

# Artificial Neural Networks

# Background

- Why we don't simply simulate human's brain ?
- What is intelligence ? *A cat that once sat on a hot stove will never again sit on a hot stove or on a cold one either-* Mark Twain.
- Ability to learn is the root of intelligence.

# Some Points

- The human brain is amazing!!
- Here are a few things that brains can do:
  - Recognize someone you haven't seen for 10 years, even if they have changed.
  - Guess that a piece of music is by a particular composer from its "style".
  - Understand speech, even if the person speaking has a strong regional dialect.
  - Instinctively "fill in" missing information.

# Who is He?



# Bill Clinton



# Initial thoughts

- In comparison to computers, the human brain is useless at several other tasks
  - Multiplying two large numbers together
  - Sorting a long list
  - Searching for a particular string in a long document
  - Switching large numbers of telephone calls

# What is the difference between these tasks?

- Humans are poor at *computation*
  - Exact, quantitative, inherently serial (although can sometimes be parallelised)
  - Very few people can compete with a computer for even simple calculations
- Humans are excellent at *pattern recognition* and *association* and other higher *cognitive* tasks
  - Inexact, qualitative, inherently parallel
  - Enormous effort has been spent trying to get computers to emulate this human performance, with only limited success

# Some questions

- Is pattern recognition important for real-life applications?
- How can humans solve some types of difficult problem incredibly fast, when they would struggle to multiply 235 by 47?
- How could we try to emulate this kind of performance with a machine?



# For what kinds of task is pattern recognition important?

- Computer vision
- Electronic “noses”
- ECG analysis
- Biometrics
  - Face recognition
  - Fingerprint recognition
- Handwriting analysis
- Speech recognition
- Security systems
- Forensics
- Fault detection
- Friend/foe recognition
- Signal processing

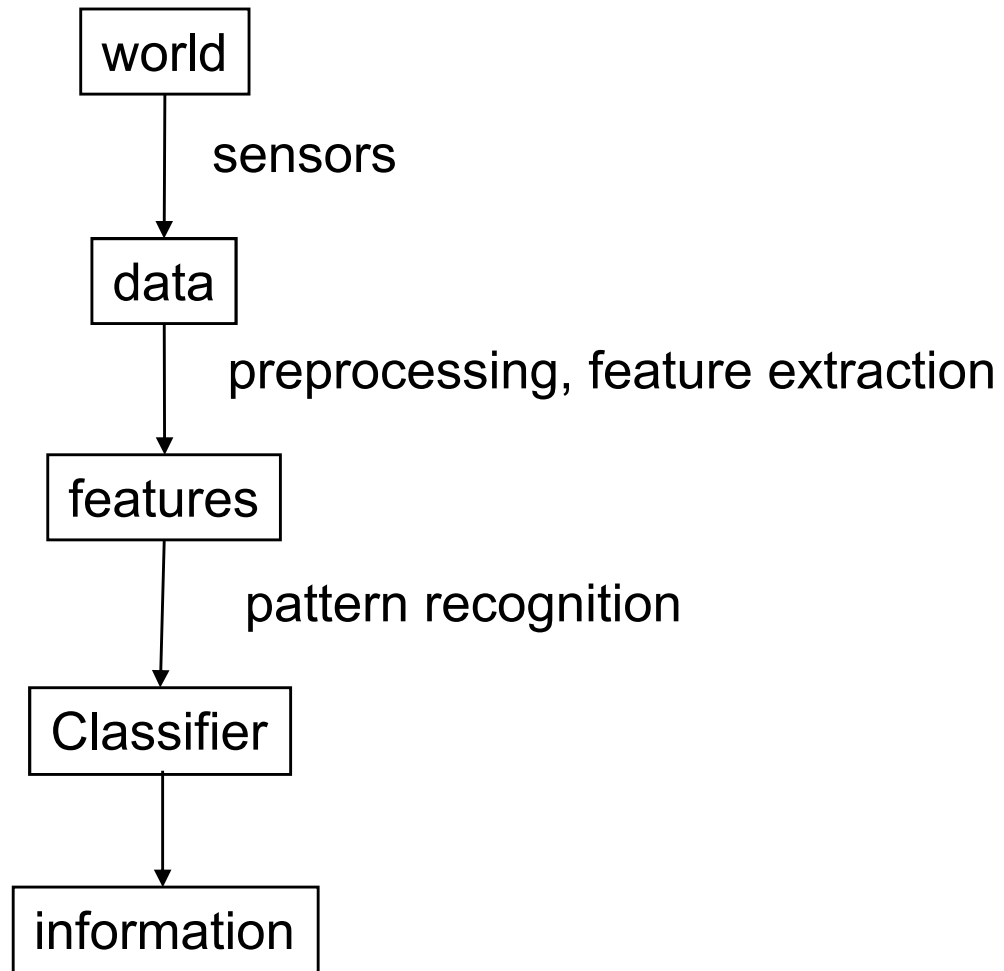
# Key tasks

- Information reduction
  - Large number of data points → small number of data points which contain (almost) the same information
- Mapping
  - millions of pixels → name
- Classifying
  - This face is a woman, but that face is a man

Which gender is each person?



# From the world to information



# Sensors

- We are not going to look at sensors and hardware signal processing in this course
- We assume that data has been collected using a camera, microphone or some other apparatus and that analogue information has been digitised
- A raw data set from a sensor is often very large and noisy

# From raw data to features

- The data must often be:
  - Cleaned, for example to detect periods of time where the sensor was not working properly
  - Sampled, for example particular frames selected from a video
- We must then extract features
  - For example if we want to tell whether there is a traffic sign in a picture, we want to extract information which is relevant
    - looking for bright colours and geometrical shapes is clearly relevant
    - whether the picture is light or dark is not relevant
  - It is at this stage that *information reduction* happens

# From features to information...

- Finally we have to classify or recognise
  - This is the pattern recognition task
- How can we go about this?
  - Build an algorithm by hand?
  - Use a statistical method?
- Neither of these methods fits how the brain works....they are essentially *computational* methods.

# ....using a cognitive approach

- The human brain solves these kind of problems in a cognitive way:
  - There is no explicit algorithm
  - The method is clearly adaptive, as we learn over time
  - The hardware (the brain!) is pretty important and is not like a regular computer



# Questions

- How does the brain work?
  - What is it constructed of?
  - How is information transmitted?
  - How does it “learn” algorithms?
  - How does it store information?
- Can we model the brain with a computer?
  - Can we use such a problem to solve problems which seem to be best tackled using cognitive approaches, rather than computational?
  - Can we formalise this approach and make it rigorous?
    - If we want to use this approach for important problems we need to have a theoretical ground to stand on

# Different philosophies

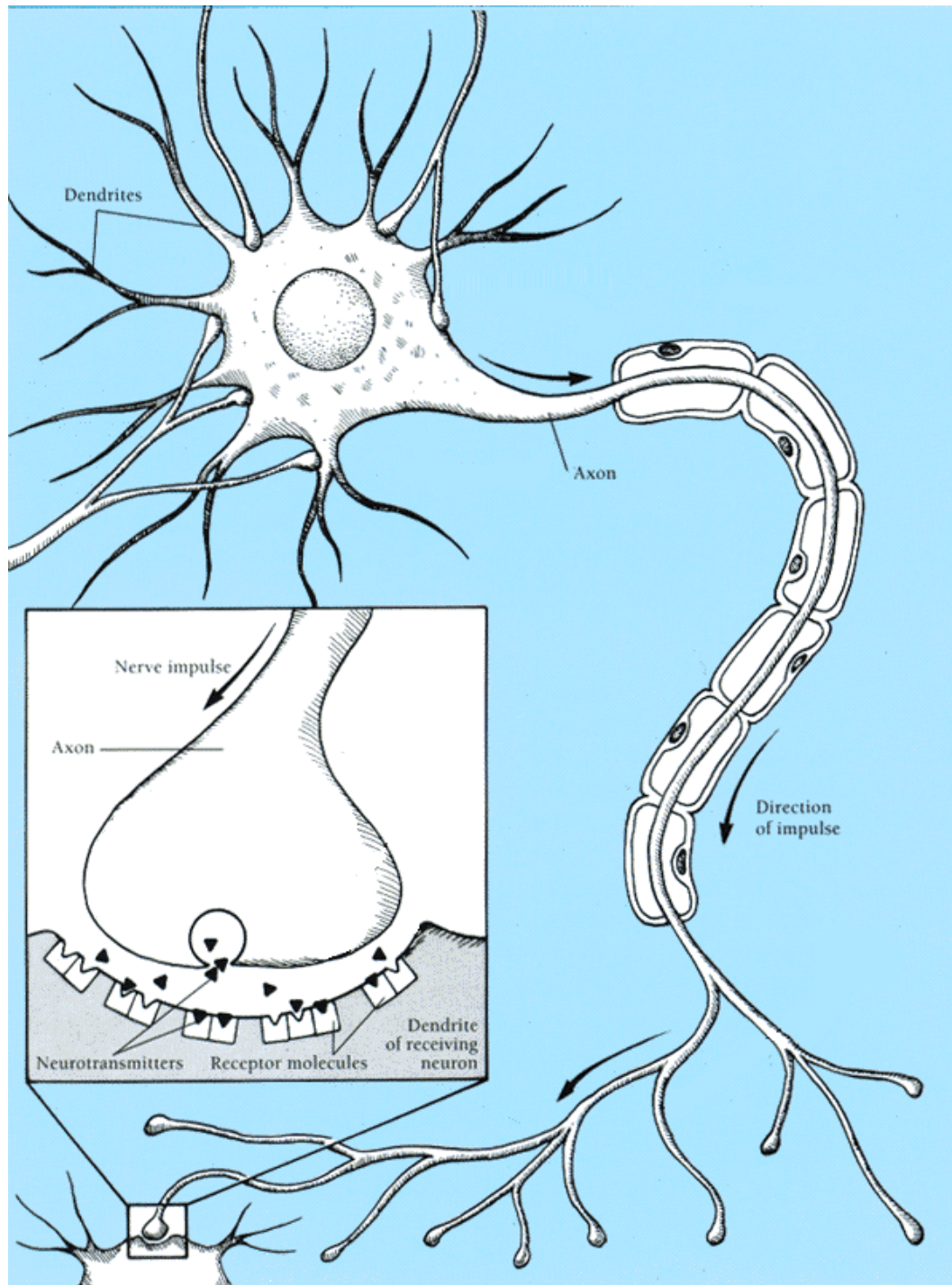
- This question about finding a formal ground to stand on is an important philosophical problem
  - Should the theory be human-based (i.e. based on theories derived from neuroscience, psychology, and so on)?
    - This is known as cognitive science
  - Or should the theory be based on mathematics, statistics and computing?
    - People who espouse this philosophy use the term “*artificial neural networks*” to emphasise that they do not believe in a cognitive approach

# A short course in neuroscience

- The brain is made of a large number of individual cells, known as neurons
- All of the neurons in the brain are quite similar (on an individual basis)
- However, different parts of the brain have varying structure – how the neurons arranged is not the same

# Some facts about the human brain and nervous system

- It's slow at processing information serially
  - Our reaction time (e.g. from burning a finger to saying "ow") is about 20ms, which is very slow compared to a modern computer
- It can process information in parallel
- Information is stored in a distributed fashion
  - People who lose the function of part their brain often don't lose a "well defined" set of memories or mental functions
- Early experiments showed that electricity is somehow involved
- Chemistry is involved in the brain (hence the severe effect on the brain of drugs like heroin and alcohol)



A neuron

# Operation of a neuron

- A neuron performs a mapping of input to output
- Input comes when the *dendrites* are excited
- “sufficient” excitation results in the neuron firing an electrical pulse out along the *axon*
- The other end of the axon is connected to one or more other dendrites (of other neurons)
- The connection is not a direct electrical contact, but made through a *synapse*
  - The electrical signal is converted (via an electro-chemical reaction) into a chemical change in the synapse
  - This change excites dendrites on the other side of the synapse

# Synaptic efficiency

- Synaptic efficiency varies.
- If the connection is strong, a small signal on the axon will be sufficient to greatly excite the dendrites on the other side.
- A weak connection implies the reverse

# What does this explain?

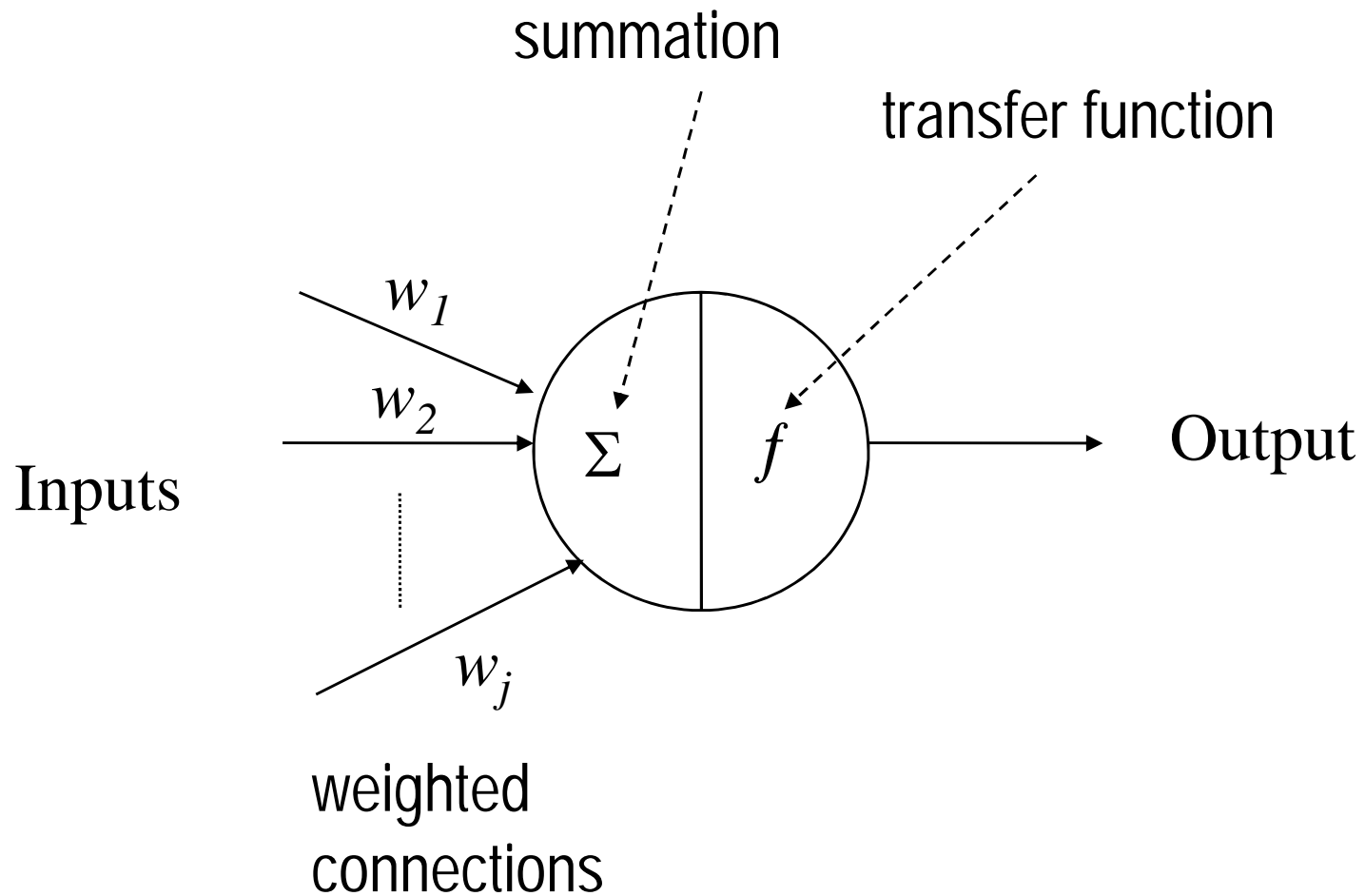
- The function of the neuron and structure of the brain (made of approx 10 billion neurons) explains:
- The slow serial performance
  - transmission across the synapses is slow
- The inherent ability to process and store information in a distributed fashion
  - The brain is a massively parallel machine



# How does the brain learn?

- We don't know exactly
- What we do know is that chemical changes in the synapses are not just temporary
  - The synapses function as memory
- What is still not well understood is how information is organised in the brain
- We therefore take a “bottom-up” approach
  - If we can model and understand how a single neuron behaves, maybe that will give us an idea of how higher level learning might work

# An artificial neuron



# Modelling the neuron

- You can see that the structure of the artificial neuron is quite similar to a neuron
  - Information is gathered from many inputs
  - The weighted sum models combining all the inputs together
  - The transfer function models deciding whether the axon should “fire” or not
  - The output is the signal which goes out along the axon

# Adaptation

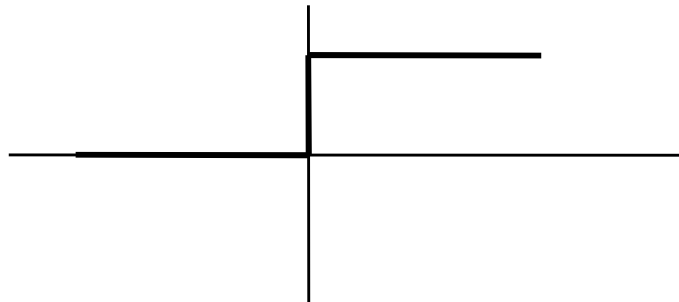
- For learning to take place, the neuron must be able to adapt.
- This is achieved by changing the weights
  - We will discuss how this is done in detail in future lectures
- Thus we can make a further analogy, which is to state that the weights model the synaptic connections
  - A large weight implies a strong synaptic connection
  - A small weight implies a weak synaptic connection

# Key insight

- Hebb (1949) noted:
  - *When an axon of a cell A is near enough to excite a cell B and repeatedly or persistently takes place in firing it, some growth process or metabolic change occurs in one or both cells such that A's efficiency, as one of the cells firing B, is increased.*
- We will come back to this in our study of perceptrons

# The transfer function

- Remember the wording I used:
  - *“sufficient” excitation results in the neuron firing an electrical pulse*
- The transfer function has to model this behaviour
- The simplest function with the kind of properties we want is the step function:



# Practical issues concerning NN

- A simulation of human way of thinking
- Number of neurons, layer, activation function, learning rate
- Not enough neurons: cannot learn complex things
- Too much neurons: learn too complex things (tends to memorize training's example rather than learning a general rule from them)  
**Overtraining.**
- Speed

# Some advantages of NN

- Ability to **learn and discover**
- Very useful to deal with fuzzy “criterias” (like pattern recognition,...)
- Specific way of solving problem.



# Some disadvantages of NN

- Often slow
- Black box: very difficult to interpret result and find the motivation of a result
- Often needs to feature extractions to be efficient