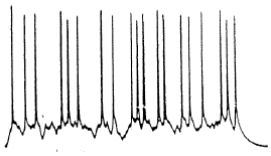
Neural Coding

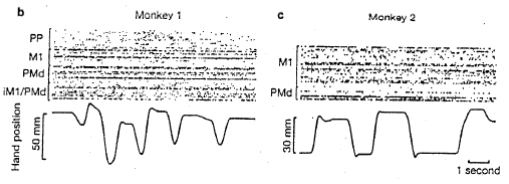
Computing and the Brain

How Is Information Coded in Networks of Spiking Neurons?

- Coding in spike (AP) sequences from individual neurons

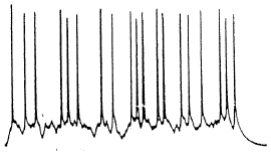


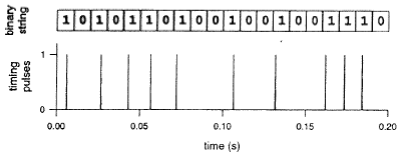
- Coding in activity of a population of neurons



Coding in Single Neurons

- Binary coding
  - Presence or absence of spikes
  - Logical 1 if neuron fires an AP in a given time window; 0 otherwise
- Rate coding
  - Average firing frequency over a given time
  - Analogue (number)
- Temporal coding
  - Interspike interval
  - Temporal sequence of spikes

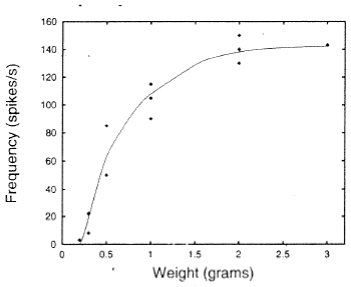


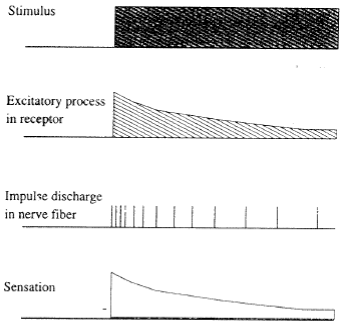


(CS92 Fig 3.4)

Rate Coding in Sensorimotor Systems

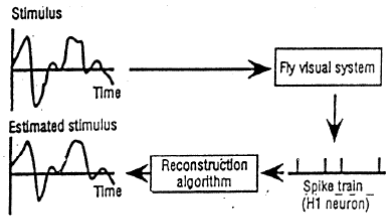
- Muscle stretch receptors fire in proportion to stretch (weight)
  - Experimental data from Adrian, 1928
- Sensation of a stimulus is proportional to the firing rate
  - Hypothesis by Adrian





Temporal Coding in Sensorimotor Systems

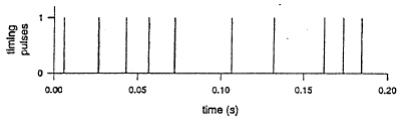
- H1 neuron in the fly visual system
- Responds to movement of objects in the world
  - Angular velocity
- Movements can be reconstructed from measurements of the interspike intervals



(from Spikes, MIT Press, 1997)

Dynamic Range of Codes

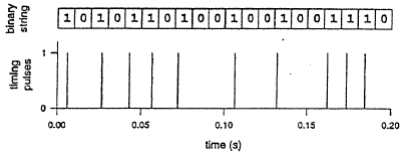
- Suppose a neuron is capable of firing from 0 to 100 spikes per sec
- Neurons that receive inputs from this neuron have 200 msecs to "decode" the signal from the neuron
  - Information coded in spikes fired by neuron in a 200 msec time window
- Given this scenario, what "code" is best?
  - Rate versus temporal coding



- **Rate code**
  - Rate is number of spikes divided by time interval
  - Roughly 0 to 20 spikes could occur in 200 msecs
  - Only 20 states can be distinguished
  - 0, 5, 10, 15, 20 Hz etc

Dynamic Range (2)

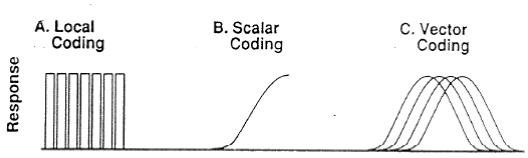
- **Temporal code**
  - Measure interspike intervals with 10 msec precision
  - 20 time bins in which spikes can be detected
  - 20 element binary vector
  - Over one million (2^{20}) possible states
    - Different spike patterns giving different binary vectors



- 200 msecs is often too long in the real nervous system
  - House fly performs visual responses in 30 msecs
  - Human can recognise visual objects in 150 msecs
  - Time for only 1 or 2 spikes per neuron

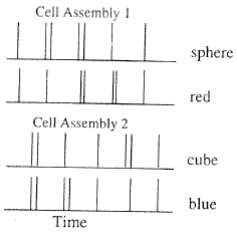
Coding in Networks

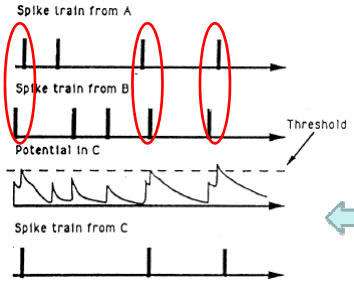
- How are “features” of a stimulus encoded in a network of neurons?
  - Eg shape, colour, size etc
- *Local coding*: single neuron per feature
- *Scalar coding*: feature encoded by firing rate of a single neuron
- *Vector coding*: feature encoded by firing rates of a population of neurons that have overlapping tuning curves



Temporal Binding

- How can the activity of neurons responding to different features of a single stimulus be combined?
- *Cell assembly*: group of neurons that fire at the same time
- *Temporal binding*
  - E.g red sphere and a blue cube

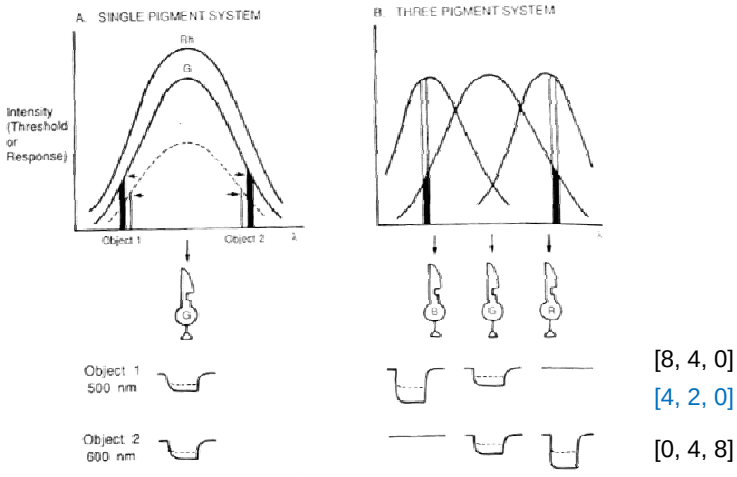




- Coincidence detection
- e.g. Cell C encodes a red sphere

Vector Coding of Features

- Three colour system of *colour* encoding

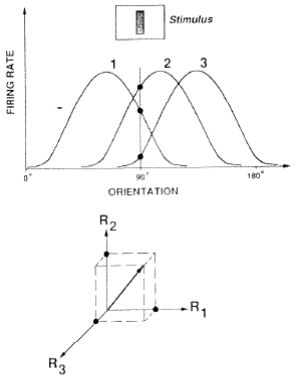


[8, 4, 0]
[4, 2, 0]
[0, 4, 8]
[0, 2, 4]

(CS92 Fig 4.15)

Vector Coding of Features

- Visual stimulus *orientation* encoding
- Example shows 3 neurons that respond maximally to different orientations of a bar of light
- How many neurons with different tuning curves are required to encode orientation?

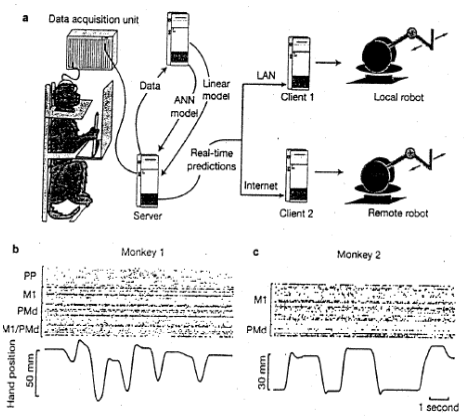


(CS92 Fig 4.21)

Prediction of Hand Movements

- Recording from 100 neurons in groups of 20 from different areas of motor cortex
- Monkey moves joystick to track onscreen cursor
- Predictions of hand movements based on:

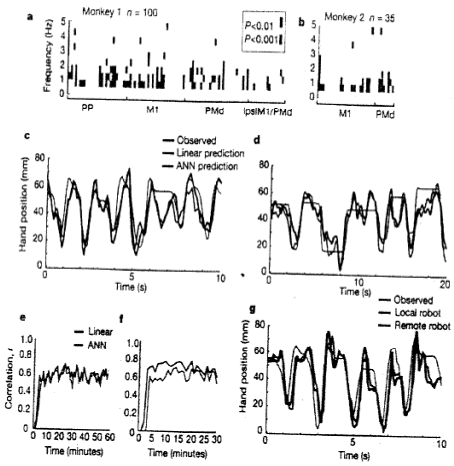
1. Average firing rate of each neuron in 100msec time bins
2. 10 bins per neuron, covering 1 second of activity immediately preceding movement



(Wessberg et al, Nature 408:361-365, 2000)

Prediction of Hand Movements (2)

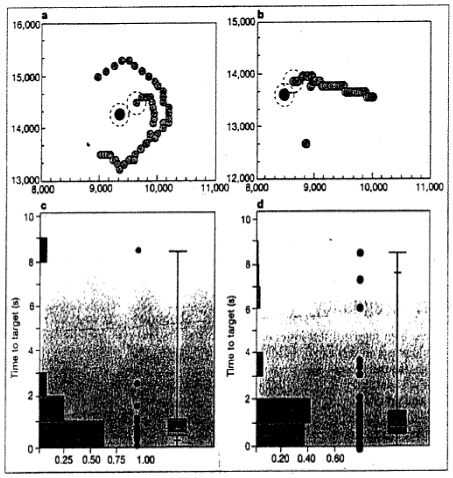
- Linear and nonlinear (ANN) models
  - Inputs are neuronal firing rates
  - Output is predicted movement
- Initial model parameters derived from first minute of experimental data
- Parameters updated on each 10 minutes of data
- 60% accuracy
- Estimate 90% accuracy from 1000 neurons



(Wessberg et al, Nature 408:361-365, 2000)

Neural Control of Cursor Movement

- Again, monkeys use joystick to move onscreen cursor
- Recorded between 7 and 30 motor cortex neurons
- Hand movement predictions based on neuron firing rates measured in 50 msec time bins
- Linear models with parameters based on 3 minutes of data
- Once model was trained the joystick was disconnected from the computer…
  - Performance maintained
  - Sometimes monkeys stopped making hand movements!



(Serruya et al, Nature 416:141-142, 2002)