第一讲
技术背景（I）
Lecture 1
Technical Background (I)

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人工智能
Artificial Intelligence

- 到上世纪40年代，人们业已在不同的学科领域取得了一系列的重要的成就，概要如下：

  In the 1940s, several key developments took place in different disciplines. Here are some notable achievements from that era:

  - 在数学和逻辑学方面，形式逻辑的开拓性工作为智能推理和演绎提供了基础，而概率论和优化算法等数学技术在学习和决策过程中发挥着重要作用。

    In mathematics and logic, pioneering work in formal logic by mathematicians provided the basis for reasoning and inference. Mathematical techniques, such as probability theory and optimization algorithms, also play a crucial role in the learning and decision-making processes.

  - 在控制论领域，学者Norbert Wiener系统地发展了控制论的相关知识，学者Rudolf Kalman的工作使分析和设计能够实现预期目标的控制系统成为可能。

    In cybernetics, the scholar Norbert Wiener formed and solved several fundamental problems and systematically developed the theory and practice of cybernetics, or control theory in general. The scholar Norbert Wiener's work on feedback mechanisms and self-regulating systems put the design and implement of control systems with desired objectives into reality.

人工智能
Artificial Intelligence

- 在神经科学和认知科学领域，人们对大脑的结构在细胞层次上已经有了较为深刻的认识，包括神经元的电生理现象。另外，对行为学的研究促使人们思考一些新的计算范式。

  In the fields of neuro- and cognitive science, people have gained a deeper understanding of the brain‘s structure at the cellular level, as well as the electrophysiological phenomena of neurons. Research in behavior has prompted people to contemplate new computational paradigms.

- 在电子工程领域，1940年代出现了首台电子计算机，其代表了计算能力的重大进步，同时也展示了自动化复杂计算的巨大潜力。基于此，大家对图灵在《可计算数》的论文中提出的通用机，即能够执行可由算法描述的任何计算的机器，持更为乐观的态度。

  In electronic engineering, the first electronic computer emerged in the 1940s, representing a significant advancement in computing power. It also showcased the immense potential for automating complex computations. Based on that, optimistic atmosphere hovered over the universal machine capable of performing any computation proposed by Turing in his "Computable Numbers" paper.

人工智能
Artificial Intelligence

- 尽管在一些学科上取得了瞩目的成就，但是在解决如下对人类轻而易举的问题上，不能说其它学科是无能为力的，但至少是捉襟见肘的：

  Despite the remarkable achievements made in various disciplines, it cannot be said that other fields are powerless in addressing the following seemingly trivial human problems. However, they may at least struggle to find satisfactory solutions:

类别	任务	Category	Task
感知	视觉	Perception	Vision
	声音		Audio
语言	理解	Language	Understanding
	生成		Generation
	翻译		Translation
推理		Reasoning	

人工智能
Artificial Intelligence

- 实际上，对上述问题的反思，人们至少觉得如下三个问题，直到现在都不太容易回答：
  - 对于上述的此类对人类而言的平凡任务，实际上从数学的角度来讲，可能是高度非线性的。人们并不清楚如何建立一个数学模型来描述，甚至不太确定这样的数学描述或模型到底存在不存在，即模型的存在性问题；
  - 假设这个模型存在，学者可能不确定怎样对这个模型进行求解。尽管在当时数学上已取得了很高的成就，但根据人们研究非线性问题的经验，模型就算有解，在当时的算力情况下可能也无法解出，即模型的可解性问题；
  - 假设这个模型存在且可解，人们并不确信一个模型的结果能否平滑地迁移到与之类似的问题上。假设可以迁移，模型对于新问题还在多大程度上有效，即模型的扩展性问题。
- 由于上述这些平凡任务对我们人类来说是轻而易举的，因此，审视大脑的工作原理，从而建立与之类似的处理模型来解决这些问题，这个想法与动机是非常自然的。

人工智能
Artificial Intelligence

- In fact, when reflecting on the aforementioned problems, people feel that at least the following three questions are not easy to answer even up to now:
  - For these seemingly trivial tasks for humans, they may actually be highly nonlinear from a mathematical perspective. It is unclear how to establish a mathematical model to describe them, and it is even uncertain whether such a mathematical description or model exists, i.e., the issue of model existence.
  - Assuming this model exists, scholars may be unsure how to solve it. Despite significant achievements in mathematics at the time, based on people's experience in studying nonlinear problems, even if the model has a solution, it may not be solvable given the computational power available at that time, i.e., the issue of solvability of the model.
  - Assuming this model exists and is solvable, people are not certain whether the model can smoothly generalize to similar problems. If generalization is possible, to what extent is the model still effective for new problems, i.e., the issue of the generalization of the model.
- Since these trivial tasks are effortless for us humans, it is only natural to examine the workings of the brain and establish similar processing models to solve these problems.

神经科学
Neuroscience

- 神经科学是通过研究神经系统理解人的行为与意识的学科，其和哲学、心理学、行为科学和认知科学等有较为密切的联系，在一定程度上脱胎于这些学科，并在上世纪上半叶逐渐发展成为独立的基础学科。

  Neuroscience is the topic about the study of behavior and the mind through the study of the nervous system. It has close connections with disciplines such as philosophy, psychology, behavioural science, and cognitive science. To some extent, neuroscience emerged from these fields and gradually developed into an independent foundational discipline during the first half of the last century.

- 意识与人脑的关系问题，在一定程度上也是回答智能与人脑的关系的问题

  The relation between mind and brain also reflect people's prospects about the intelligence and brain.

  - 脑是意识的基础

    "Today, some people still believe that there is a 'mind-brain problem,' that somehow the human mind is distinct from the brain. However, as we shall see…, modern neuroscience research supports another conclusion: The mind has a physical basis, which is the brain."

  - 意识与脑有区别

    Combustion of gasoline is the physical basis of a car's movement, but the car's movement is distinct from the combustion of gasoline.

神经科学
Neuroscience

- 脑主要有大脑，小脑，脑干三部分组成；组成大脑的细胞主要有以下类型：神经元，胶质细胞，毛细内皮细胞等。

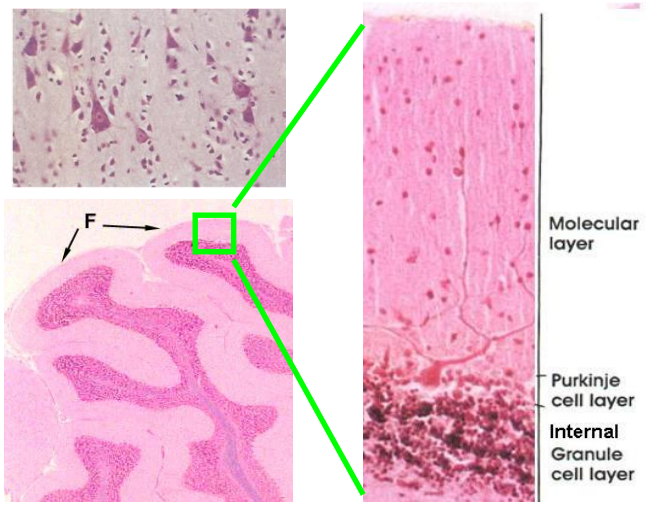
  The brain mainly consists of cerebrum, cerebellum and brainstem. The cells constituting the cerebrum include neurons, glia, capillary endothelial cells, etc.

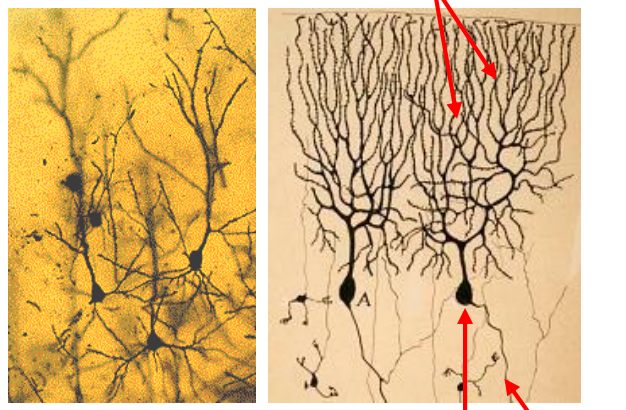
- 实际上，对人脑的认识在历史上与两种技术的发展是分不开的，一是染色技术，另外是显微技术。染色技术可以把神经元与其他类型细胞分开，显微技术可以有效观察与研究神经元。历史上定位出神经元所使用方法如下所示:

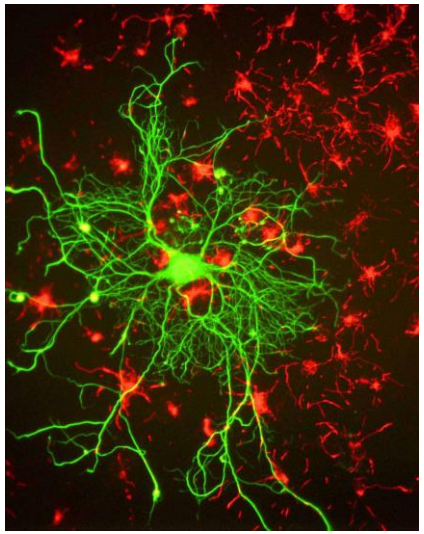
  In fact, the understanding of the human brain in history is closely intertwined with the development of two technologies: staining techniques and microscopy. Staining techniques allowed for the differentiation of neurons from other types of cells, while microscopy enabled effective observation and study of neurons. Historical methods for identifying neurons include:

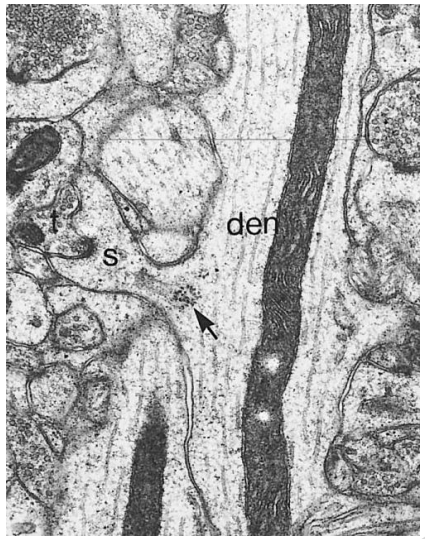
  - 尼氏染色与其它传统染色（Nissl and other traditional stains）
  - 高尔基方法（Golgi method）
  - 荧光标识（ Fluorescence labelling ）
  - 电子显微镜（ Electron microscopy ）

神经科学
Neuroscience









神经科学
Neuroscience

- 神经元或神经细胞是神经系统的重要组成部分，其包含于脑，脊髓及周边神经中。

  Neurons or neuronal cells are the core components of the nervous system, which includes the brain, spinal cord, and peripheral ganglia.

- 神经元具有电生理活动，其可以处理和传导电信号与化学信号。

  Neurons are electrically excitable and can process and transmit information by electrical and chemical signaling.

- 人脑大约包含100亿个神经元，每个神经元约与1万个其它神经元相连。

  Human brain comprises tens of billions of neurons, each linked to thousands of other neurons via the chemical channels called synapse.

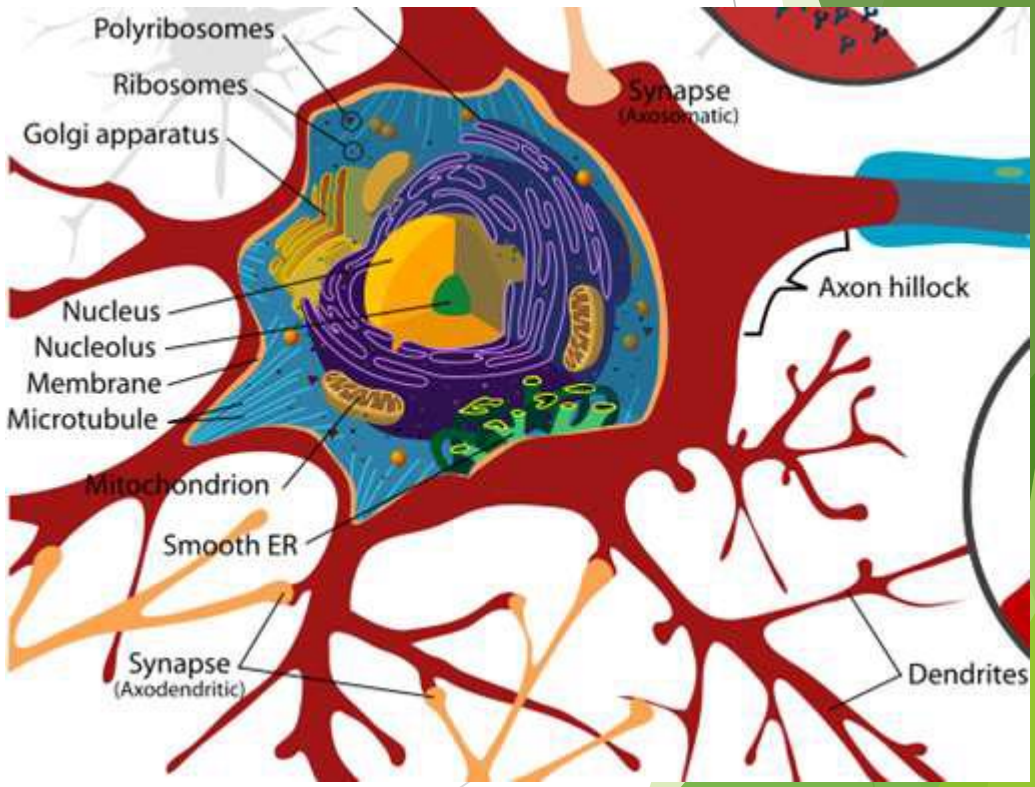
神经科学
Neuroscience

- 神经元主要有三部分组成：细胞体，树突，轴突。其中，细胞体是神经元的最重要的部分，其包含细胞质，一些重要的生化过程在细胞体内发生。

  A neuron consists of three main parts the cell body or perikaryon or soma, dendrites and axons. The cell body is the central region which is the most important part of the neuron containing the nucleus of the cell. The soma is, the site of major metabolic activity in the neuron.

- 哺乳动物的神经细胞的细胞体的大小可由0.005 mm to 0.1 mm；人体大脑的灰质层即由成团的细胞体所致。

  The size of neuronal somas range widely from 0.005 mm to 0.1 mm in mammals. Collections of cell bodies (somas) give the greyish appearance to the gray matter of the brain.



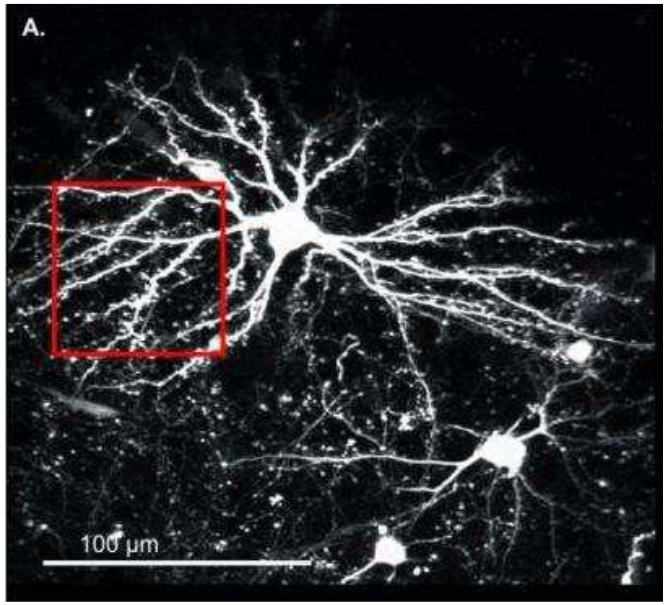
神经科学
Neuroscience

- 树突是接收由其它神经元所传入的信号的延伸结构，又称为传入纤维。神经元上往往有多个树突，以增加其接收信号的来源。

  Dendrites are extensions that carry impulses toward the cell body and are referred to as being afferent fibers. Neurons often have multiple dendrites, which increases the sources from which they can receive signals.

- 树突间接地增大了细胞体的表面积，从而使与其它神经元的通讯更加有效。

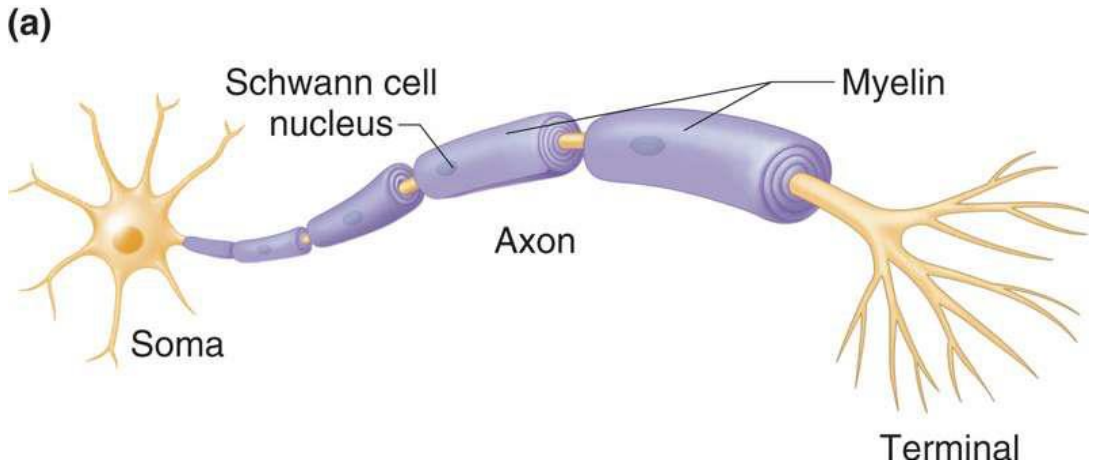
  Dendrites effectively increase the surface area of a neuron to increase its ability to communicate with other neurons.



神经科学
Neuroscience

- 轴突是从细胞体延出的狭长型的凸起，其将信号传出神经元。尽管轴突顶端往往具有分叉，可以将信号传递给多个下游神经元，但一个神经元仅有一个轴突主干。

  An axon is a long, slender protoplasmic protrusion that extrude from the cell body of a neuron. It conducts electrical impulses away from the neuron's cell body or soma. The tip of the axon often branches into spikes, allowing the transmission of signals to multiple downstream neurons, however, each neuron has only one main axon trunk.



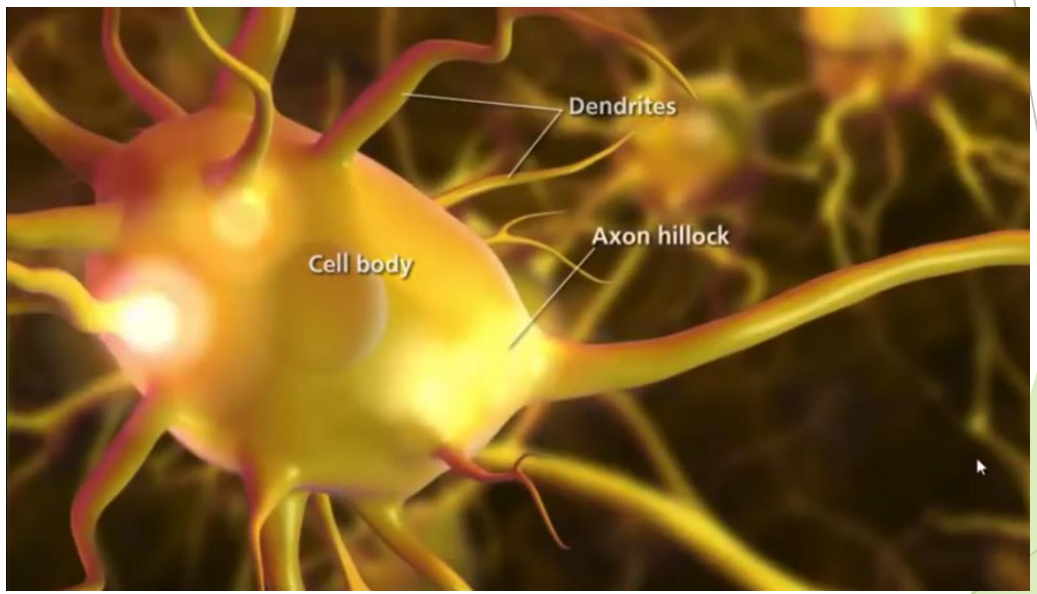
神经科学
Neuroscience

- 轴突从多个方面均与树突不同，如形态，结构，功能等。

  Axons are distinguished from dendrites by several features, including shape, structure and function.

- 轴突与细胞体相连的地方称为轴丘，其起到一个钳位电压的作用。

  The point where the axon arises from a cell body is termed as axon hillock, which presents a voltage threshold to trigger action potential.



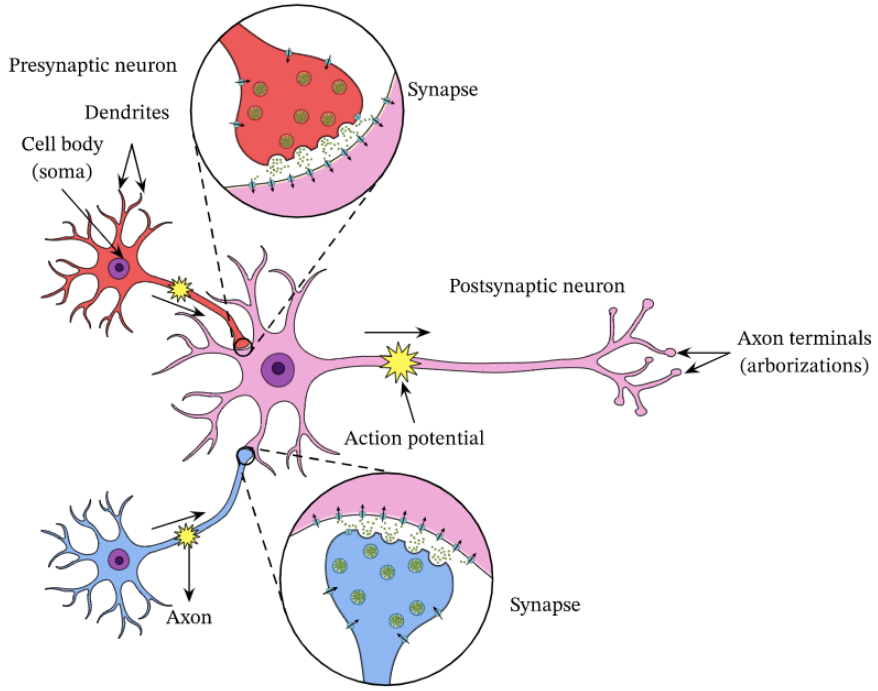
神经科学
Neuroscience

- 通常，树突与轴突相接驳的地方称为突触，为从一个神经元传递信息到另外一个神经元的地方。

  The junction between a dendrite and an axon is called a synapse. two neurons, it is where the transmission of information from one neuron to another takes place.

- 突触也可能在其他地方形成，但绝大多数是树突与轴突的结合部。

  Synapse can form in other places, but mostly occurs at the contacts between a dendrite and an axon.



神经科学
Neuroscience

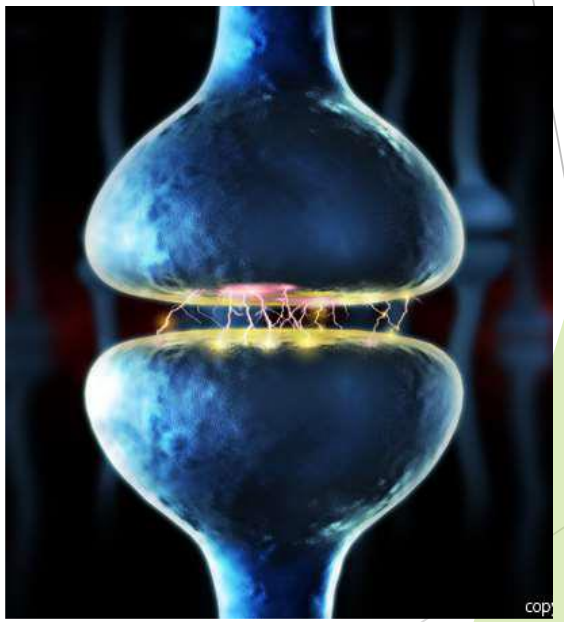
- 突触是在生理学上连续的结构，而非在解剖学上连续的结构。

  Synapse is not the anatomical continuation. But, it is only a physiological continuity between two nerve cells.

- 突触分为突触前，突触后，突触壁：

  Synapses are divided into presynaptic, postsynaptic, and synaptic cleft:

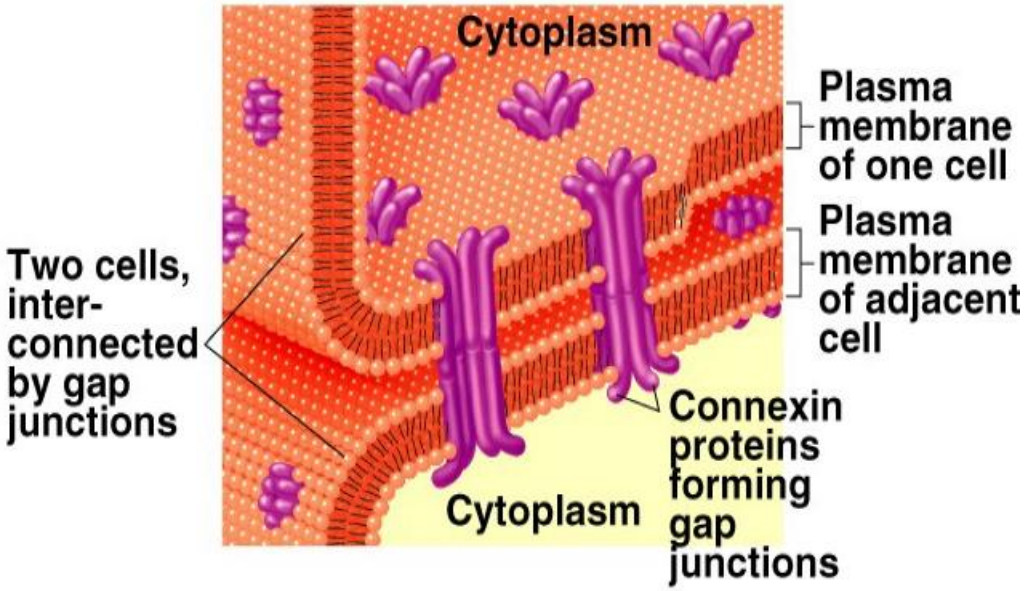
  - A presynaptic ending that contains neurotransmitters, mitochondria and other cell organelles.
  - A postsynaptic ending that contains receptor sites for neurotransmitters.
  - A synaptic cleft or space between the presynaptic and postsynaptic endings. It is about 20nm wide.

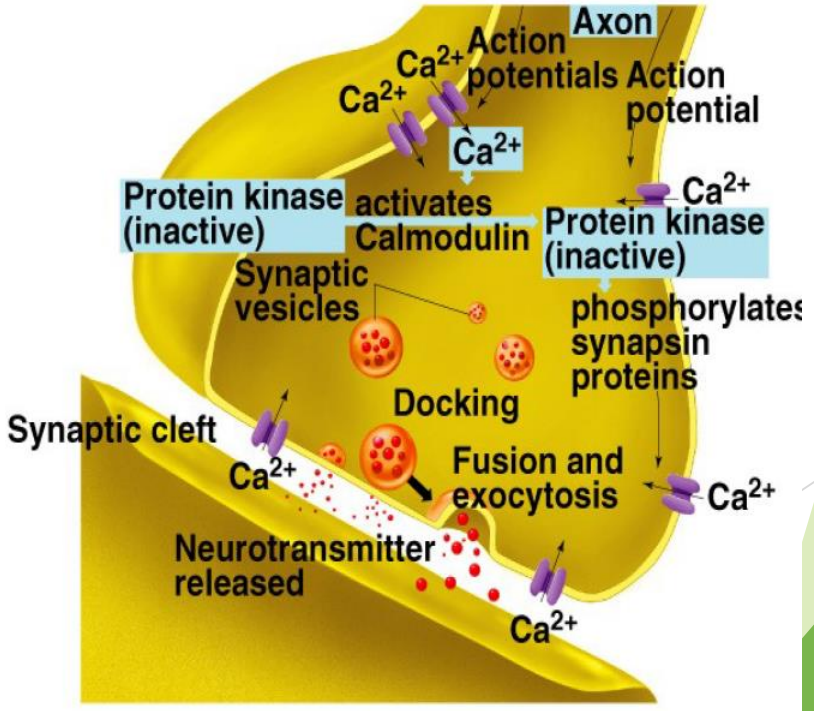


神经科学
Neuroscience

- 信息在突触之间的传递可以通过电方式，也可以通过化学方式。

  Information exchange at synapses can be achieved by electrical coupling or neurotransmitter releasing.





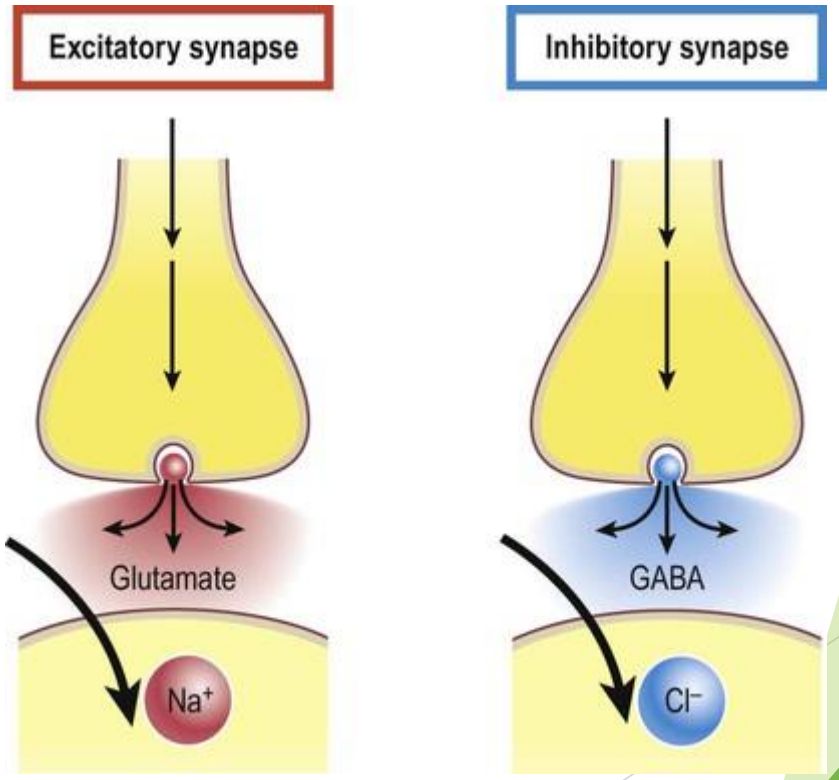
神经科学
Neuroscience

- 上游神经元可以通过前突触增强后突触所在神经元的活性，或者抑制后突触所在神经元的活性。

  The upstream neurons can excite or inhibit the downstream neurons via the interaction between pre-synapse and post-synapse.

- 大脑行使的认知功能往往是相关神经通路上，多个神经元的兴奋与抑制共同作用的结果。

  The cognitive functions performed by the brain often result from the combined effects of the excitation and inhibition of multiple neurons in relevant neural pathways.



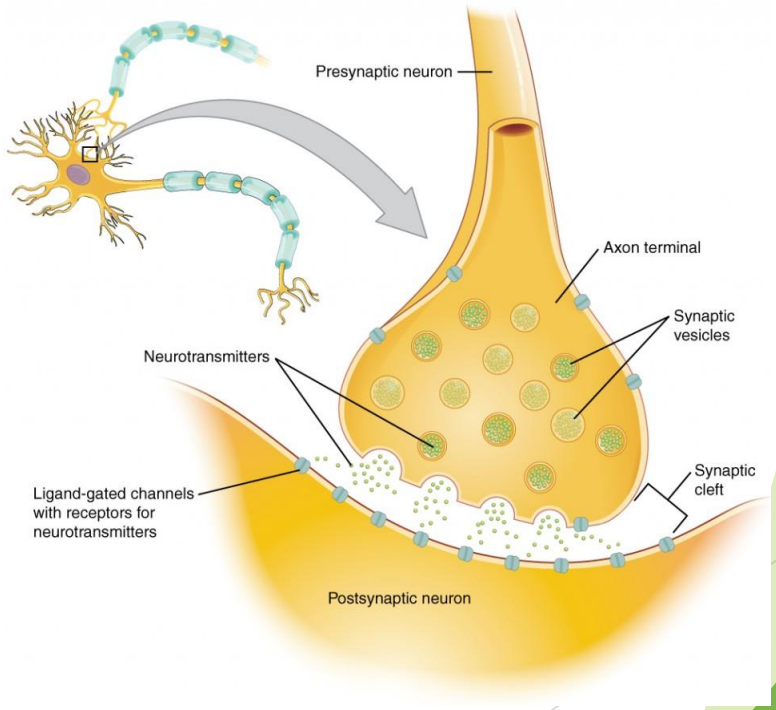
神经科学
Neuroscience

- 电生理是研究生物细胞或组织电活动特性的生理学分支；其覆盖从微观上操纵离子通道的通道蛋白，到宏观上测量器官的生理对象的电压电流变化，等等。

  Electrophysiology is the branch of physiology that studies the electrical properties of biological cells and tissues. It involves measurements of voltage changes or electric current or manipulations on a wide variety of scales from single ion channel proteins to whole organs like the heart, brain.

- 与神经元相关的电位分为两类，局部分级电位与动作电位。局部分级电位只在短距离有效，如右图所示；

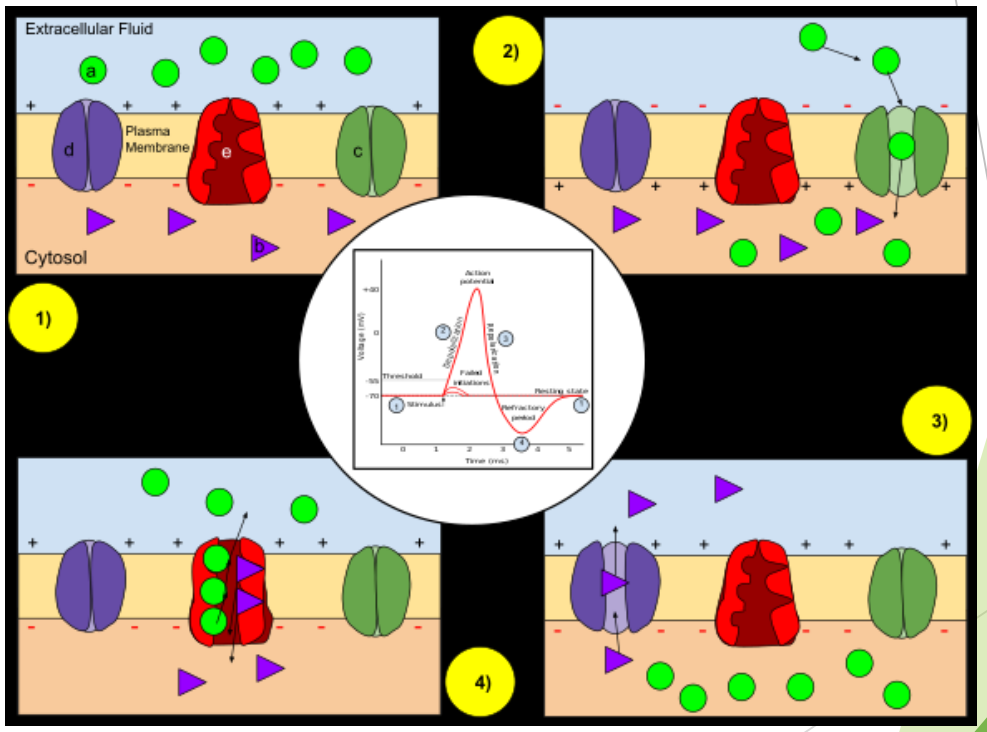
  Neurons use only two types of electrical signals: local graded potentials, which spread over short distances, as shown in the right figure:



神经科学
Neuroscience

- 而动作电位可在长距离范围内传导。对不同信号的表征，一般经由动作电位的频率与间隔进行区分。

  Action potentials, which are conducted rapidly over long distances. Different signals are generally distinguished based on the frequency and interval of action potentials.



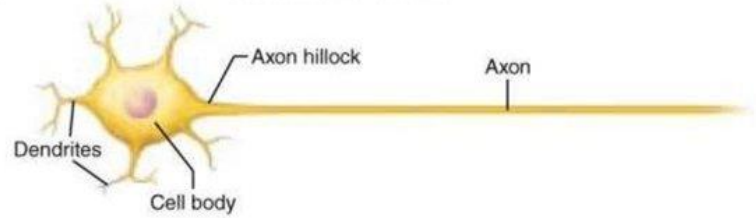
神经科学 Neuroscience

- 右表展示了局部分级电位与动作电位的区别：

  The right table describes the difference between local graded potentials and action potentials.

GRADED POTENTIALS VS. ACTION POTENTIALS (1/2)

	GRADED POTENTIAL (GP)	ACTION POTENTIAL (AP)
Location of event	Cell body and dendrites, typically	Axon hillock and axon
Distance traveled	Short distance—typically within cell body to axon hillock (0.1–1.0 mm)	Long distance—from trigger zone at axon hillock through entire length of axon (a few mm to over a meter)
Amplitude (size)	Various sizes (graded); decays with distance	Always the same size (all-or-none); does not decay with distance
Stimulus for opening ion channels	Chemical (neurotransmitter) or sensory stimulus (e.g., light, pressure, temperature)	Voltage (depolarization, triggered by GP reaching threshold)



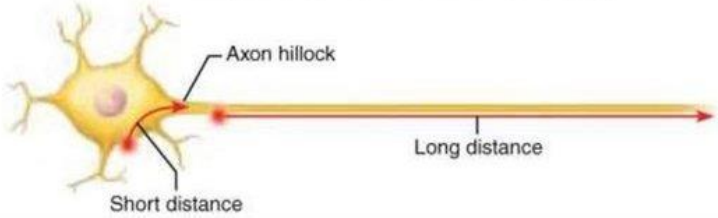
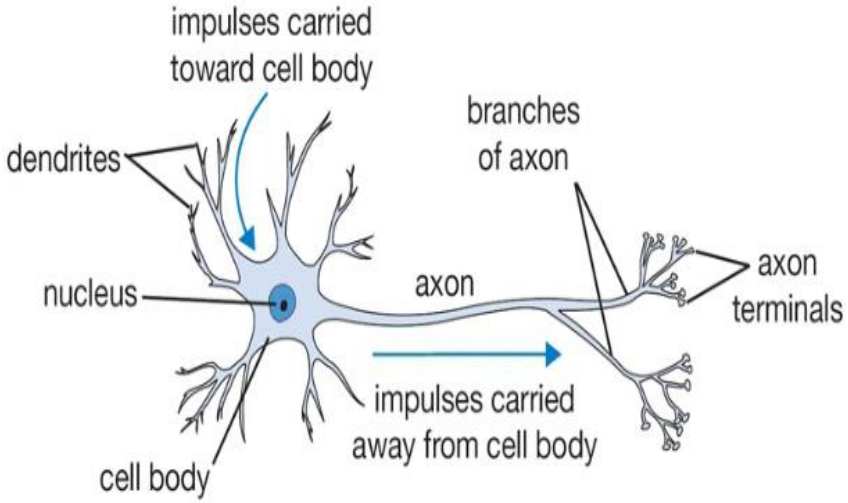


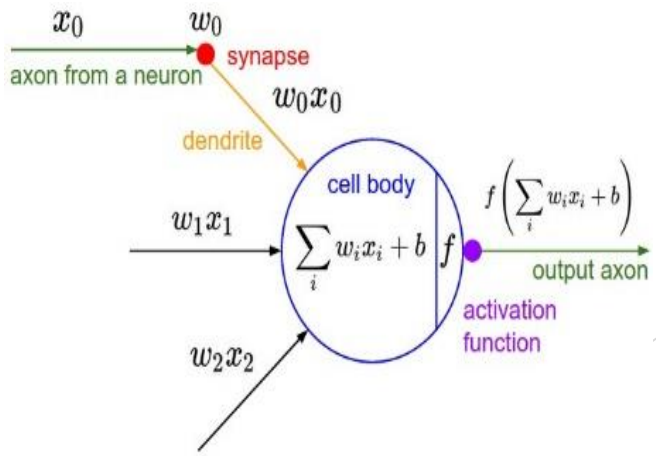
Image source: Adapted from Marieb's Anatomy and Physiology, 9th edition, Pearson.

数学建模
Mathematical Modelling

- 当我们知道神经元的结构与基本工作机理后，便可以建立简单数学模型，仿人脑的方式解决问题。下面是对单个神经元的建模：

  Once we understand the structure and basic working mechanisms of neurons, we can establish simple mathematical models to solve problems in a brain-like manner. The following is a modelling approach for a single neuron:

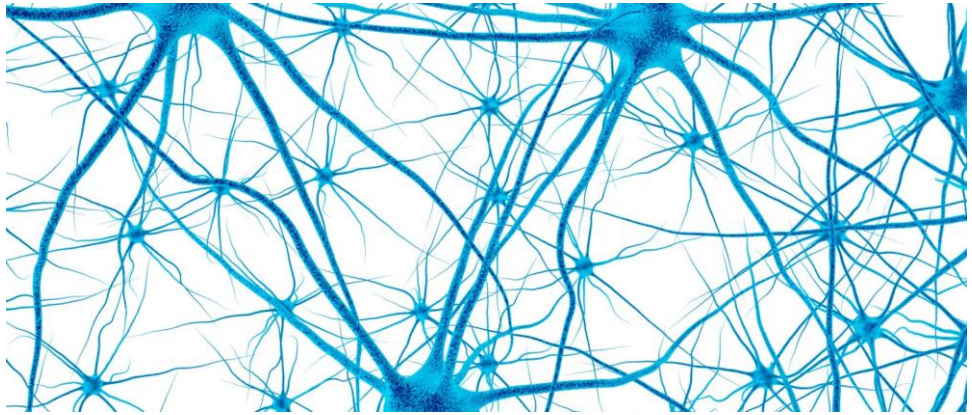


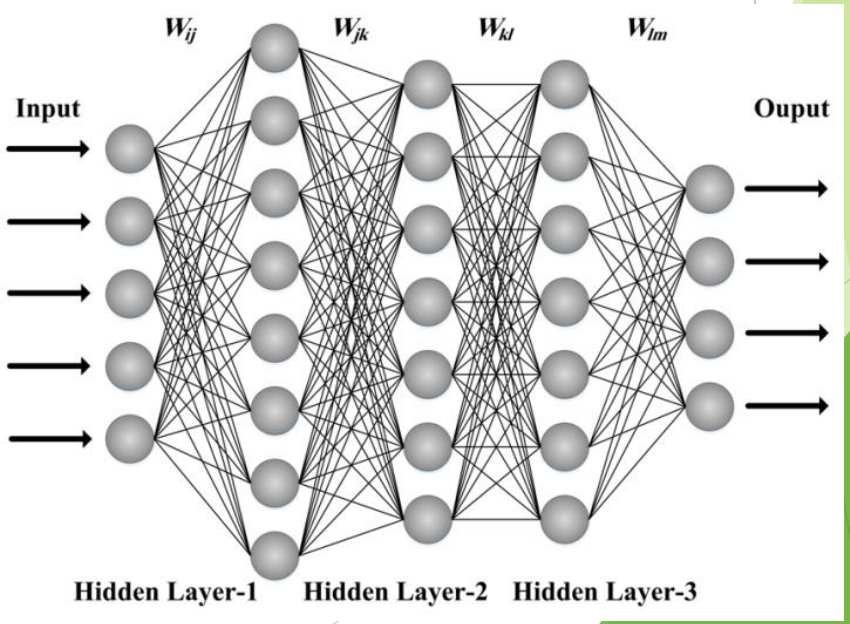


数学建模
Mathematical Modelling

- 当我们考虑由神经元构成的神经回路，或通路，或网络后，便可以构造最为简单的全连接人工神经网络：

  When we consider neural circuits, pathways, or networks composed of neurons, we can construct the simplest fully connected artificial neural network:





总结
Summary

- 我们利用基于脑启发的最简单的数学模型，便可以解决许多问题，不管是分类问题还是回归问题。同时，上面所讲的简单模型是构成复杂模型的基础，比如大语言模型。

  By using the simplest mathematically inspired models based on the brain, we can solve many problems, whether they are classification or regression problems. Moreover, the simple models discussed above serve as the foundation for constructing complex models, such as large language models.