake.
- electrical stimulation





Cognitive neuroscience time-line



from J. Ward, student's guide to cognitive neuroscience, 2007.

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

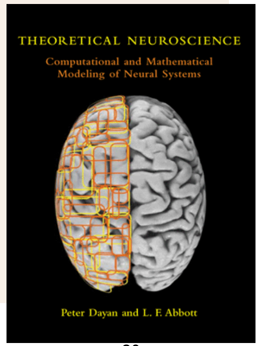
❖ Aims:
- what? description: unify data in a single framework.
- how? understand mechanisms.
- why? understand principles underlying functions (optimality for eg).
- make predictions - guide experiments. better data analysis.

❖ 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



Neuron 60, November 6, 2008 ©2008 Elsevier Inc.

Neuron
Perspective

Theoretical Neuroscience Rising

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DOI 10.1016/j.neuron.2008.10.019

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.

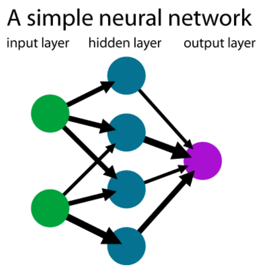
A skillful theoretician can formulate, explore, and often reject models at a pace that no experimental program can match. This is a major role of theory—to generate and vet ideas prior to full experimental testing. Having active theoretical contributors in the field allows us collectively to contemplate 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).

3) Computational Cognitive Neuroscience

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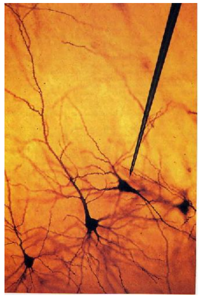
❖ New approaches. Closer to Biology. (this course)
- New data: e.g. development of electrophysiology in awake behaving monkey.
- new models: simulations of physiological data, Probabilistic / Bayesian models

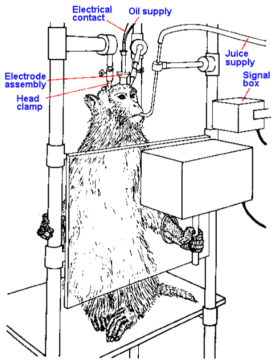
❖ new directions: decision making, psychiatry

❖ Very exciting times !

Focus of this course (1)

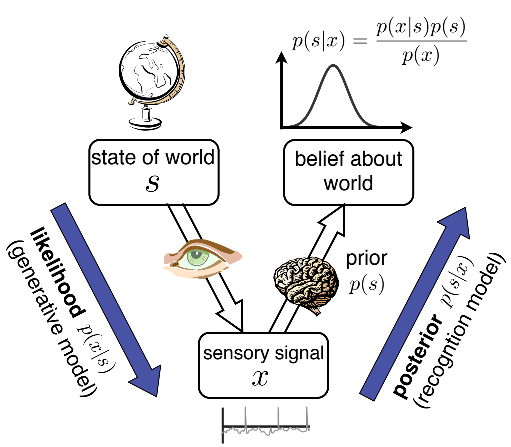


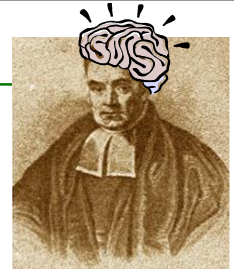
activity of individual neurons



response of animal / performances

Focus of this course (2)





The Brain a probabilistic or Bayesian machine?

Focus of this course (3)

Rough Schedule of the Course

• Perception: linking physiology and behavior (psychophysics)
- encoding
- decoding
• Models of Neurons and networks
• Learning: methods: supervised, unsupervised, reinforcement, and models of perceptual learning
• models of Memory
• models of Decision Making
• Bayesian Cognition
• Computational Psychiatry. Addiction and Mental disorders (schizophrenia, depression)