Building the mathematical mind

Key Stage 4 Programme

Pupil Name	
Handbook Designed by	R Martin

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Title	Time
1	**26/11/18**	**Introduction to mathematical modelling.**	**2pm - 3pm**
2	**03/12/18**	**The mathematics behind modelling.**	**3pm – 4pm**
3	**10/12/18**	**Microscale modelling, the smallest scale.**	**3pm – 4pm**
4	**17/12/18**	**Macroscale modelling, the largest scale.**	**3pm – 4pm**
5	**14/01/19**	**How can the same model obtain different results?**	**3pm – 4pm**
6 (Feedback)	**11/02/19**	**Feedback for corrections.**	**3pm – 4pm**
7 (Feedback)	**11/03/19**	**Feedback tutorial.**	**3pm – 4pm**

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Background, what do you already know?	03/12/18
Tutorial 2	Research a mathematical model.	10/12/18
Tutorial 3	Review and research microscale modelling.	17/12/18
Tutorial 4	Review and research macroscale modelling.	14/01/19
Tutorial 5	Final assignment draft.	04/02/19
Tutorial 6	Final assignment.	01/03/19

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 01/03/2019	10 marks deducted
Submission after midnight on 06/03/2019	Automatic fail
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Uni Pathways – Pupil Feedback Report

Grade	Marks	Guidance
1st	70+	Performing to an excellent standard at A-level.
2:1	60-69	Performing to a good standard at A-level.
2:2	50-59	Performing to an excellent standard at GCSE.
3rd	40-49	Performing to a good standard at GCSE.
Working towards a pass	0-39	Performing below a good standard at GCSE.
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Name of RIS teacher	R Martin		
Title of Assignment	Report: Mathematical modelling, from the microscale to the macroscale. Poster: Neural Modelling.		
Name of Pupil			
Name of School	Beaumont Leys		
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the PhD tutor should give an explanation in this section:

Knowledge and Understanding

Critical Evaluation/Problem Solving

Structure and Presentation

Resilience Comment

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Course Rationale

The brain is a highly complex system consisting of billions of connections. In order to understand such a complex multi-scale system, mathematicians employ neural models. Neural models use a range of mathematical and computational techniques in order to explain and predict brain function and behaviour. This course introduces the concept of mathematical modelling at a range of different scales and discusses how the models are developed.

Certain neural models are capable of exhibiting a variety of neurological phenomena, such as, for example, bumps in models of working memory and therefore play a vital role in the interpretation and understanding of the dynamic patterns of brain activity observed in modern brain imaging techniques such as EEG, MEG and fMRI. Importantly, neural field models are capable of supporting oscillatory and travelling waves, which are considered to be the signature of certain neurological diseases and understanding the types of waves, their mechanisms of synchrony and propagation through the brain promises to assist in the treatment of such diseases.

In the first tutorials we will define what a mathematical model is, what it can be used for and how one obtains such a model. The mathematics behind these models will then be introduced and we will then learn about all the components of a mathematical model. This will help us when considering varying model parameters and initial conditions. We will investigate how to influence a system and how this is beneficial to mathematicians.

You will also learn about mathematical modelling at different scales. These scales range from the microscopic scale to the macroscopic scale and we will consider the advantages of modelling at each scale and how we can use simplifications in order to move from the smallest to the largest scale of modelling.

In the final assignment you will compare and contrast the different scales of modelling when considering the brain. You will also research a different model and investigate how different parameters and initial conditions influence the system. Combining your knowledge gained from the tutorials and your own research you will produce a report and research poster presenting your work.

Mark Scheme

STEM Mark Scheme

Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)
Knowledge and Understanding	• All content included is relevant to the general topic and to the specific question/title • Good understanding of all the relevant topics. • Scientific terms are defined and used accurately throughout • Clear justification on how the content included is related to the specific issues that are the focus of the assignment	• Most of the content included is relevant to the general topic and to the specific question/title • Good understanding of most the relevant topics • Scientific terms are used accurately but not always clearly defined. • Adequate justification on how the content included is related to the specific issues that are the focus of the assignment	• Some of the content included is relevant to the general topic and to the specific question/title • Good understanding on some of the relevant topics but occasional confusion on others. • Scientific terms are used mostly accurately with occasional confusion and often not defined. • Some justification on how the content included is related to the specific issues that are the focus of the assignment
Critical Evaluation/ Problem solving	• Moved beyond description to an assessment of the value or significance of what is described • Evaluative points are consistently explicit/systematic/reasoned/justified • Effective critiques on the reliability of sources provided • Consistently demonstrate clear, analytical and logical steps to solving problems	• Mostly description but some assessment of the value or significance of what is described • Evaluative points are mostly explicit/systematic/reasoned/justified • Some evidence of critiques on the reliability of sources provided • Some examples of solving problems but not consistently clear, analytical and logical	• Only description with minimal assessment of the value or significance of what is described • Evaluative points are at times explicit/systematic/reasoned/justified • Limited evidence of critiques on the reliability of sources provided • Demonstrate clear steps to solving problems but not consistently analytical or logical

Structure and Presentation	• Ideas are presented in paragraphs and arranged in a logical structure that is appropriate for the assignment • The introduction clearly outlines how the essay/report will deal with the issues • The conclusion summarises all the main points clearly and concisely • All calculations, formulas and methods are clearly structured, clear to follow and correct • Tables and graphs are effectively constructed including appropriate headings, units and scales. • All sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure that is mostly appropriate for the assignment • The introduction adequately describes how the essay/report will deal with the issues • The conclusion summarises most of the main points clearly • Calculations, formulas and methods are mostly structured, clear to follow and correct • Most tables and graphs are well constructed • Most sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure • The introduction mentions how the essay/report will deal with the issues • The conclusion summarises some of the main points clearly • Calculations, formulas and methods are not always structured, clear to follow and correct. • Some tables and graphs are well constructed but contains some errors • Some sources are referenced correctly in the agreed format with occasional errors

Subject Vocabulary

Word	Definition	In a sentence
Neural	Relating to the nervous system.	People can suffer from neural disorders.
Microscale	A small or microscopic scale. Cannot be observed by the naked eye.	When modelling the brain at the microscale we consider an individual neuron.
Mesoscale	An intermediate scale between the microscale and macroscale.	The transition between the microscale and macroscale passes through the mesoscale.
Macroscale	A large or macroscopic scale. Can be observed with the naked eye.	When modelling the brain at the macroscale we consider the brain as a whole.
Differential equation	An equation involving derivatives of a function.	We use differential equations in mathematical modelling.
Parameter	A quantity whose value is selected for a particular circumstance.	An example of a parameter when modelling a single neuron is an external input.
Variable	Able to assume different numerical values.	When modelling the brain, a variable we can consider is brain activity.
System	A set of equations working together to for a mathematical model.	We can model the properties of a neuron as a system of four equations.
Initial condition	The value assigned at the beginning of a simulation for the variable/s in the system.	When simulating a model, we can set the initial condition to achieve different results.
Simplification	The process of making something simpler or easier to model/understand.	Modelling at the macroscale requires a simplification of the properties in the model.
Function	A variable quantity observed in relation to a variable in terms of a value on which it depends.	We can display a variable as a function of time i.e. we can track how a variable changes over time.

Use this table if you come across any other key words throughout the course that are not given above.

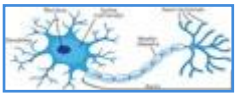
Word	Definition	In a sentence

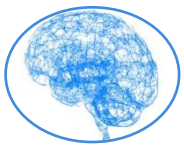
Knowledge Organiser

Mathematical modelling

Mathematical models are used to predict, design and construct. They are a simplification of reality intended to promote understanding. These models can be considered at a range of scales. The scales range from the smallest scale (microscale) to the largest scale (macroscale). Here we focus on the mathematical modelling of the brain.

Microscale → Mesoscale → Macroscale





At the microscale we consider an individual neuron.	At the mesoscale we consider networks of neurons.	At the macroscale we consider the entire brain.

One approach at modelling at the macroscale is neural field models. Importantly neural field models are capable of supporting pattern formations that can be linked to brain diseases/disorders. Understanding these patterns promises to assist in the treatment of diseases/disorders.

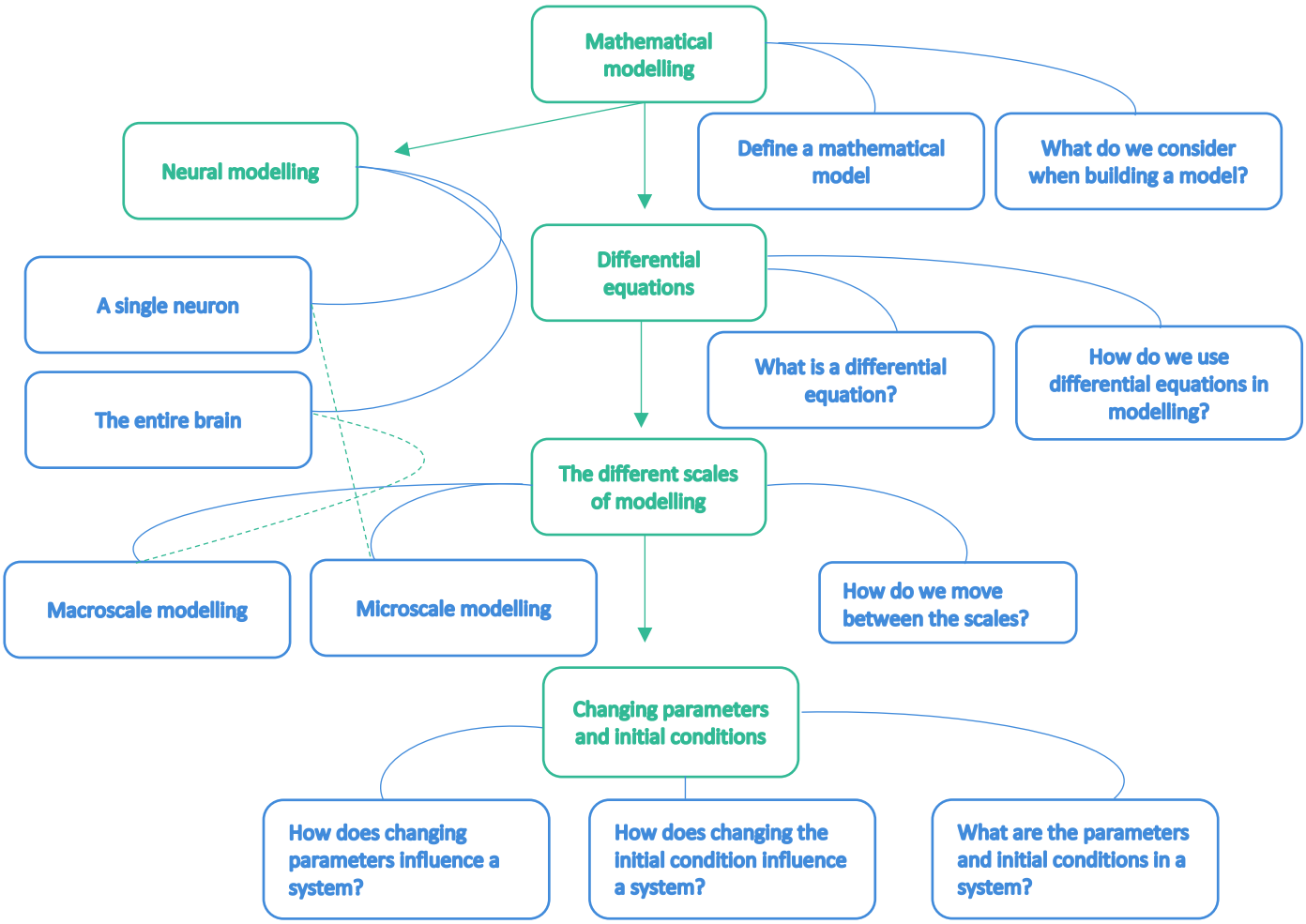
Brief historical background

In 1952 Sir Alan Lloyd Hodgkin and Sir Andrew Fielding Huxley developed one of the most widely used microscale models in neuroscience. The Hodgkin-Huxley model consists of four coupled differential equations and was developed to investigate the properties of action potentials in the squid giant axon.

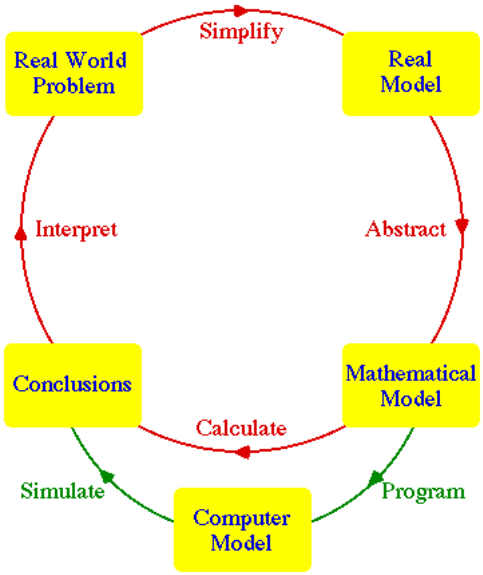
Many areas of the brain are organised into units containing thousands of neurons that are similar and for this reason population models (neural mass models) have become increasingly popular. Such mesoscale models were first introduced in the seminal work of Hugh Wilson and Jack Cowan in the early 1970's.

At the macroscale the limiting case of neural mass models is considered. These models are known as neural field models and treat the spatial domain as continuous. The work by Wilson-Cowan along with that of Amari and Nunez provide the starting point for the formulation currently in common use.

Learning objectives knowledge structure



Tutorial 1 – Introduction to mathematical modelling.



What is the purpose of Tutorial 1?

- To be able to define what a mathematical model is.
- Describe what we need to consider when building a mathematical model.

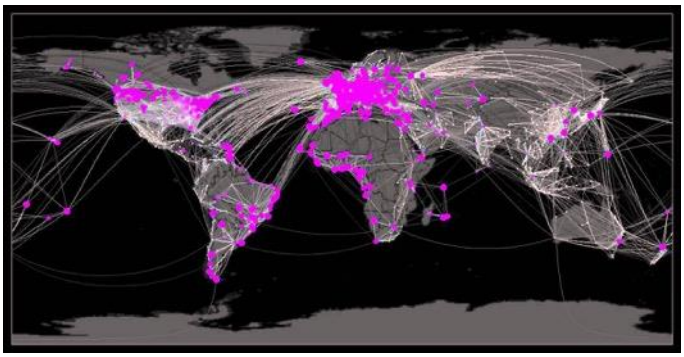
<u>Discussion:</u> (Think-Pair-Share)

What is a model? What about a mathematical model? What do you think a mathematical model looks like? Where do you think we use them? Can you give an example?

Definition: Mathematical model

Predict, design and construct

Here are three examples of when a mathematical model has been used to predict, design or construct. Which image best represents each of the three terms? Explain your answer. How do you think the models work?

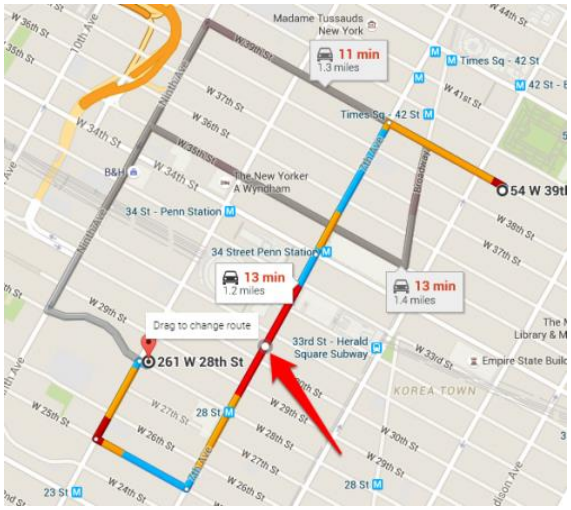


A model has been used to…

How and why? Other examples.

A model has been used to…

How and why? Other examples.



How and why? Other examples.

A model has been used to…

Lecture 1: A model is a simplification of reality intended to promote understanding.

Modelling activity

Use the space below to draw what you are modelling and how. How might it may change over time? Think about any simplifications you could incorporate.

Notes

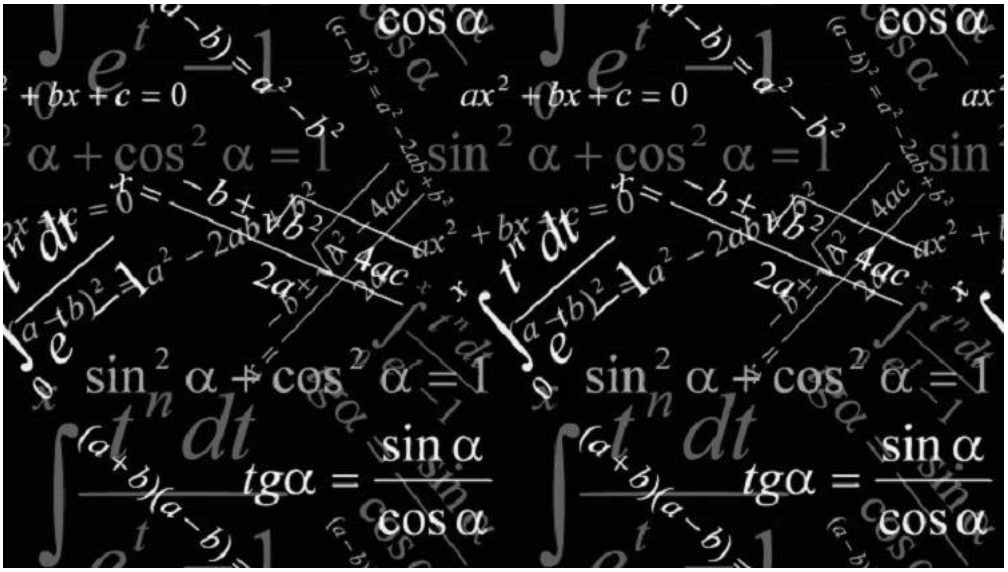
Baseline Assignment

Write a small scientific report (500 words) which answers the following questions:

- What is a mathematical model? Where do we use them? What do they look like? (approx. 100 words)
- What do you know about the brain? Think about what it looks like, what it contains, how it functions etc. (approx. 100 words)
- Can we use mathematical modelling to study the brain? (approx. 150 words)
- How do we study the brain? Why do/should we study the brain? (approx. 150 words)

You will be assessed on your written communication. If you use any resources (books/websites) ensure you include them, see Appendix 1. You should include diagrams to aid your explanations where possible.

Tutorial 2 – The mathematics behind modelling.



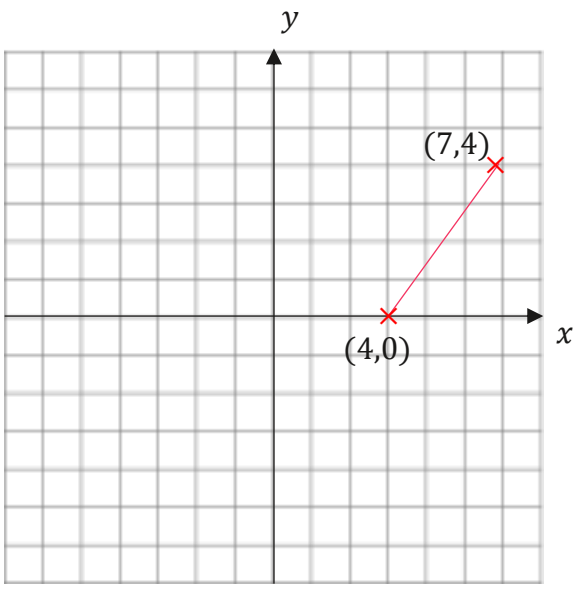
What is the purpose of Tutorial 2?

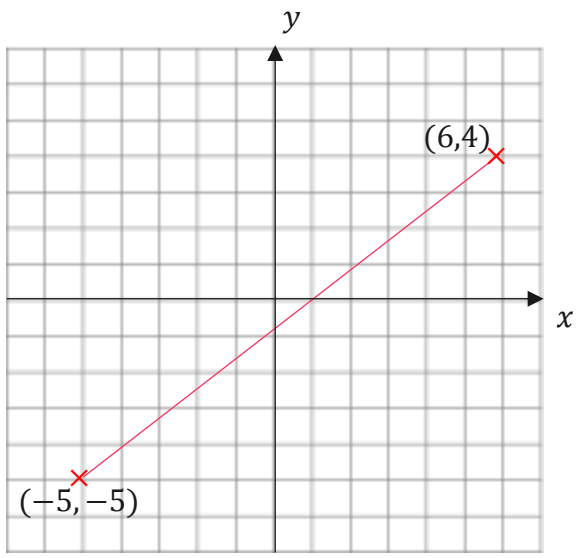
- To be able to define what a differential equation is.
- To write a model down mathematically and describe all of the parameters.

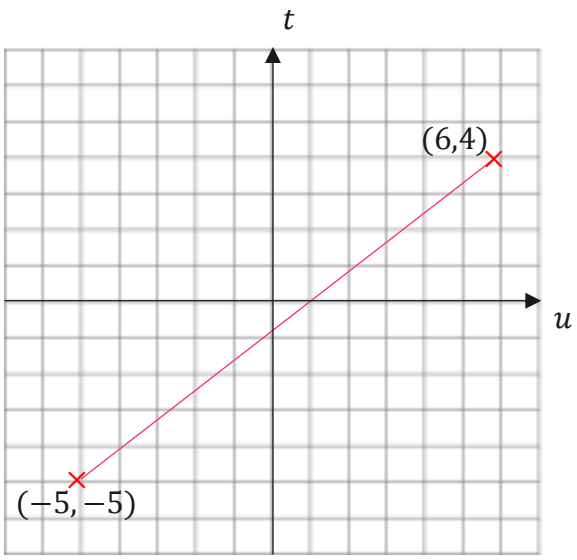
<u>Do you know what the gradient of a line is? How do you calculate it?</u> (Group discussion)

Write your ideas and explanations here. Use a diagram to help with your explanation.

Find the gradient of the following, use the differential equation notation:







Lecture 2: How we use differential equations in modelling.

Parameters and variables

Using your notes write down the definition of a parameter and variable.

Definition: Parameter

Definition: Variable

Modelling activity revisited

Write the model you considered in the last session as a mathematical equation. Describe what each component is, clearly defining the parameters and variables.

Research skills: where to look and what to look for.

I will provide you with a list of resources when considering neural modelling. When researching a different mathematical model, you need to use your research skills in order to find what you are looking for efficiently.

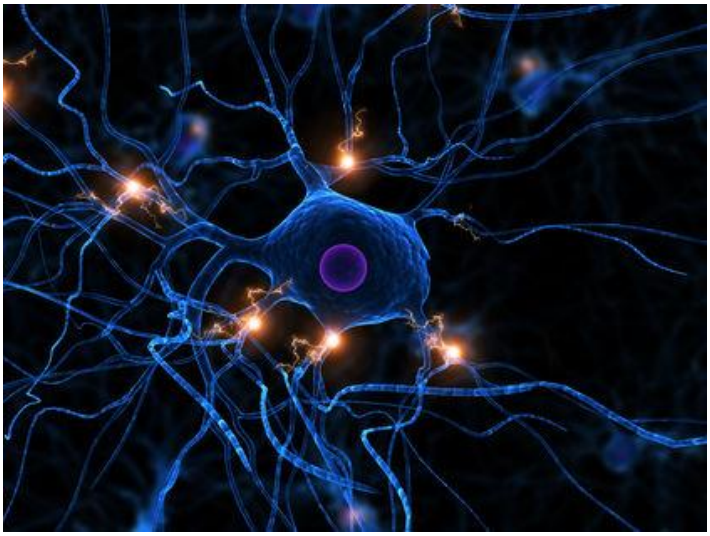
Notes:

Homework

Research a mathematical model, produce a piece of work that includes:

- A detailed description of what you are modelling. What is it used for? (approx. 250 words)
- A diagram of what you are modelling.
- The mathematical description of what you are modelling.
- A discussion on what the parameters and variables are in your model. (approx. 200 words)

Tutorial 3 – Microscale modelling, the smallest scale.



What is the purpose of Tutorial 3?

- To define what microscale modelling is.
- To consider a model at the microscale.
- To consider discrete and continuous modelling.

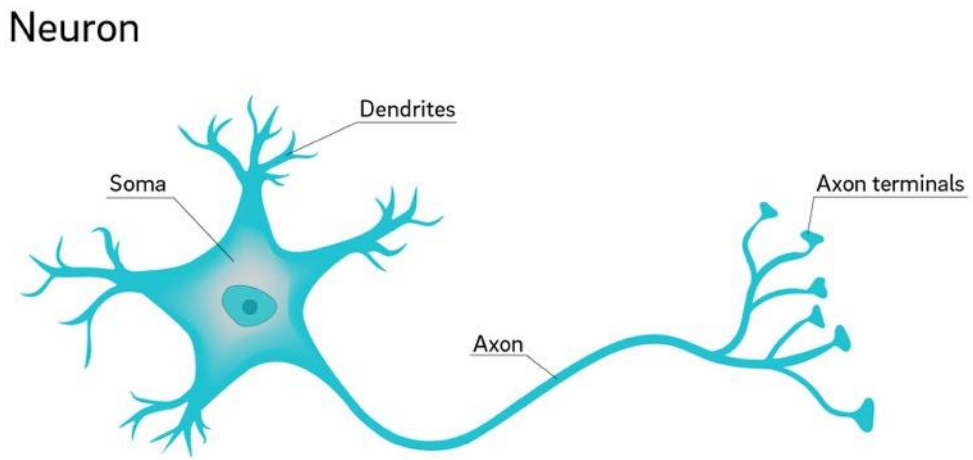
<u>Can you guess what is pictured from the `microscale' section?</u> (Quiz)

Use this space to write your answers.

Lecture 3: Microscale modelling.

Neural modelling at the microscale

At the microscale we consider individual neurons. Below is a diagram of a neuron, use the space below to describe what each of the labelled parts of the cell are. See if you can find a mathematical model of an individual neuron. Use your notes from the lecture and the laptops. (Research/note taking practice)



Single neuron model – use this space to write down the mathematical model for an individual neuron and label each component.

There are approximately 10^{11} neurons with 10^{14} connections embedded in the nervous system. How can we model the brain when it contains so many neurons? Can we use individual neuron models? (Think, pair, share)

Discrete and continuous modelling

Which definition fits with the term?

Discrete	Individually separate and distinct
Continuous	Forming an unbroken whole; without interruption

From the definitions given, can you identify which is discrete modelling and which is continuous modelling? Tick the box you think is correct and explain your answer.

Microscale

At the microscale we consider an individual element, i.e. in neural modelling we consider an individual neuron.

Discrete | Continuous

Mesoscale

At the mesoscale we consider more than one element connected together, i.e. in neural modelling we consider a number of connected neurons.

Discrete | Continuous

Macroscale

At the macroscale we consider the entire structure at the largest scale, i.e. in neural modelling we consider the entire structure of the brain as a whole.

Discrete	Continuous

Mesoscale modelling

This is the intermediate stage between micro- and macro-scale modelling. When considering neural models, the mesoscale considers a number of connected neurons.

How do you think we consider these connected neurons? (Think, pair, share)

Summation notation

$$\sum_{i=1}^{n} x_i = x_1 + x_2 + \cdots + x_n$$

We can write a summation using the above notation, making equations more concise. At the bottom of the summation we write the starting point and at the top the end point of the sum we wish to evaluate. The letter i denotes where we wish to substitute the numbers in the sum. For example, in the above we are summing x values from 1 to n.

Evaluate the following summations.

$$\sum_{i=1}^{3} x_i =$$

$$\sum_{j=1}^{10} 1^j =$$

$$\sum_{i=1}^{4} 2 =$$

$$2\sum_{k=1}^{3} y_k =$$

Write the following as a summation.

$$a_1 + a_2 + a_3 + a_4 + a_5 =$$

$$2 + 4 + 8 + 16 =$$

$$12 =$$

$$4x_1 + 4x_2 + 4x_3 =$$

Notes:

Homework

Write a review of microscale modelling. Use your notes from today's session. You should include:

- The definition of microscale modelling. (approx. 100 words)
- Microscale modelling of the brain. What do we consider at the microscale? What is the mathematical model? What can these models be used for? (approx. 200 words)
- Find the microscale of the model you researched previously. Explain what the model variables and parameters are and research what it has been used for. (approx. 250 words)

Tutorial 4 – Macroscale modelling, the largest scale.

What is the purpose of Tutorial 4?

- To be able to describe how we move from microscale modelling to macroscale modelling.
- To define what macroscale modelling is.
- To research a model at the macroscale.

<u>From the microscale to the macroscale</u>

What do we know? Write some notes/use diagrams to illustrate what you know. (Think, pair, share)

Microscale

↓

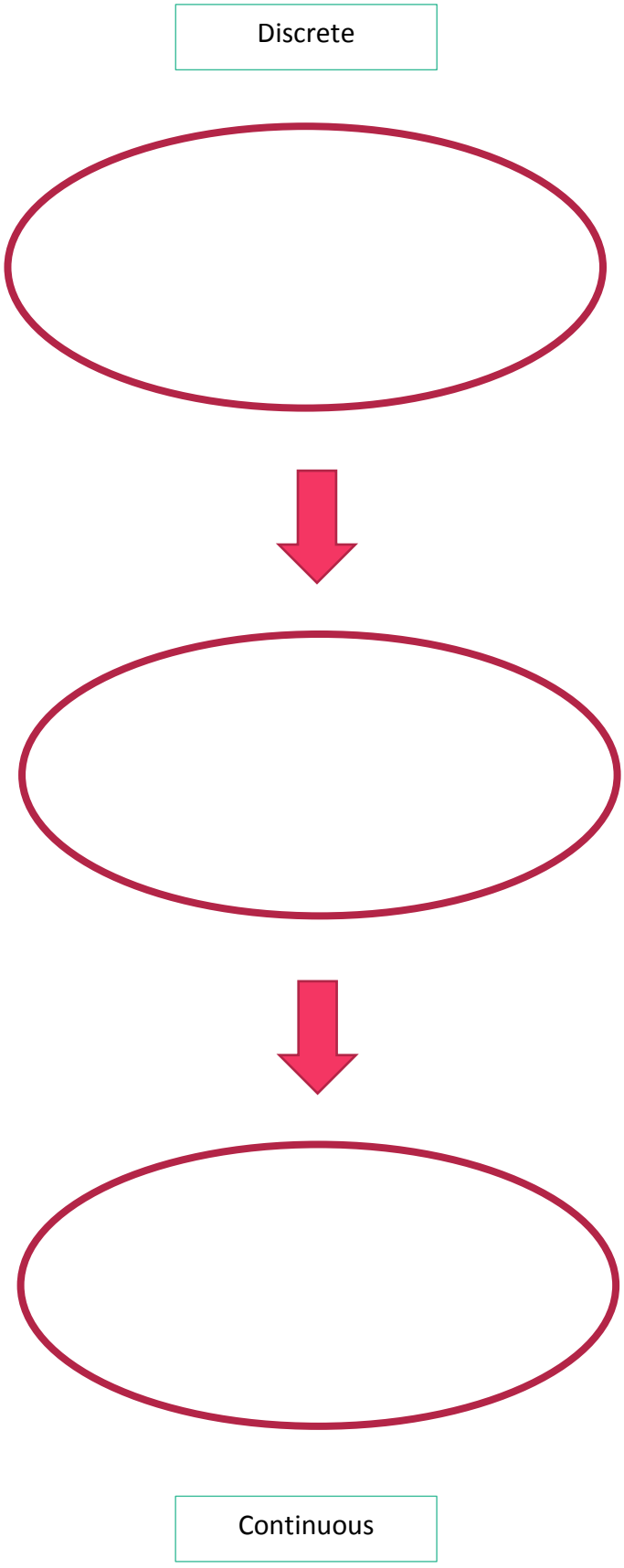
Mesoscale

↓

Macroscale

Discrete to continuous

In the previous session we discussed discrete and continuous modelling. We are now going to investigate how and why we can move from discrete models to continuous models.



Mesoscale to macroscale modelling

In the previous session we considered the summation notation. This notation is used for mesoscale modelling of the brain. Below is a firing rate model for a number of connected neurons.

$$\frac{du_i}{dt} = -u_i + \sum_{j=1}^{N} w_{ij} S(u_j(t))$$

If we consider the continuum limit of such a model we reach a neural field model.

Notation

As N approaches ∞,

$$\sum_{j=1}^{N} \approx \int_{\Omega}$$

the sum approaches an integral. Here Ω denotes the domain under consideration. For example

$\int_0^1 x$ means we are considering the real line, $\mathbb{R}$, between 0 and 1.

What do the following integrals denote?

$$\int_{-1}^{4} x$$

$$\int_{-\infty}^{\infty} x$$

$$\iint_{0}^{1} x$$

Lecture 4: Neural modelling at the macroscale

Instead of considering a discrete number of neurons the sum is replaced by an integral. This means that at each point there are infinitely many neurons.

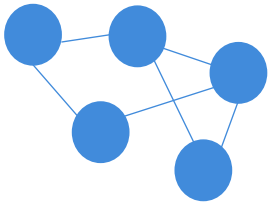
Mathematical model

Annotate the mathematical model below. What does everything mean?

$$\frac{\partial u(x,t)}{\partial t} = -u(x,t) + \int_{-\infty}^{\infty} w(x,x')S(u(x',t))dx'$$

Microscale

When moving from the microscale to the mesoscale we consider a finite number of connected neurons. This means we introduce the $\sum$ notation!



Mesoscale

When moving from the mesoscale to the macroscale we consider an infinite number of neurons. This means we replace the $\sum$ notation with the $\int$ notation!

Macroscale

Comparing the micro- and macro-scale

Research task. Think about the differences between the microscale and macroscale. Link your ideas to neural modelling and the model you are investigating. What are some of the applications of these models at each scale?

Microscale	Macroscale

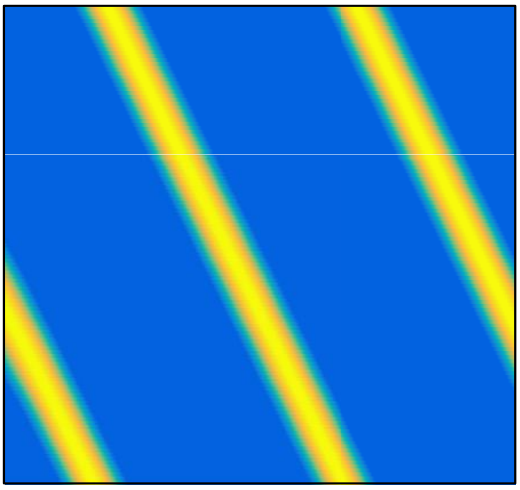
Notes:

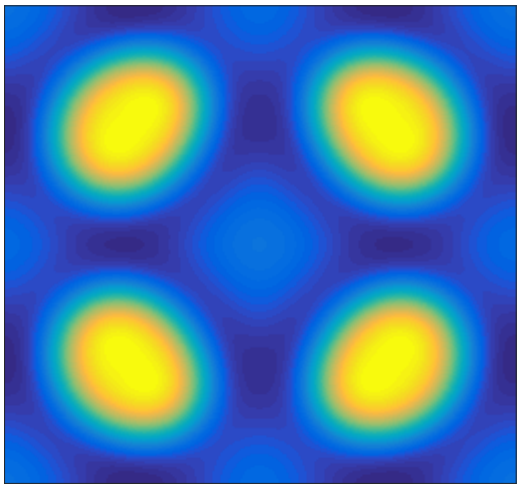
Homework

Write a review of macroscale modelling. Use your notes from the last two sessions to help you. Make sure you introduce the correct mathematical notation where necessary. You should include:

- How can we move from the microscale to the macroscale? (approx. 200 words)
- The definition of macroscale modelling. How is different from the other scales? (approx. 150 words)
- Macroscale modelling of the brain. What do we consider at the macroscale? What is the mathematical model? What can these models be used for? (approx. 200 words)
- Find the macroscale of the model you researched previously. Explain what the model variables and parameters are and research what it has been used for. (approx. 250 words)

Tutorial 5 – How can the same model obtain different results?





What is the purpose of Tutorial 5?

- To consider numerical methods and how we use them to solve models.
- To define what an initial condition is and how it is used.
- To investigate how varying parameters and initial conditions effect a systems outcome.

How do you solve…

What methods do you know for solving equations?

$$x + 3 = 6$$

$$x^2 = 4$$

$$x^2 + 4x + 3 = 0$$

What if the methods you know couldn’t be implemented in order to solve an equation?

Lecture 5: Numerical methods

Iterative methods

Iterative methods are numerical methods which are implemented in order to approximate a solution. When solving neural models we use time iterative methods in order to find a solution.

Consider the equation

$$x^3 - 3x - 1 = 0.$$

In order to solve this equation using iteration we must first find an interval in which a solution lies. In order to do so we substitute number into the equation as follows.

Let $x = -1$, then

$$-1^3 - (3 \times -1) - 1 = 1.$$

Let $x = -2$, then

$$-2^3 - (3 \times -2) - 1 = -3.$$

Since the answer when subbing in these two values changes from positive to negative, i.e. 1 to -3, there must be a solution between $x = -1$ and $x = -2$.

Where there is a sign change, there is a solution.

Now we have an interval we can start the iterative process. We fist rearrange our equation so that it is of the form $x = \cdots$.

If we consider the rearrangement,

$$x = \sqrt[3]{1 + 3x}$$

we must write the following

$$x_{i+1} = \sqrt[3]{1 + 3x_i}$$

in order to start the process. This means that the next value of x relies on the previous value of x. We now start with an initial value of x, in this case we start with -1.

This initial value is known as an initial condition and is denoted by x_0.

If $x_0 = -1$ we can find the value of x_1.

Varying parameters and initial conditions

Looking at the videos can you identify which has had a change in parameter values and which has a different initial condition? What happens when we change the initial condition and/or parameter values?

Parameters	Initial condition

Using numerical methods and computational techniques allows us investigate how different parameters and conditions influence a system. Consider a neural field model, what could we change and how would it influence the solution?

Notes:

Final Assignment

- Produce a poster based on neural modelling (700 words) (50%) – poster template provided. Make sure you use your notes and homework, you should include the following at a minimum.
    a. Consider the different scales of modelling and relate these to neural modelling. Discuss how we move between the different scales, include the mathematical notation and what it means.
    b. Show the mathematical equations, make sure you define all the variables and parameters.
    c. Compare and contrast the different scales, discuss what they consider and where they have been used in research.

- Produce a report based on the model of your choice (1000 words) (50%) – report template provided. Make sure you use your notes and homework, you should include the following at a minimum.
    a. Introduce mathematical modelling.
    b. Discuss what the model describes and where it has been used in research (if applicable).
    c. Show the mathematical equations, make sure you define all the variables and parameters.
    d. Discuss the different scales of the model, if applicable.
    e. Discuss numerical methods and how they are used.
    f. Discuss how varying the parameters or changing the initial conditions may influence the system.

Tutorial 6 – Feedback tutorial

What is the purpose of Tutorial 6?

- To receive feedback on final assignment drafts.
- To share examples of best practice with the other pupils in your group.
- Create an action plan for the final assignment.

Tutor feedback – Final assignment draft

What I did well	What I can improve

Targets for final submission:

Group discussion – peer feedback

In a small group/pair discuss your written feedback and the assignment. Ask for some advice on part of the assignment you are most worried about and offer some advice to your peers. Discuss and write an action plan for the final assignment.

Action plan

What am I going to do?	When will I do this?	Do I need any further guidance?

Tutorial 7 – Feedback tutorial

What is the purpose of Tutorial 7?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

What I did well…	What I could have improved on…

My target for future work is…

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?

What did you find challenging about the programme?	How did you overcome these challenges?

Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. **A marker in your assignment**: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. **Bibliography**: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

    a. **Websites** – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

    E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

    b. **Books** – Author, date published, title of book (in italics), pages where the information came from.

    E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

    c. **Articles** – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

    E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

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Building the mathematical mind

Key Stage 4 Programme

researchersinschools.org