



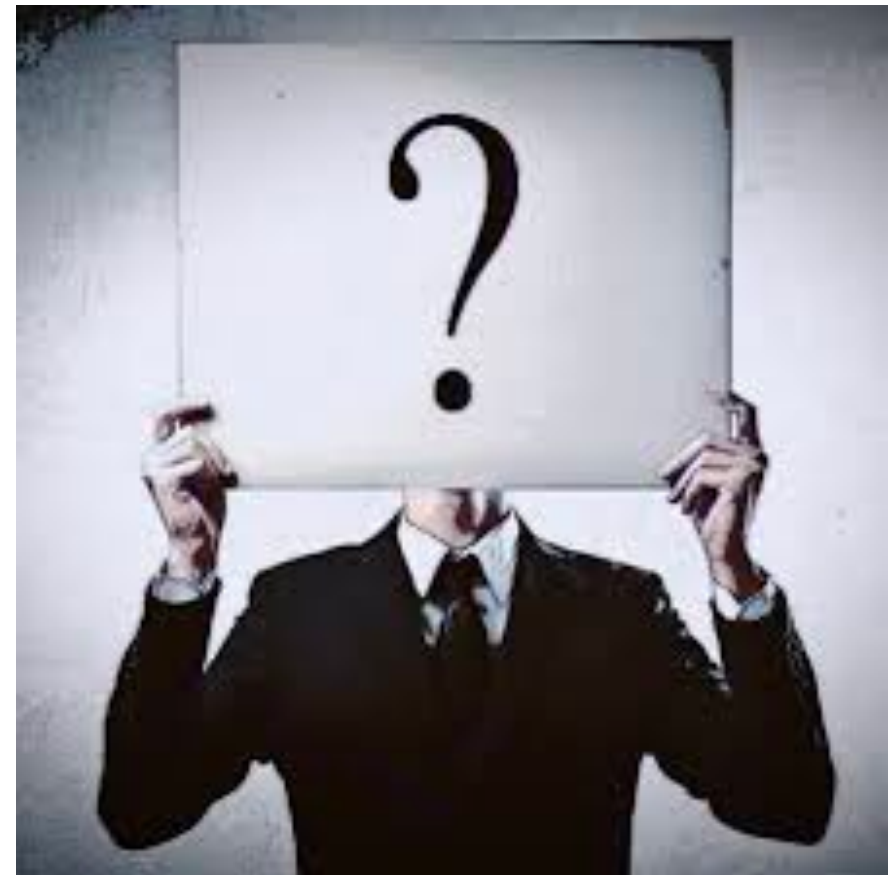
Introduction to Computational Cognitive Neuroscience (CCN)

Peggy Seriès, PhD

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

Spring 2026

- CNS?
- UG4?
- Class only?
- Informatics? PPLS? Other?
- Python?



Welcome to CCM



- **Goal of CCM:** Understand how the brain works, **how cognition and behaviour are generated by the brain, and how it can go wrong** (computational psychiatry)
- **Highly interdisciplinary field:** Combines ideas from computer science, maths, physics, biology, psychology, artificial intelligence, machine learning, etc.
- **Learning outcomes:** **understand** computational models of brain function/cognition, **implement** models in Python, **think** critically about how to model aspects of brain function and cognition, **critically evaluate** research articles in the field and **write** scientific reports, understand current challenges for **mental illness**.

Is CCN for You?



- CCN is a course about the **brain, cognition, and mental illness/psychiatry**
- We make *extensive* use of (not very advanced) **mathematics and computational/ numerical techniques** to build and interpret models of brain function and cognition
- CCN is **not** a course that is widely useful for industry or applications (such as AI/ML) - though interest is growing
- Problems in CCN are usually **open-ended**, the biology is messy, the brain is too complex to modelled exactly – you need to be comfortable with vagueness and uncertainty, and willing to do some independent reading!
- Computational neuroscience/psychiatry an extremely interesting and exciting fields!

Requirements for this Course - Maths

- **Maths:** linear algebra, probability theory, differential equations, optimisation methods
- Not very advanced but used extensively.
- Examples: linear first order ODE, Poisson distribution, matrix/vector algebra, Bayes rule, maximum likelihood

Handwritten notes illustrating Bayes' theorem for a ball selection problem. The notes are written on a white background with purple and red ink.

At the top right, it says: 40 Green Balls = G, 20 Red Balls = R.

The formula for Posterior Prob. is given as: $\text{Posterior Prob.} = \text{Prior Prob.} \times \text{Likelihood of } x$.

The likelihood of x given G is $\frac{1}{40}$. The likelihood of x given R is $\frac{3}{20}$.

The prior of Green is $\frac{40}{60}$. The prior of Red is $\frac{20}{60}$.

The posterior for green is calculated as: $\frac{40}{60} \times \frac{1}{40} = \frac{1}{60}$.

The posterior for red is calculated as: $\frac{20}{60} \times \frac{3}{20} = \frac{1}{20}$.

A comparison is made: $\frac{1}{20} > \frac{1}{60}$, with a note: "Red wins So x is Red".

A small diagram shows a circle with 'R' and 'G' inside, labeled "What is x ".

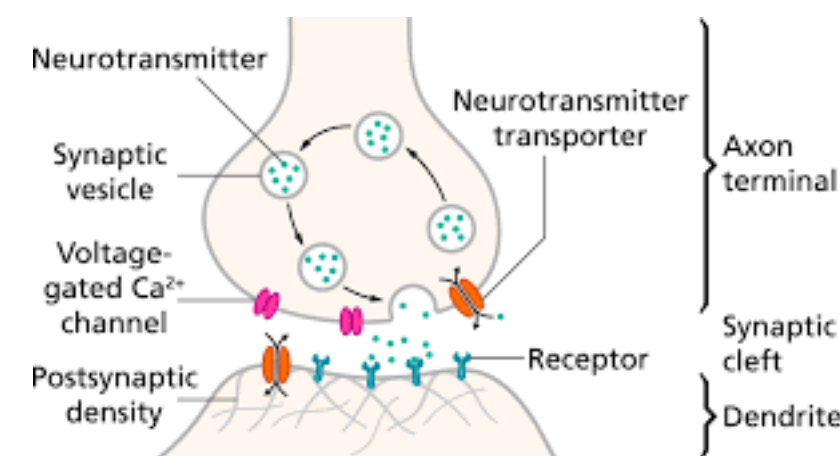
Requirements for this Course - Coding

- **Coding:** Numerical computing, typically in **Python** (previously Matlab)
- The course material assumes Python, but you are free to use any language you choose
- You will need to solve differential equations numerically, plot the results, etc.



Requirements for this Course - Biology

- No formal knowledge of neurobiology is required
- Some background reading is highly recommended (see Learn for basic resources)
- We aim to provide the bare minimum of biology needed to understand the key concepts, but there is a whole world of messy biological details out there!
- **Read the Neuroscience Primer** on Learn to get started!



Assessment

- 30% Coursework
- 70% Exam
- Assignment: Implement a model in Python. Simulate, critically evaluate, and present results in the format of a scientific report.
- **Deadlines:**
 - Assignment 1 [30%] Released 2/03 - Deadline 23/03

Lectures

- Delivered **in person** - recordings will be available on Learn Slides on Opencourse <https://opencourse.inf.ed.ac.uk/ccn>
- Lectures times: Monday & Thursday @12:10pm
Monday: 1.2 - Lister Learning and Teaching Centre
Thursday: Teaching Room 13 (01M.473) - Doorway 3 - Medical School, Teviot
- Lecturer: Peggy Seriès

Tutorials/Labs

- Labs: Every two weeks to do **at home**
- Format of labs: coding and implementation of models in Python. Labs are good practice for the assignment and will help with exam!
- *Python tutorial on week 1* – optional but highly recommended if you need a refresher for Python
(available on Opencourse <https://opencourse.inf.ed.ac.uk/ccn>)

Virtual Office Hours, Discussion, etc.

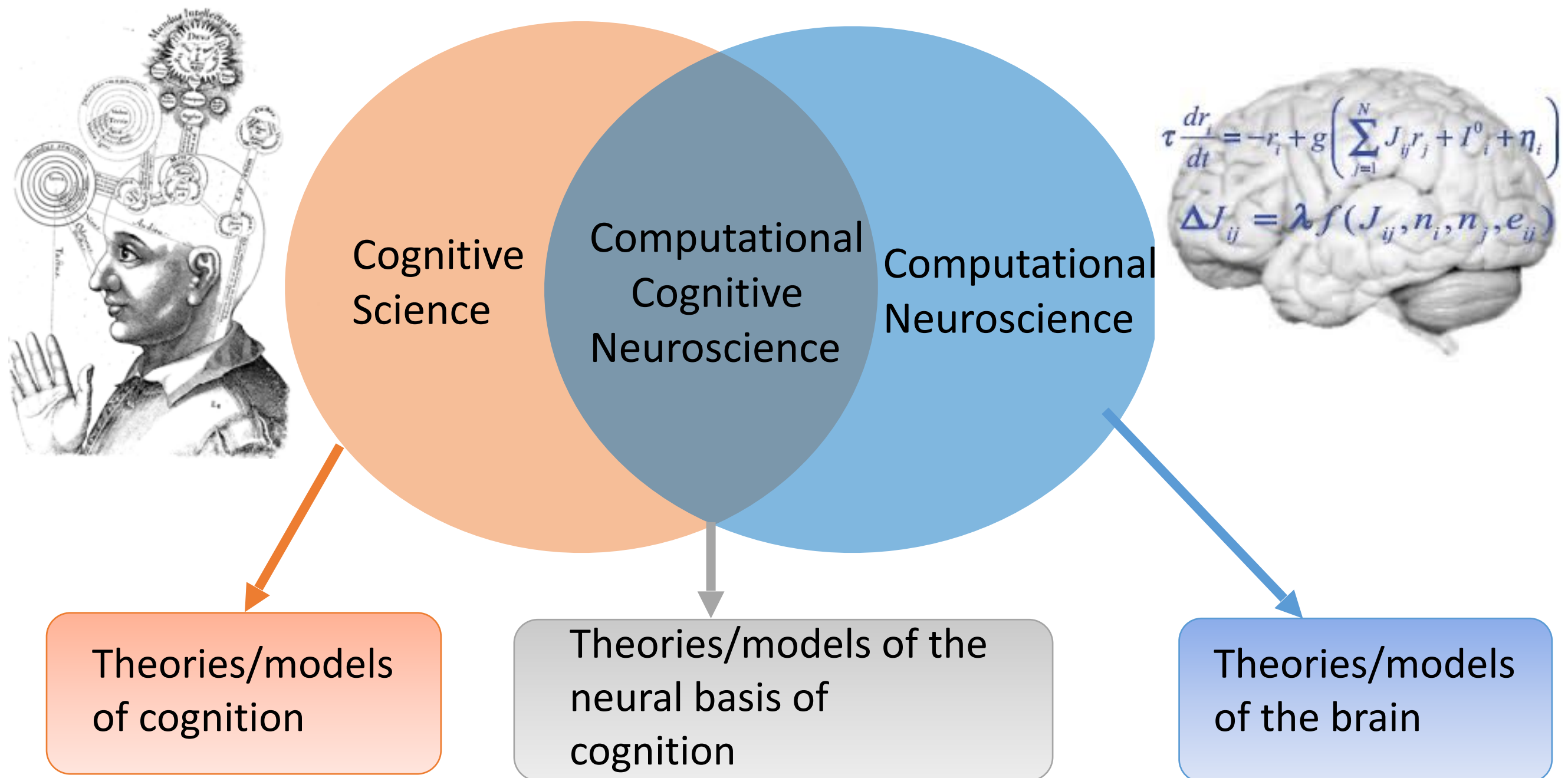
- **Office Hour:** Peggy after lectures or with TA Lars Werne (time TBC)
- **On Piazza:** Post questions/discussion about the course

Course Contacts

- **Lecturers:** Peggy Series (pseries@inf.ed.ac.uk)
- **TA:** Lars Werne (l.p.j.werne@sms.ed.ac.uk)
- **Markers:** Jeffrey Scholes (assignment)
Peggy Series (exam)



What is Computational Cognitive Neuroscience?



Questions of Computational Cognitive Neuroscience

Computational cognitive neuroscience: emphasises understanding how *cognitive processes* are implemented in the brain (a subset of computational neuroscience)

Central question:

How are **perception, learning, memory, decision making, language, etc.** generated by the concerted action of billions of neurons?

Sub-questions:

What are the underlying **principles** behind cognition (cognitive science)?
How are these principles implemented in the brain (computational neuroscience)?

The Data of Cognitive Neuroscience

Human and animal studies: primates, cats, rodents, birds, insects, etc.

Measurements of behaviour: e.g., psychophysics, memory, linguistic tasks

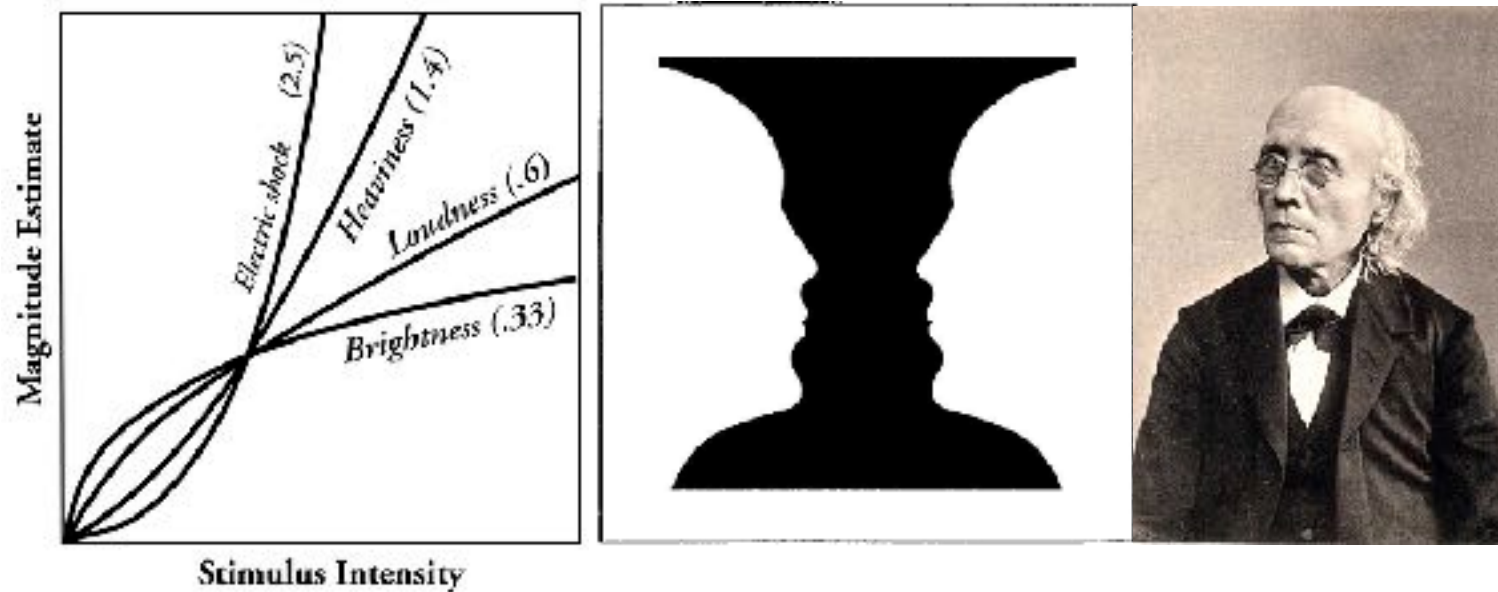
Measurements of neural activity: e.g., EEG, fMRI, intracellular recordings,

Perturbations of neural activity or behaviour: e.g., pharmacological, electrical, optogenetic

Lesion studies: e.g., accidental injuries (gunshot wounds, WW1), result of brain disease, result of corrective surgery (e.g., split brain patients)

Case studies: neurological disorders (blindsight, hemispatial neglect, face blindness...)

Measuring Behaviour/Perception



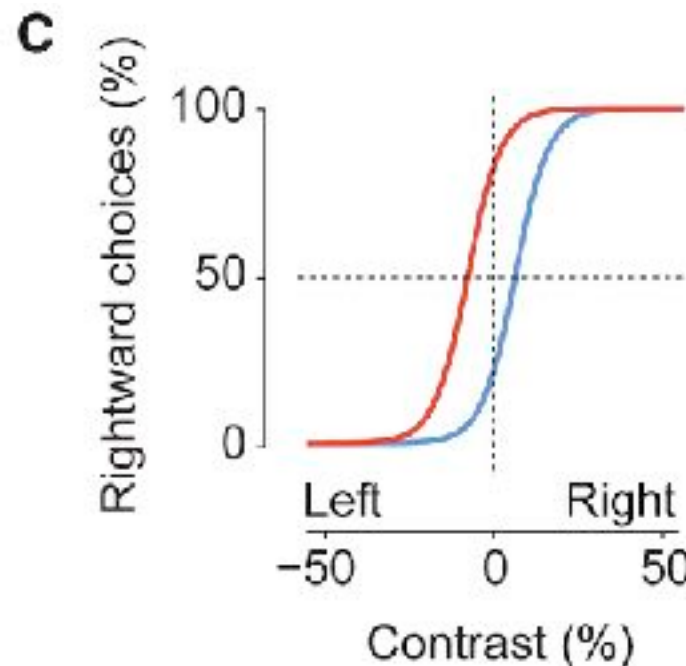
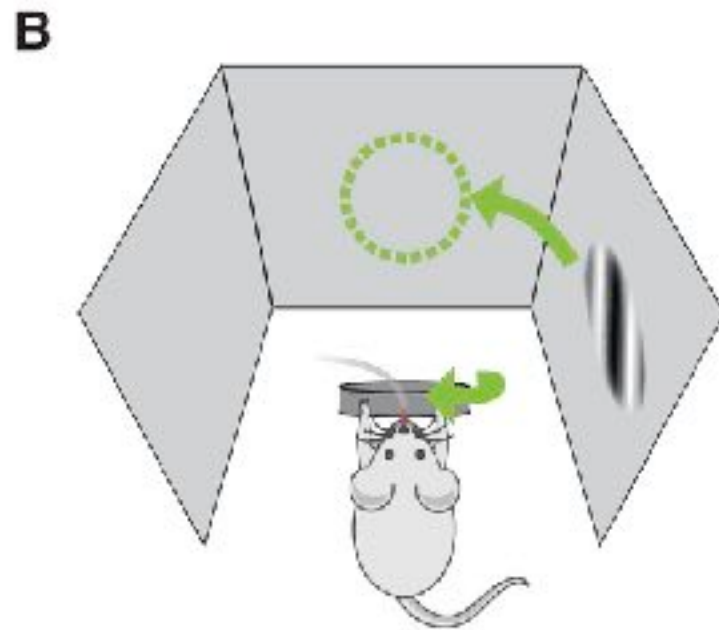
Human Psychophysics:

Behavioural report of perception

Left: How intense? (Fechner's law)

Middle: Face or vase?

Right: Gustav Fechner (1801-1887)



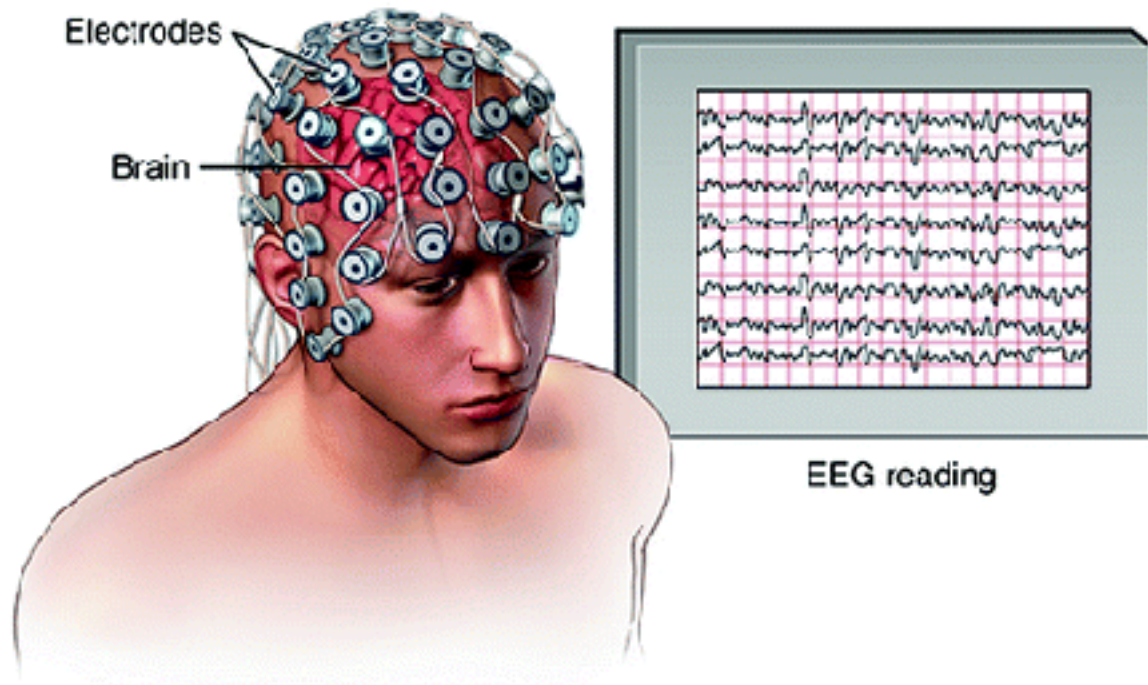
Animal Psychophysics:

Left: Mouse behavioural task

Right: Measured Psychophysical curves

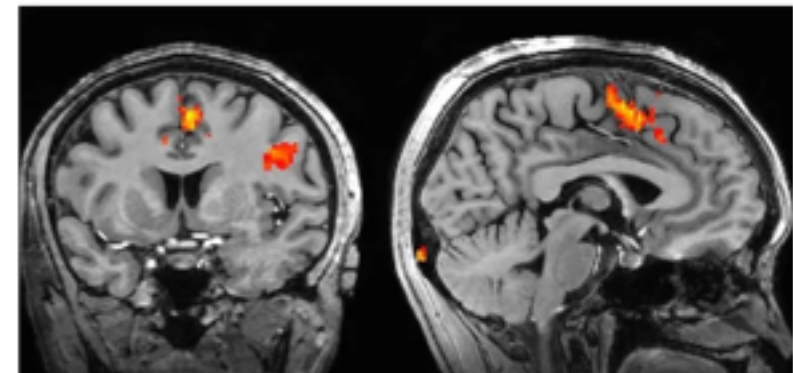
Measuring Neural Activity – Non-invasive Imaging

Electroencephalogram (EEG)



EEG – high temporal but low spatial resolution. Noisy, contaminated, indirect measurement of brain's electrical field.

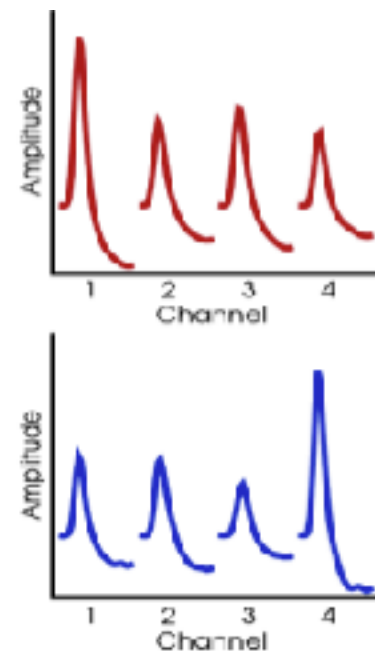
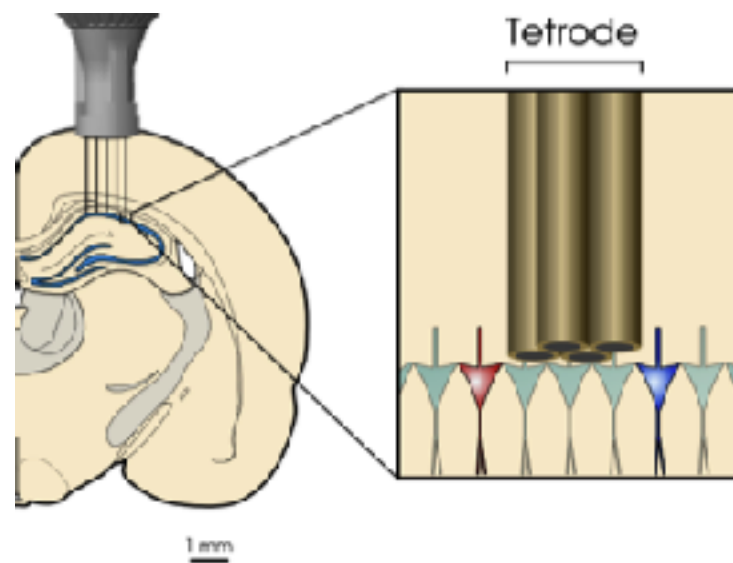
fMRI



Low temporal but high spatial resolution. Measures BOLD signal (blood flow)

Measuring Neural Activity – Invasive Electrodes

Electrodes: intracellular or extracellular.

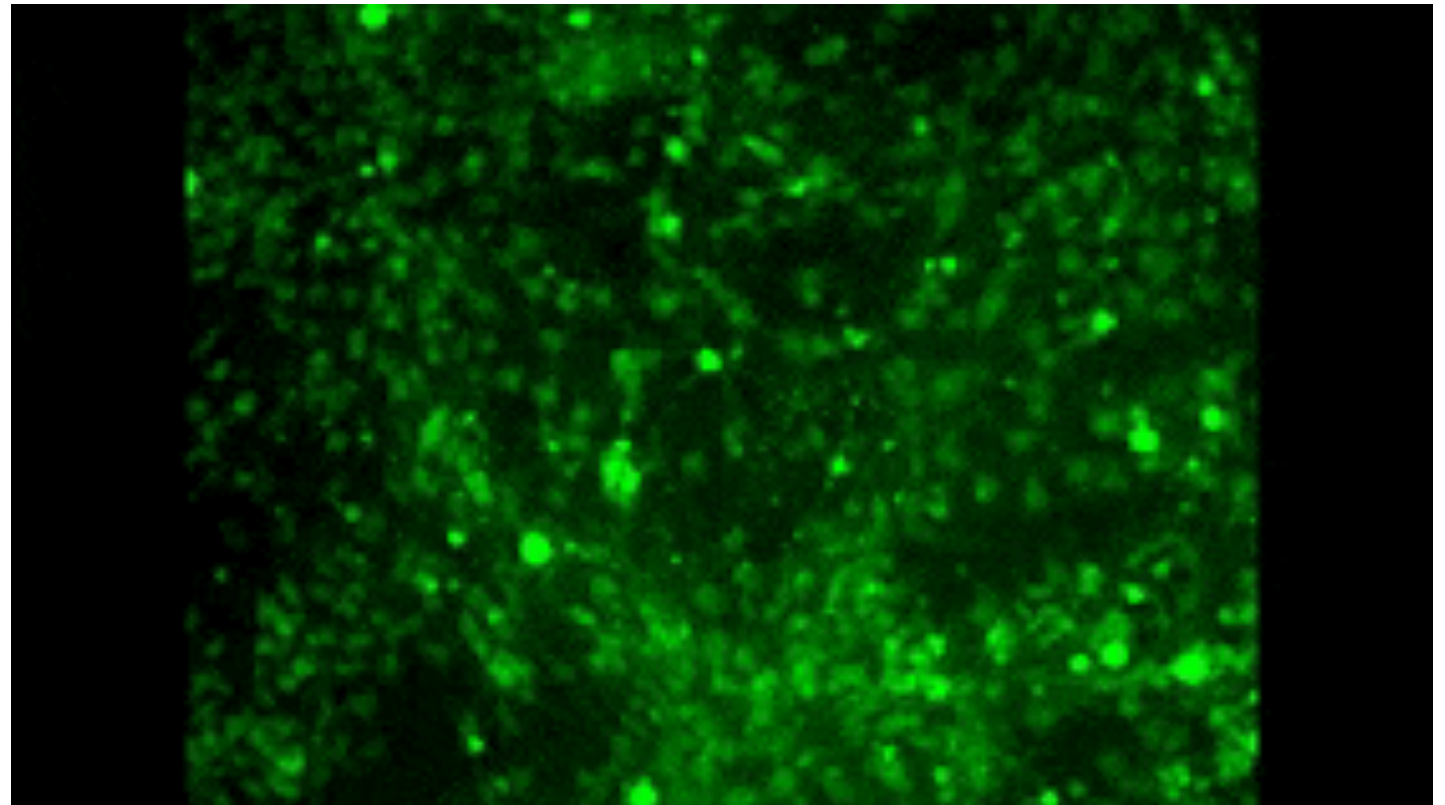
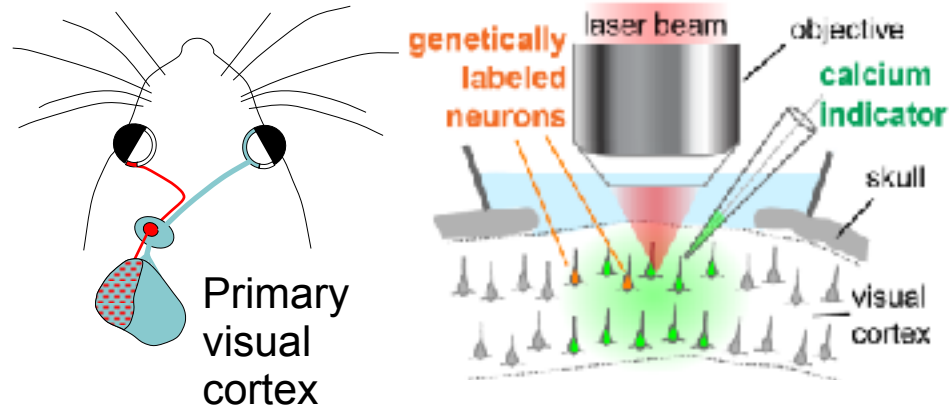


Pros: get signals in single neurons at high temporal resolution, measure electrical activity

Cons: Invasive, limited to working with animals, can't record from many cells simultaneously, data pre-processing tricky

Measuring Neural Activity – Invasive Imaging

Two-photon calcium imaging



Pros: Many cells at once, high spatial resolution

Cons: Invasive, measure calcium fluorescence, low temporal resolution, data pre-processing tricky

Tools of Computational Neuroscience

Computational Neuroscience: uses computational/mathematical tools to understand the brain, by developing:

- Theories about the brain (using maths)
- Computer simulations (“in silico” experiments)
- Data analysis methods (e.g., machine learning)

Try to answer:

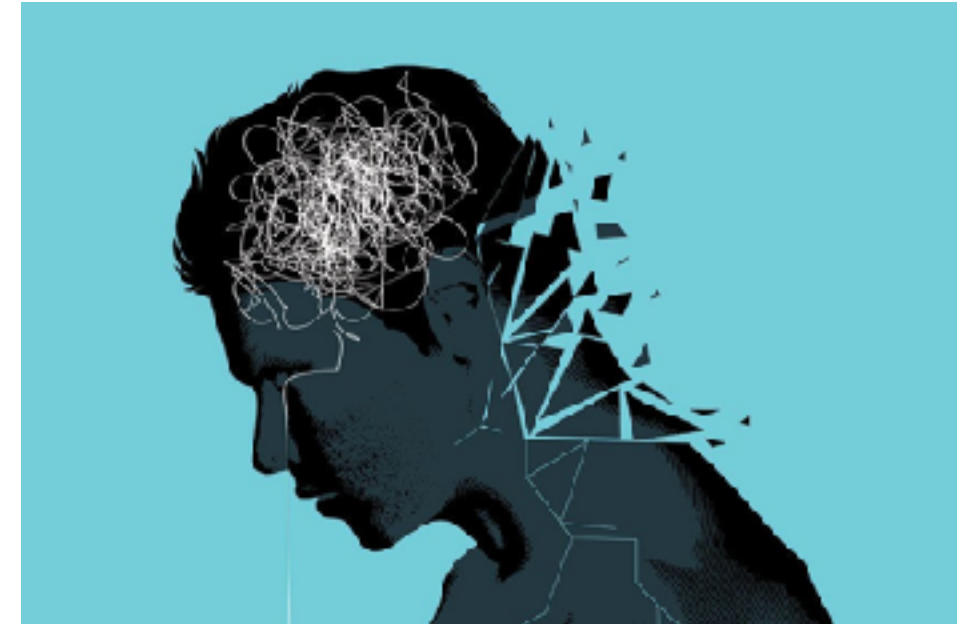
What? Descriptive/phenomenological/statistical explanation

How? “Mechanistic” explanation, i.e. *causal* or *physical* explanation in terms of biology

Why? “Teleological”/functional/normative explanation (in terms of *optimality*, i.e. evolution)

Why a focus on Mental Illness ?

- In the UK, mental ill health is recognised as **the single largest cause of disability**, contributing almost 23% of the disease burden and costing over £100 billion a year in services, lost productivity, and reduced quality of life.
- Every year in the EU, about **27%** of adults are affected by mental disorder of some kind.
- In the US, almost **one in two** people will meet the criteria for a mental disorder in the course of their lifetime.



A Crisis in Psychiatry

- Diagnosis based on DSM leads to **heterogenous** patient groups
- **comorbidity**
- **stagnation in drug development**
- symptoms- based no link with potential **causal factors** (**neuroscience**)

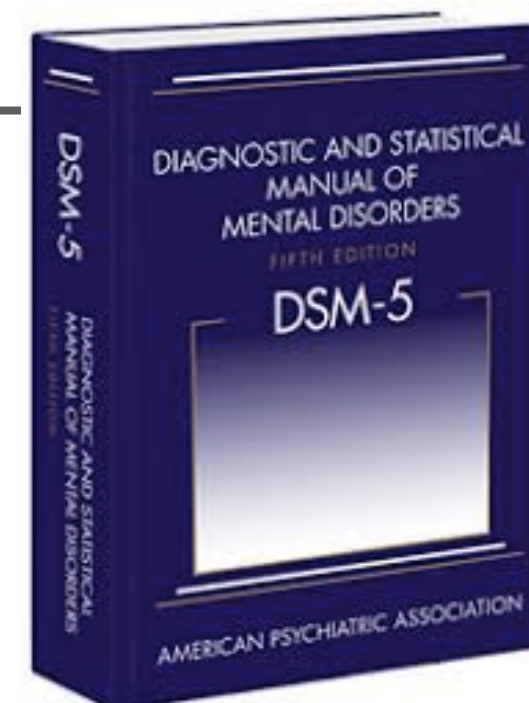


Table 1 DSM-5 criteria for MDE

- At least five of the following symptoms that cause clinically significant distress or impairment in social, occupational, or other important area of functioning
- At least one of the symptoms is 1) depressed mood or 2) loss of interest or pleasure
- Symptoms must be present almost every day for at least 2 weeks
 1. Depressed mood most of the day
 2. Diminished interest or pleasure in all or most activities
 3. Significant unintentional weight loss or gain
 4. Insomnia or sleeping too much
 5. Agitation or psychomotor retardation noticed by others
 6. Fatigue or loss of energy
 7. Feelings of worthlessness or excessive guilt
 8. Diminished ability to think or concentrate, or indecisiveness
 9. Recurrent thoughts of death
- Diagnosis of recurrent MDD requires ≥ 2 MDEs separated by at least 2 months in which criteria are not met for an MDE

Abbreviations: DSM-5, Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition; MDD, major depressive disorder; MDE, major depressive episode.

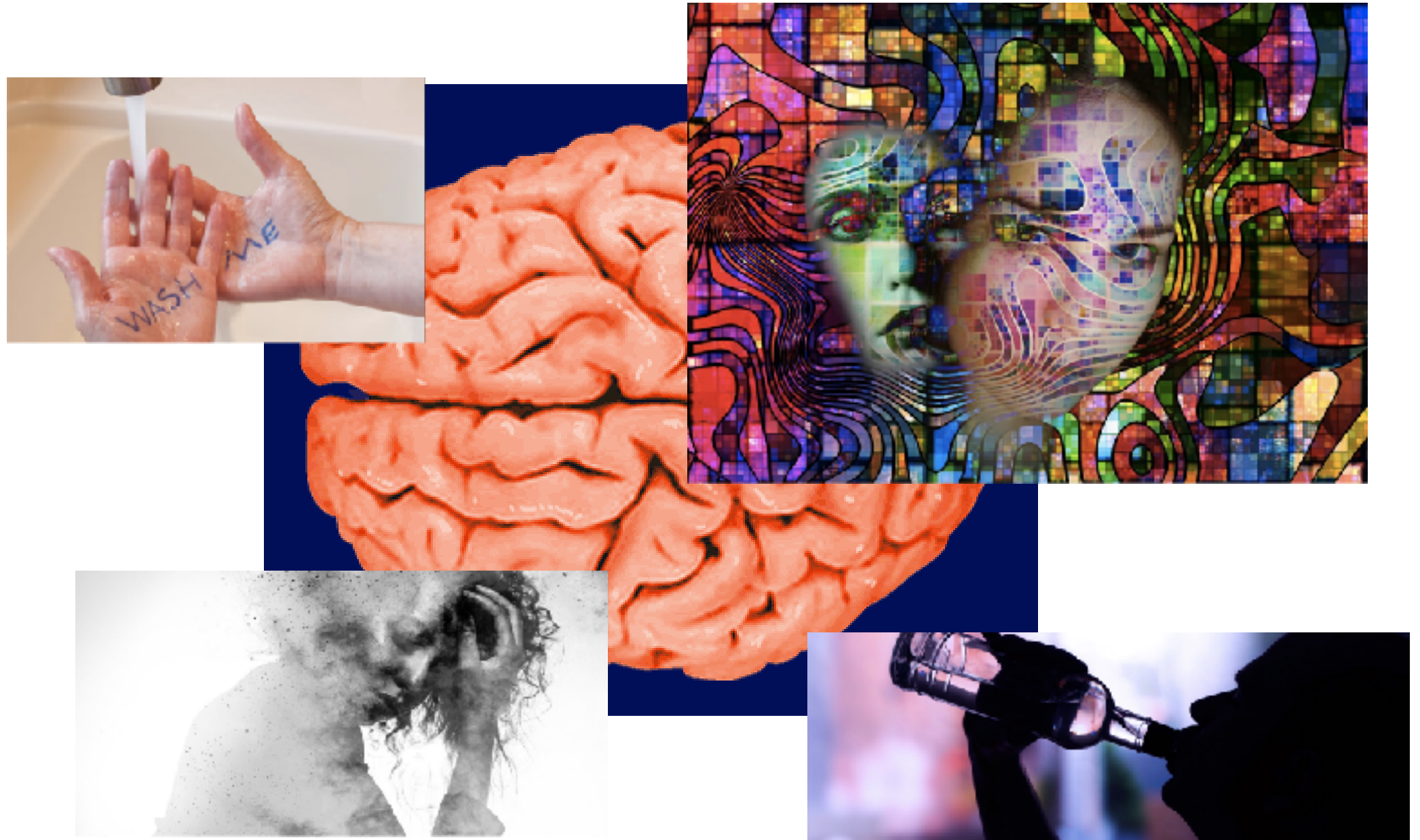
RDOC framework in Psychiatry

- Building upon ongoing advances in the **behavioural and neurobiological sciences**
- "RDoC is an attempt to create **a new kind of taxonomy** for mental disorders by bringing the power of modern research approaches in genetics, neuroscience, and behavioral science to the problem of mental illness."
[Elevag et al 2016]
- From a categorical to a **dimensional** approach.

NIMH Research Domain Criteria (RDoC)									
Functional Domains									
Negative Valence Systems (e.g., fear, anxiety, loss)		Positive Valence Systems (e.g., reward, learning, habit)		Cognitive Systems (e.g., attention, perception, memory)		Systems for Social Processes (e.g., attachment, communication, perception of self & others)		Arousal and Regulatory Systems (e.g., arousal, circadian rhythms)	
Units of Analysis									
Genes	Molecules	Cells	Circuits	Physiology	Behavior	Self-Reports	Paradigms	Genes	Molecules

Computational Psychiatry

Can computational approaches help us understand how the brain generates dysfunctional behaviours?



The Emerging Rise of Computational Psychiatry

Neuropsychiatry



OPEN ACCESS

REVIEW

Computational Psychiatry: towards a mathematically informed understanding of mental illness

Rick A Adams,^{1,2} Quentin J M Huys,^{3,4} Jonathan P Roiser¹

¹Institute of Cognitive Neuroscience, University College London, London, UK

²Division of Psychiatry, University College London, London, UK

³Translational Neuromodeling Unit, University of Zürich and Swiss Federal Institute of Technology, Zürich, Zürich, Switzerland

⁴Department of Psychiatry, Psychotherapy and

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REVIEW

FOCUS ON NEURAL COMPUTATION AND THEORY

nature
neuroscience

Computational psychiatry as a bridge from neuroscience to clinical applications

Quentin J M Huys^{1,2,5}, Tiago V Maia^{3,5} & Michael J Frank⁴

Translating advances in neuroscience into benefits for patients with mental illness presents enormous challenges because it involves both the most complex organ, the brain, and its interaction with a similarly complex environment. Dealing with such complexities demands powerful techniques. Computational psychiatry combines multiple levels and types of computation with multiple types of data in an effort to improve understanding, prediction and treatment of mental illness. Computational psychiatry, broadly defined, encompasses two complementary approaches: data driven and theory driven. Data-driven approaches apply machine-learning methods to high-dimensional data to improve classification of disease, predict treatment outcomes or improve treatment selection. These approaches are generally agnostic as to the underlying mechanisms. Theory-driven approaches, in contrast, use models that instantiate prior knowledge of, or explicit hypotheses about, such mechanisms, possibly at multiple levels of analysis and abstraction. We review recent advances in both approaches, with an emphasis on clinical applications, and highlight the utility of combining them.



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Computational Psychiatry

Peter Dayan and Read Montague, Editors

Computational Psychiatry publishes original research articles and reviews that involve the application, analysis, or invention of theoretical, computational and statistical approaches to mental function and dysfunction. Topics include brain modeling over multiple scales and levels of analysis and the use of these models to understand psychiatric dysfunction, its remediation, and the sustenance of healthy cognition through the life span. The journal also has a special interest in computational issues pertaining to related areas such as law and education.

Computational Psychiatry is an Open Access journal.

Visit computationalpsychiatry.org.

Continuous Publication

8 1/2 x 11

Founded: 2017

Computational Psychiatry
Mathematical Modeling of Mental Illness



Edited by
Alan Anticicovic • John D. Murray



Computational Psychiatry

New Perspectives on Mental Illness

EDITED BY
A. David Radach and
Joshua A. Gordon



STRÖMANN FORUM REPORTS

2017 Annual Computational Psychiatry Course

July 24-25, 2017 @ University College London

[Register today](#)

Lecturers

Rick Adams
Peter Dayan
Vincenzo Fiore
Xiaosi Gu

Topics

Computational phenotyping
Modeling inference and choice
Fitting models to data
Schizophrenia



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Computational Psychiatry

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Chapter 1: Introduction: Toward a Computational Approach to Psychiatry

Janine M. Simmons, Bruce Cuthbert, Joshua A. Gordon, & Michele Ferrante.

Chapter 2: Methods of Computational Psychiatry: A brief Survey

Peggy Seriès

Chapter 3: Biophysically Based Neural Circuit Modeling of Working Memory and Decision Making and Related Psychiatric Deficits

Xiao-Jing Wang and John D. Murray

Chapter 4: Computational Models of Cognitive Control: Past and Current Approaches

Debbie M. Yee and Todd S. Braver

Chapter 5: The Value of Almost Everything: Models of the Positive and Negative Valence Systems and their relevance to Psychiatry

Peter Dayan

Chapter 6: Psychosis and Schizophrenia from a Computational Perspective

Rick A Adams

Chapter 7: Depressive Disorders from a Computational Perspective

Samuel Ruppel, Vincent Valton, Peggy Seriès

Chapter 8: Anxiety Disorders from a Computational Perspective

Erdem Puleu and Michael Browning

Chapter 9: Addiction from a Computational Perspective

David Redish

Chapter 10: Tourette Syndrome from a Computational Perspective

Vasco A. Conceição and Tiago V. Maia

Chapter 11: Perspectives and Further Study in Computational Psychiatry

Peggy Seriès

A New Model for Mental Illness

Mental illness is the result of an impairment in **prediction**, due to having a **distorted internal model** of the world, possibly due to abnormal exposure (trauma) or to an impairment in **learning**.



Overview of Upcoming Lectures

- Introduction to Neuroscience
- Foundations of Computational Neuroscience (1): Models of Neurons
- Foundations of Computational Neuroscience (2): Models of Networks - Neural network models
- Schizophrenia, Attractors and Working Memory
- Multi-sensory integration and causal inference
- Decision making and drift diffusion models (DDM)
- Reinforcement learning models
- Bayesian models

and application to psychiatry: addiction, schizophrenia, autism, depression and anxiety, PTSD.

Questions?

