Stochastic Models of Ion Channels
Sketch of Cerebellar Neurons by Santiago Cajal (1899)

A: Purkinje cells
B: Granule cells
A Single Neuron

A stained neuron with an extensive dendritic tree
A Population of Neurons

Several stained and possibly interconnected neurons
Structure of a Neuron
The Plasma Membrane

Figure 1

Plasma Membrane Structural Components

- Hydrophilic Region
- Carbohydrate Side Chain
- Glycoprotein
- Hydrophobic Region
- Integral Protein
- Fluid Mosaic Membrane Model
- Transmembrane Protein
- Phospholipid
- Hydrophobic Region
- Hydrophilic Region
Atomic Model of an Ion Channel

The bacterial KcsA $K^+$ channel
Ion Flow Through an Ion Channel

Only the $K^+$ ions get through, the $Cl^-$ stays put. The membrane acts as a semipermeable membrane.
Setup for Patch Clamp Recordings
Cell-Attached Patch Clamp Recording

Recording from a patch of membrane containing approximately 4 ion channels (maybe more, but not less)
Monte Carlo Simulation of a Single Ion Channel

A. $k^e=0.1$, $k^-=0.1$

B. $k^e=0.2$, $k^-=0.2$

C. $k^e=0.2$, $k^-=0.05$

Time (msec)
Monte Carlo Simulation of 4 Ion Channels

$k^+ = 0.1$, $k^- = 0.1$

$k^+ = 0.2$, $k^- = 0.2$

$k^+ = 0.2$, $k^- = 0.05$
Binomial Distributions
Deterministic Morris-Lecar Model

Deterministic Morris-Lecar with small-amplitude sinusoidal input
Stochastic Morris-Lecar Model

Stochastic Morris-Lecar (N=20) with small-amplitude sinusoidal input
Stochastic Morris-Lecar Model

Stochastic Morris-Lecar (N=100) with small-amplitude sinusoidal input. The spiking frequency is approximately that of the forcing frequency.
Stochastic Morris-Lecar Model

Stochastic Morris-Lecar (N=1000) with small-amplitude sinusoidal input. The cell rarely spikes.
Stochastic Morris-Lecar Model

Summary of the response vs. number of channels
Double-Well Potential
Stochastic Resonance with a Double-Well Potential

Sinusoidal signal (green) alters the shape of the potential function. The size of the circle reflects the probability that the particle is in a particular well.