Introduction to neuroscience
Diffusion
Diffusion in the brain

Diffusion processes in the brain

Fredrik E. Pettersen

April 28, 2014

Introduction to neuroscience
Diffusion
Diffusion in the brain

Contents

Introduction to neuroscience
Diffusion
Diffusion in the brain

The Central Nervous System

- All invertebrates except sponges and radially symmetric animals have one.
- Consist of spinal cord and brain in vertebrates.
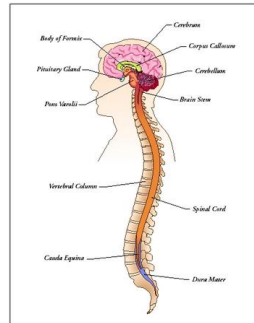- Tasked with gathering and processing information.

Figure: Human CNS

Introduction to neuroscience
Diffusion
Diffusion in the brain

Some words about the brain

- Labeled the most complex object in the universe.
- $\sim$ 200 billion neurons with $\sim$ 125 trillion connections in neocortex alone.
- Different parts associated with different tasks.
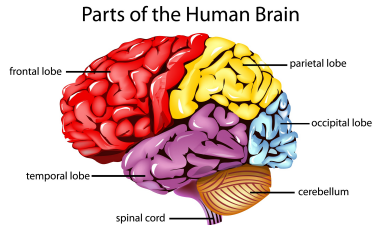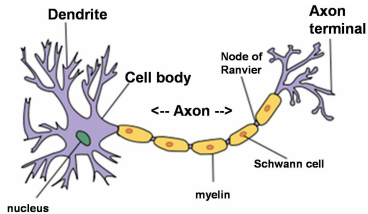- Many underlying processes are very inefficient.

Parts of the Human Brain

Figure: Human brain with labels

Introduction to neuroscience
Diffusion
Diffusion in the brain

Cells in the brain

Neurons:

- Signal processing

Neuroglia:

- Janitorial tasks

Introduction to neuroscience
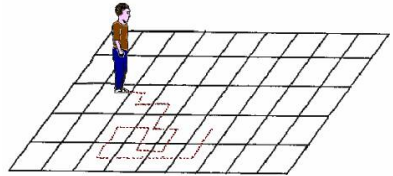**Diffusion**
Diffusion in the brain
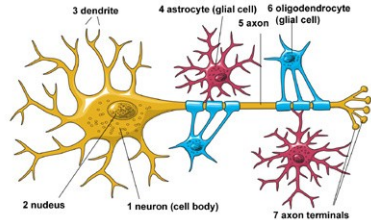
Normal diffusion

- Process of net movement due to a difference in concentration.
- Formulated in 1855 by Adolf Fick in the modern way.
- Widely used across many diciplines like social studies, economics and biology.

$$\frac{\partial C}{\partial t} = D\nabla^2 C$$

Introduction to neuroscience
Diffusion
Diffusion in the brain

Random walks

- Also widely used in many diciplines.
- "Endless" possibilities for added complexity.
- Conceptually not that difficult.
- Recreates diffusion

Introduction to neuroscience
Diffusion
Diffusion in the brain

Diffusion across synapses

- Two types of synapses connect neurons - electrical and chemical.
- Action potentials triggers release of neurotransmitter into synaptic cleft.
- Receiving end passes input on to cell body.
- Diffusion across synaptic cleft takes $\sim \mu$s or less.

Figure: Chemical synapse with dendritic spine.

Introduction to neuroscience
Diffusion
Diffusion in the brain

PKCγ diffusion into spines

- PKCγ is an enzyme associated with learning.
- Released from cell body and diffuses through dendrite into spines.
- Very low concentrations could require multi scale modeling.

Introduction to neuroscience
Diffusion
Diffusion in the brain

Thank you!

Introduction to neuroscience
Diffusion
Diffusion in the brain
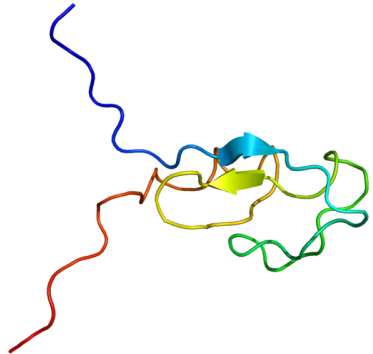
Firing in auditory nervous system

Introduction to neuroscience
Diffusion
Diffusion in the brain

Cells with specific tasks

Introduction to neuroscience
Diffusion
Diffusion in the brain

Visual cortex

Introduction to neuroscience
Diffusion
Diffusion in the brain

Lobes

Frontal lobe is associated with short term memory, social intelligence, reward, attention and planning

Pareital lobe is in charge of integrating sensory information like spatial orientation

The temporal lobes are involved in the retention of visual memories, comprehending language, storing new memories, emotion, and deriving meaning.

The Occipital lobe is mainly in charge of processing visual information.

Introduction to neuroscience
Diffusion
Diffusion in the brain

From RW to diffusion

A large number, N, of walkers can be described by their concentration $C(x,t) = NP(x,t)$. The concentration is conserved, so any amount that flows out of an area must reflect as a decrease in concentration. This is expressed by the flow of concentration

$$\frac{\partial C}{\partial t} - \nabla \cdot \vec{J} = S \quad (1)$$

where $\vec{J}$ is the flow vector and S is a source term which for now is zero. Through Fick's first law the diffusive flux is related to the concentration gradient $\vec{J} = -D\nabla C$. Inserting this gives

$$\frac{\partial C}{\partial t} = \nabla \cdot (D \cdot \nabla C) \quad (2)$$

Introduction to neuroscience
Diffusion
Diffusion in the brain

Applications of RW

- GPS map-navigation
- Percolation theory (for flow simulations)
- Estimate size of internet