

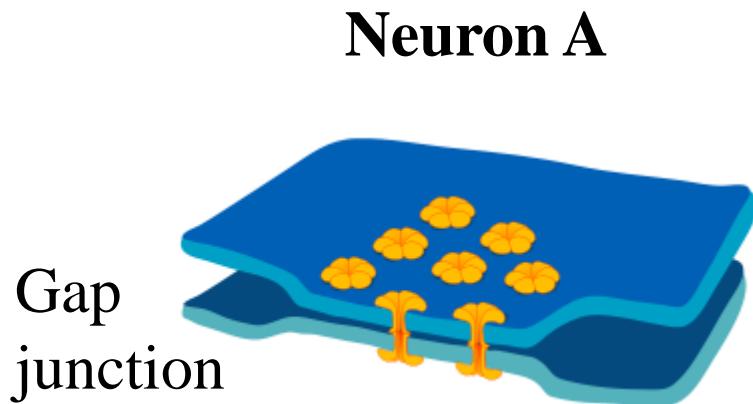
What happens  
to the spike  
(action  
potential) when  
it reaches the  
end of an axon?

Enter...  
the Synapse

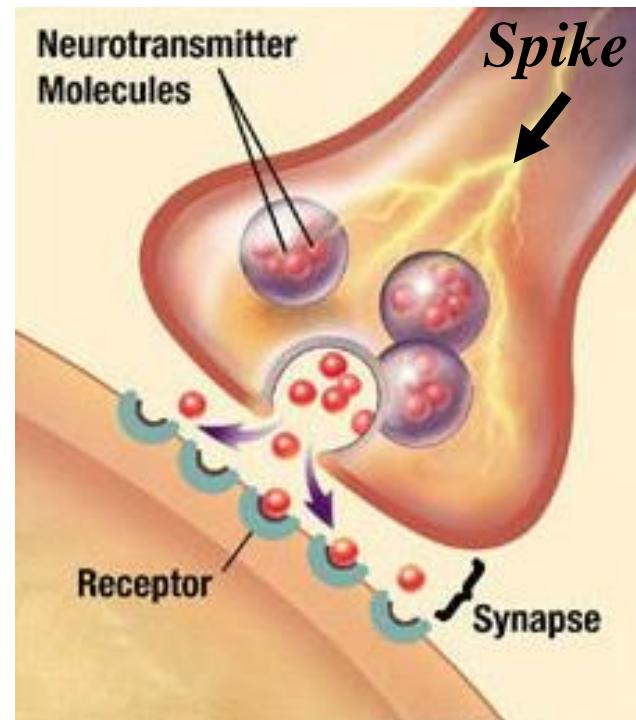
# What is a Synapse?

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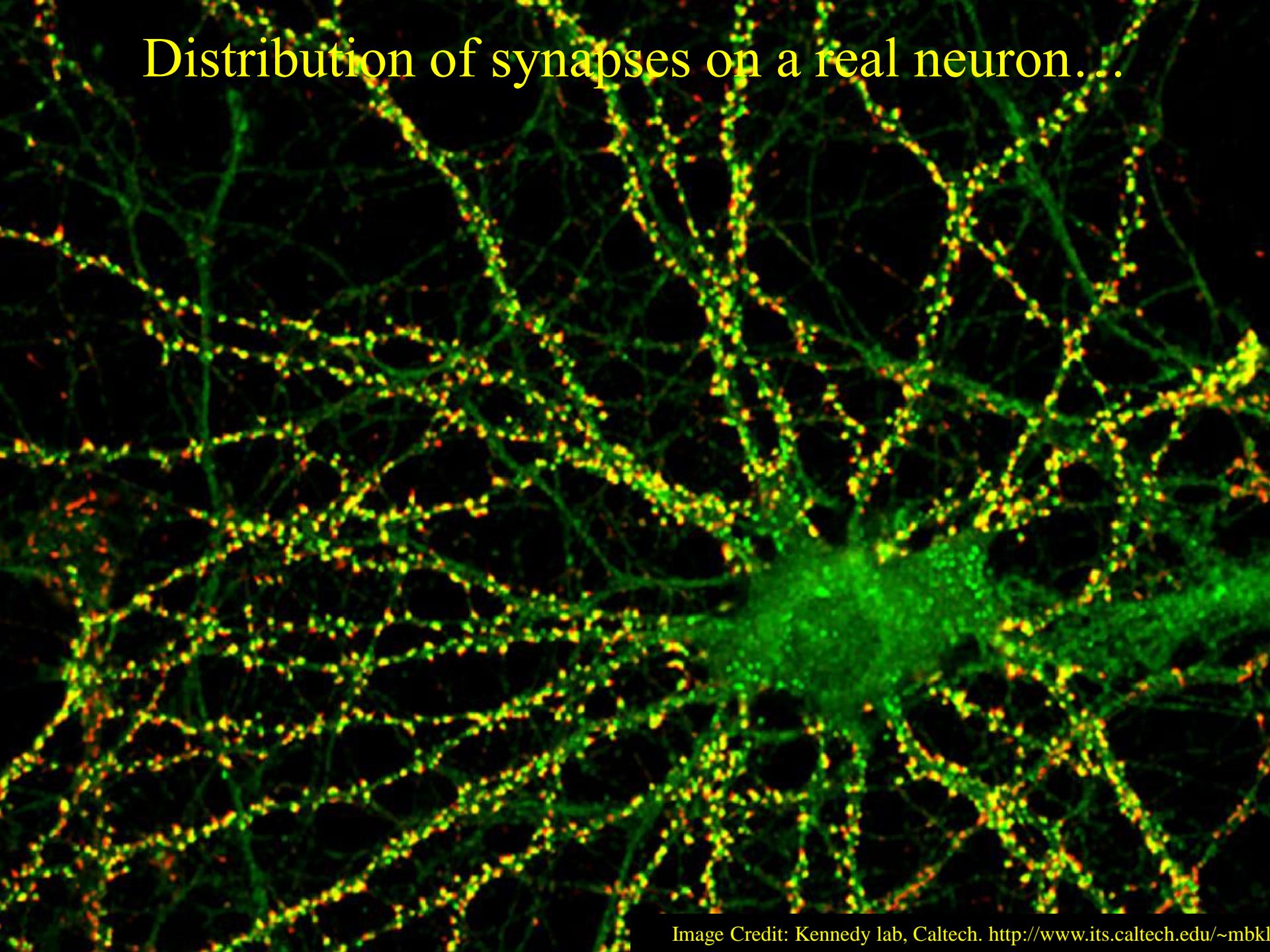
- ◆ A Synapse is a “connection” or junction between two neurons
  - ⇒ Electrical synapses use *gap junctions*
  - ⇒ Chemical synapses use *neurotransmitters*



**Neuron B**

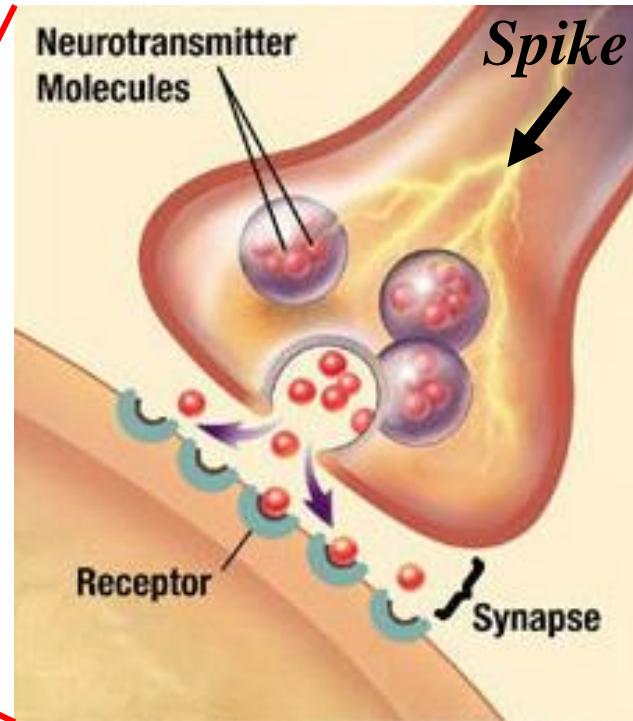
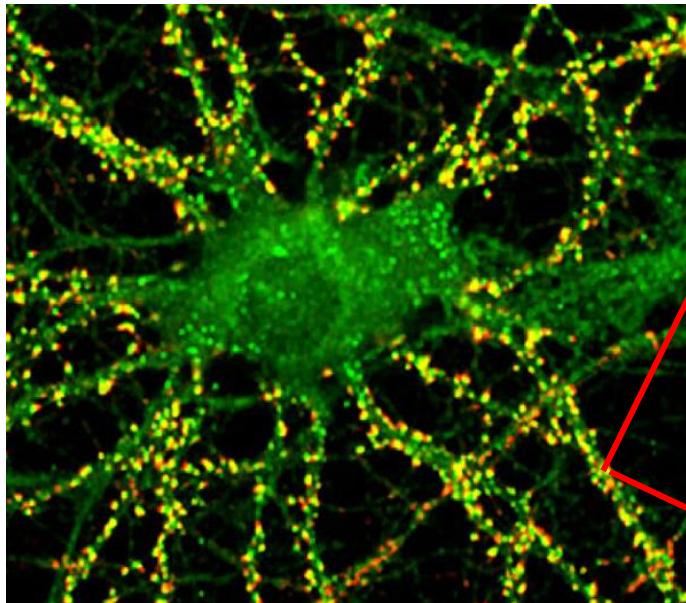


Distribution of synapses on a real neuron...



# Synapses can be Excitatory or Inhibitory

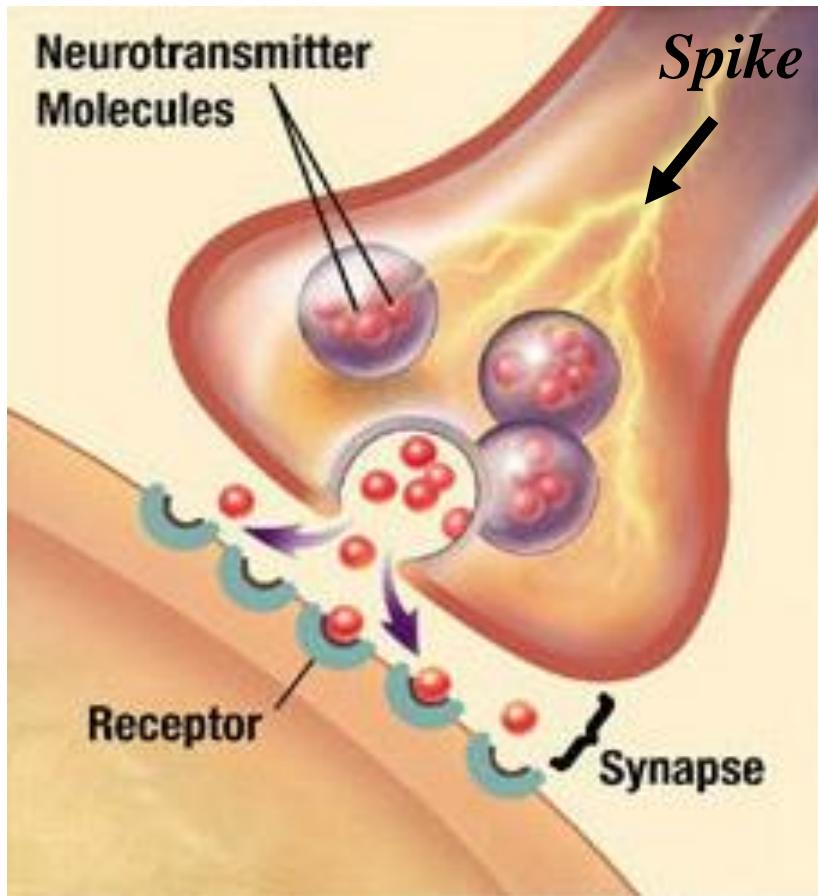
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**Increase or decrease postsynaptic membrane potential**

# An **Excitatory** Synapse

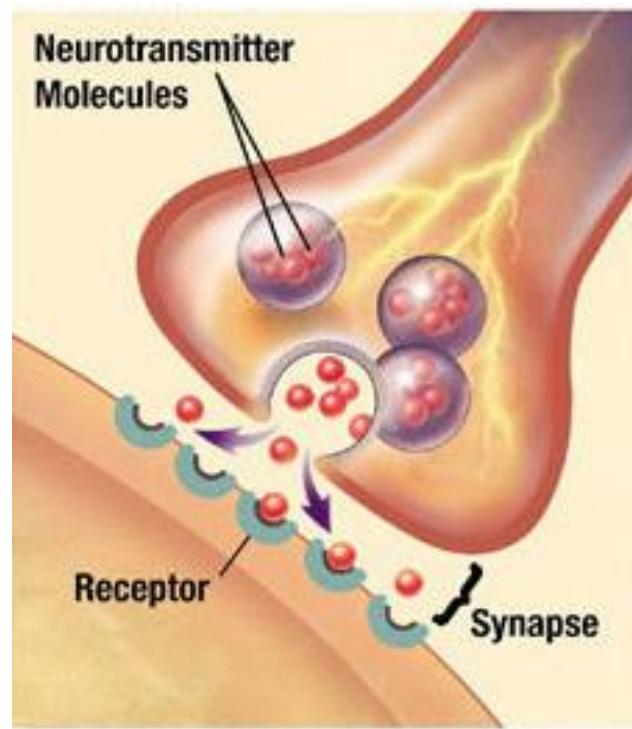
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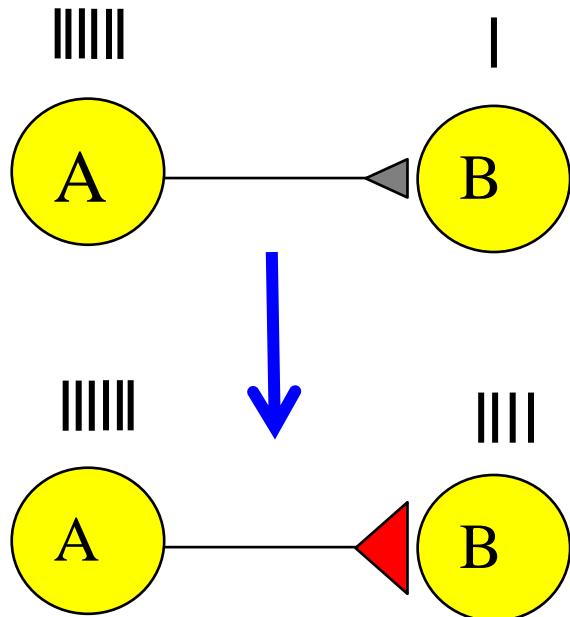
Input spike →  
Neurotransmitter release (e.g., Glutamate) →  
Binds to ion channel receptors →  
Ion channels open →  
 $\text{Na}^+$  influx →  
Depolarization due to EPSP (excitatory postsynaptic potential)

## The Synapse Doctrine

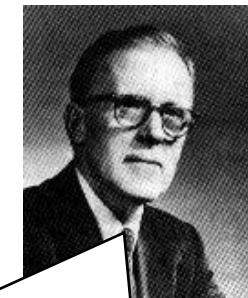
Synapses are the basis for **memory** and **learning**



# How do Brains Learn? Synaptic Plasticity



## Hebbian Plasticity



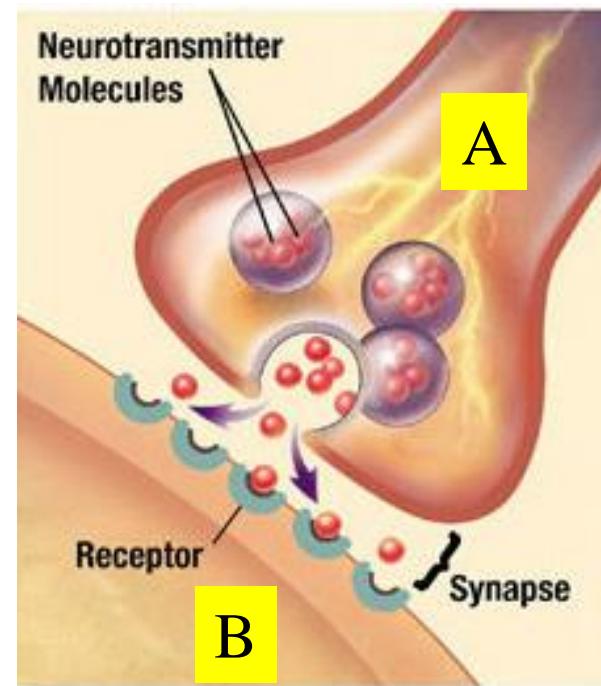
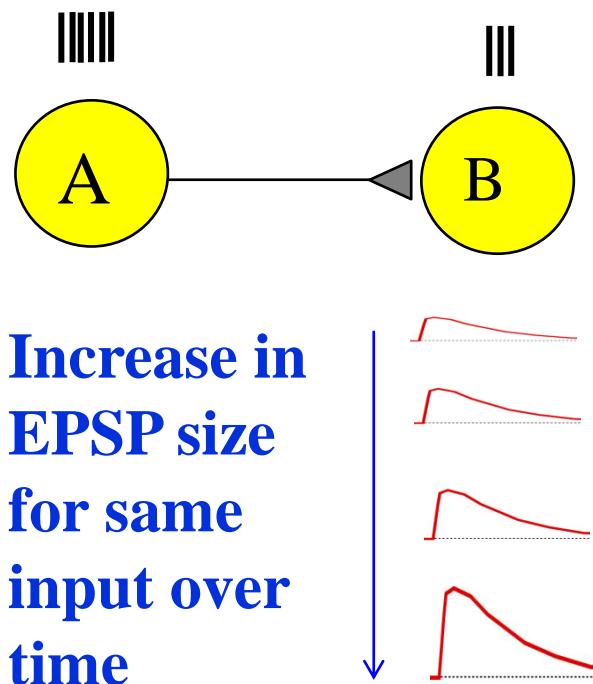
If neuron A repeatedly takes part in firing neuron B, then the synapse from A to B is strengthened



**“Neurons that fire together wire together!”**

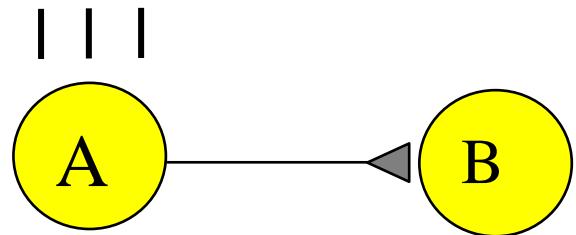
# Long Term Potentiation (LTP)

LTP = Experimentally observed *increase* in synaptic strength that lasts for hours or days

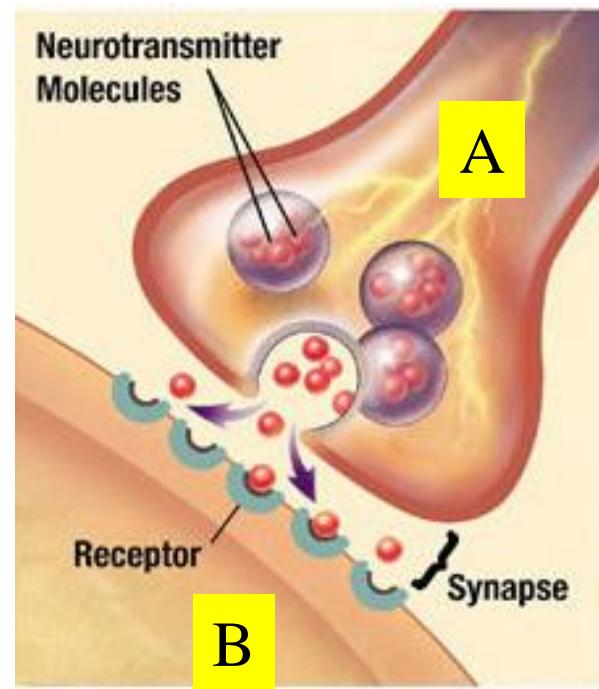
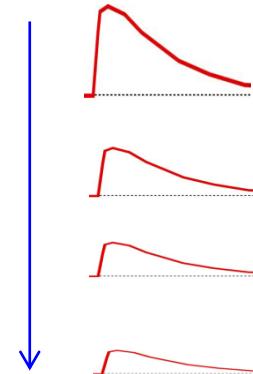


# Long Term Depression (LTD)

LTD = Experimentally observed *decrease* in synaptic strength that lasts for hours or days



Decrease in  
EPSP size  
for same  
input over  
time



# Synaptic Plasticity depends on Spike Timing!

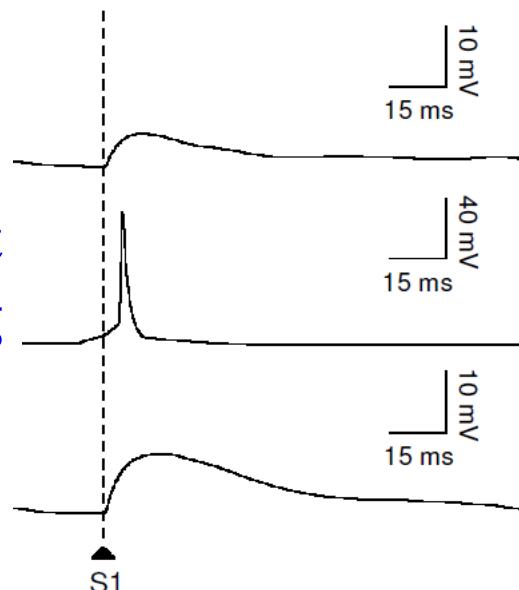
LTP/LTD depends on relative timing of input and output spikes

Input Spike before Output Spike

EPSP Before

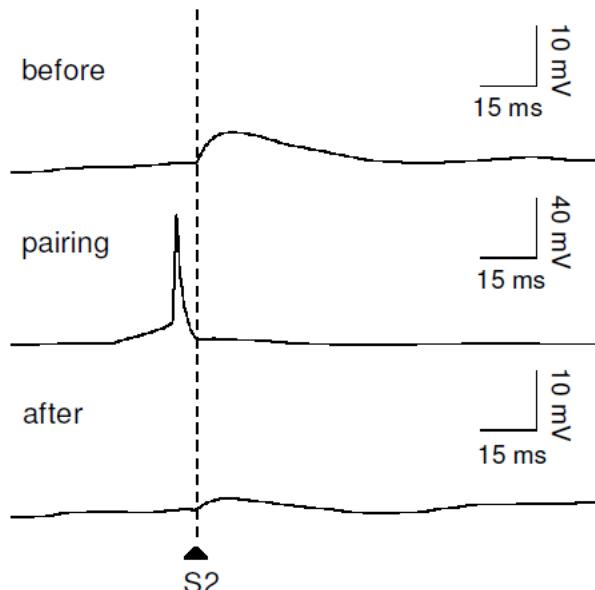
Input-Output  
Pairing

EPSP After



LTP

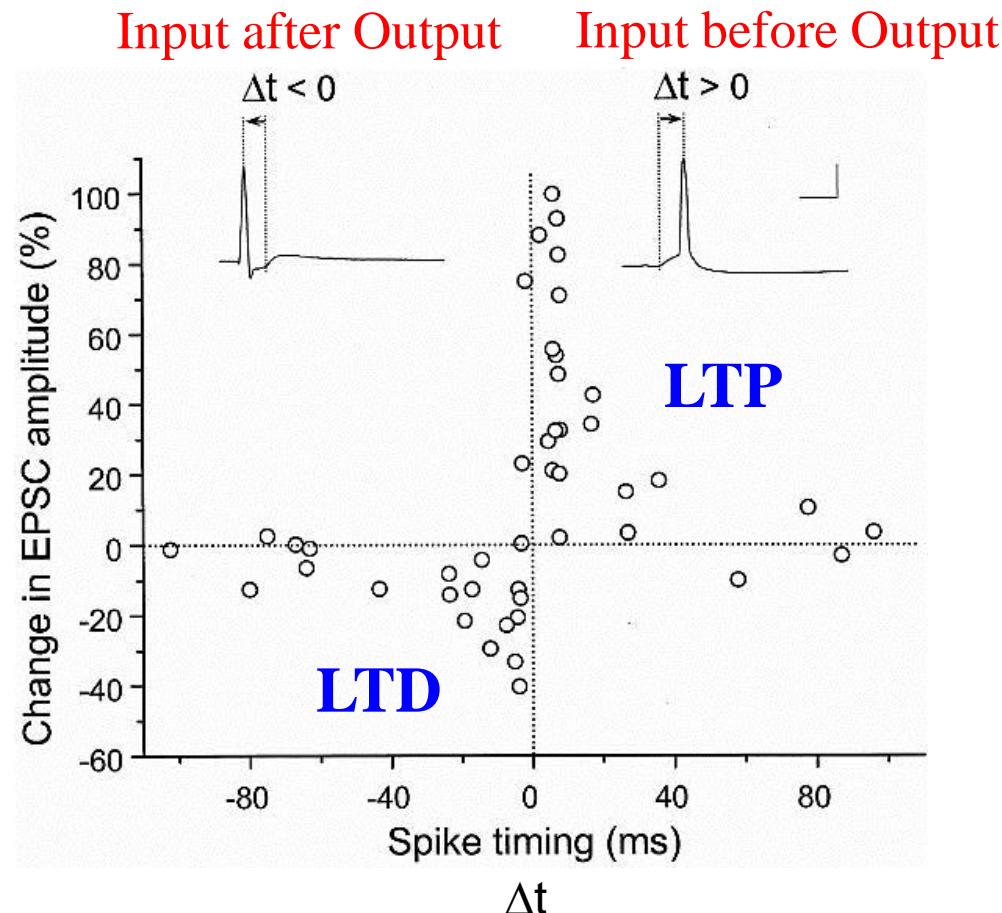
Input Spike after Output Spike



LTD

# Spike-Timing Dependent Plasticity (STDP)

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(Bi & Poo, 1998)

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We seem to know a lot about channels,  
neurons, and synapses...

What do we know about how networks of  
neurons give rise to perception, behavior, and  
consciousness?



# Not as much

Next: Brain organization and information  
processing in networks of neurons