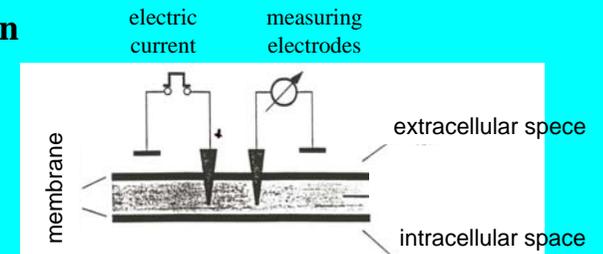


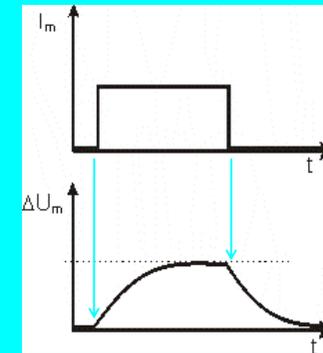
## Alteration of resting membrane potential

1. "passive" electric properties of the membrane

## Observation



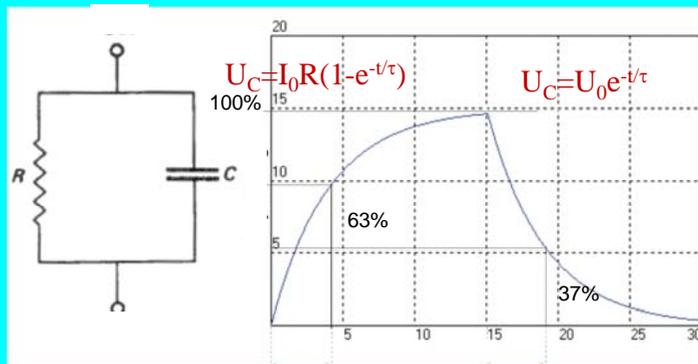
Inward current



Depolarization of the membrane

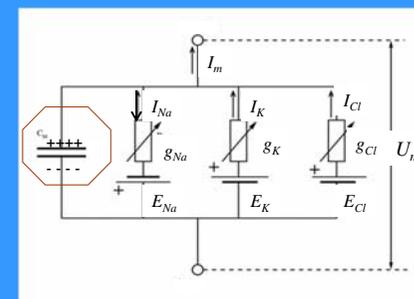
What is it like?

Charge and discharge of RC-circuit



$$\tau = RC$$

Interpretation with equivalent circuit model:



$$I_{ion} + I_c = I_m = 0$$

$$g_{Na} (U_m - E_{Na}) = I_{Na}$$

$$g_{ion} (U_m - E) = I_{ion}$$

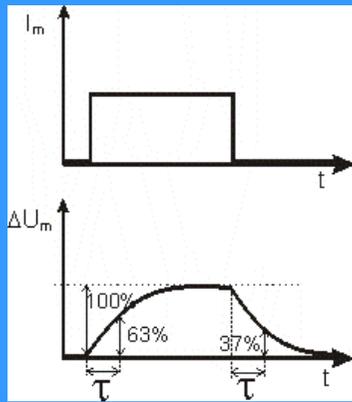
$$C_m \frac{\Delta U_m}{\Delta t} + \frac{\Delta U_m - E}{R_m} - I_{stimulus} = 0$$

Time from the beginning of stimulus

$$U_m(t) = U_t \left[ 1 - e^{-\frac{t}{R_m C_m}} \right]$$

Membrane potential after  $t$

Saturation value of membrane potential



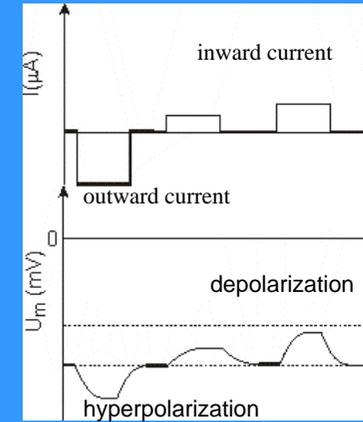
Capacitance of the membrane      Resistance of the membrane

$$\tau = C_m R_m$$

**τ: time constant of membrane**

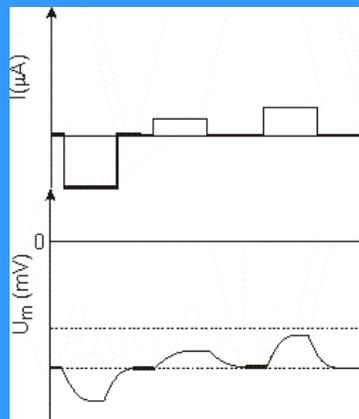
- the time required for the membrane potential to reach 63% of its saturation value
- during which the membrane potential decreases to the e-th of its original value

$$U_m(t) = U_i \left[ 1 - e^{-\frac{t}{R_m C_m}} \right]$$



$U_i$  is proportional to the stimulating current  
 The rate of the change depends on  $U_i$

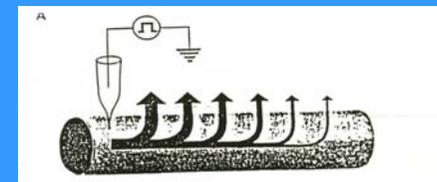
***Local changes of membrane potential***



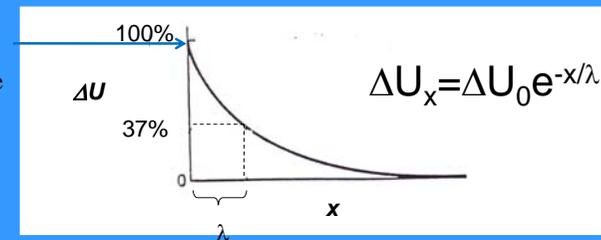
obligate graded  
 magnitude varies directly with the strength of the stimulus  
 direction varies with the direction of the stimulus  
 „localized”

***The local changes are not isolated from the neighborhood***

**Observation**



Membrane potential change at the site of stimulation

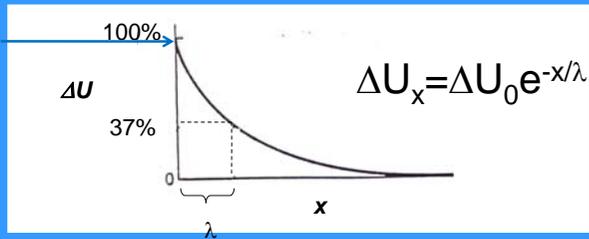


Decrease in amplitude with distance due to leaky membranes

**$\lambda$ : space constant of the membrane:**

distance in which the maximal value of induced membrane potential change decreases to its e-th value

Membrane potential change at the site of stimulation



$$\lambda \sim \sqrt{\frac{R_m}{R_i}} \leftarrow \text{Resistance of intracellular space}$$

***Local changes of resting membrane potential can be induced***

- by electric current pulses
- by adequate stimulus at receptor cells
- by neurotransmitters at postsynaptic membrane
  - excitatory postsynaptic potential - depolarization
  - inhibitory postsynaptic potential - hyperpolarization

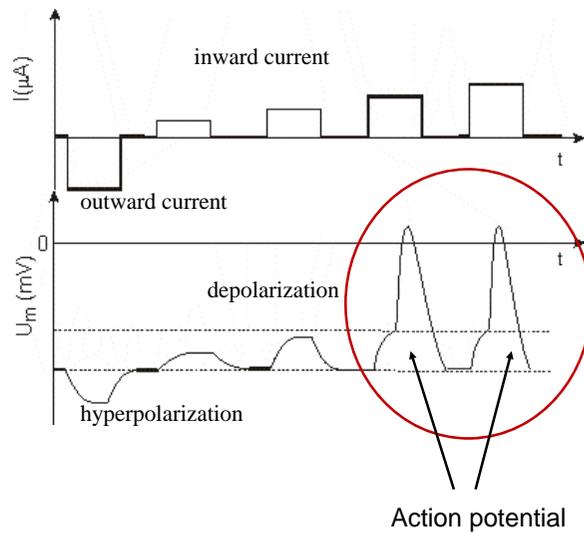
***Significance of the local changes of resting membrane potential***

- Sensory function
- Impulse conduction
- Signal transduction

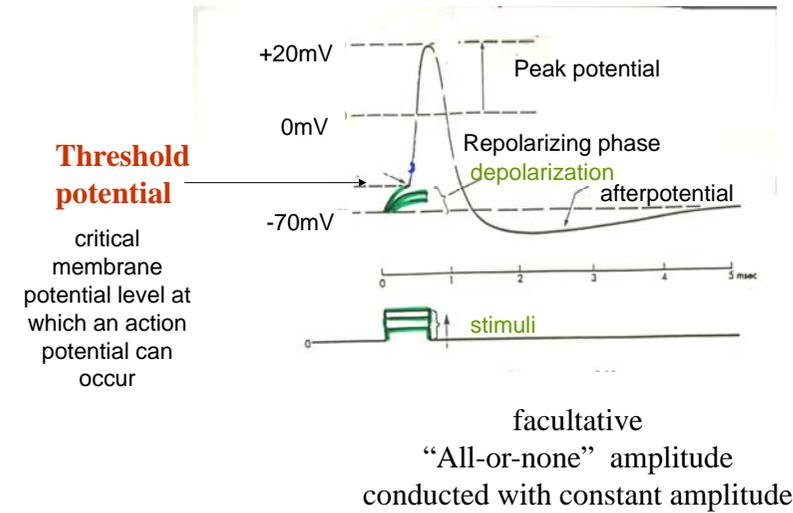
***Alteration of resting membrane potential***

2. “active” electric properties of the membrane in excited state

## Observation



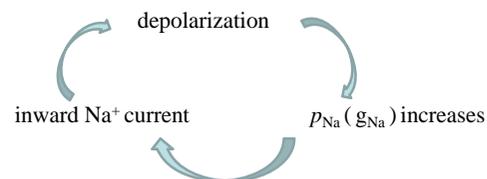
## Phases and landmark of the action potential



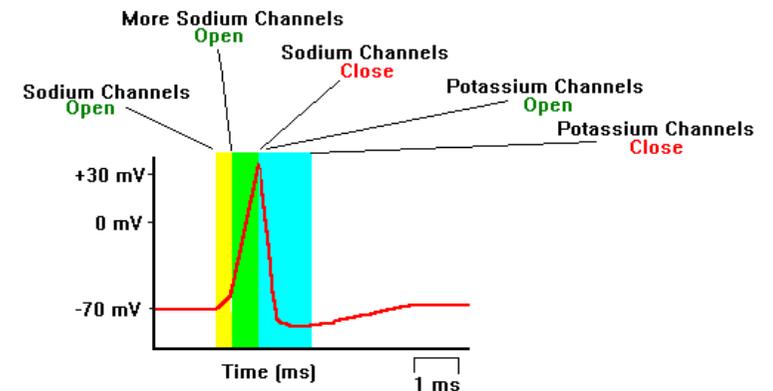
## Hodgkin-Katz hypothesis of action potential generation

Voltage-gated, potential sensitive ion channels

$$\varphi_e - \varphi_i = -\frac{RT}{F} \ln \frac{\sum p_k^+ c_{ke}^+ + \sum p_k^- c_{ki}^-}{\sum p_k^+ c_{ki}^+ + \sum p_k^- c_{ke}^-}$$



## Hodgkin-Katz hypothesis of action potential sequence





Andrew Fielding Huxley  
(1917-)

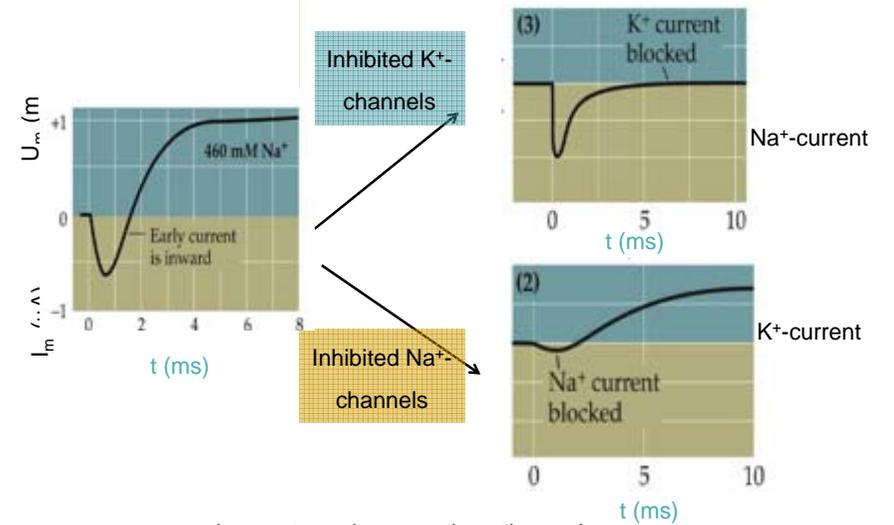


Alan Loyd Hodgkin  
(1914-1998)

The Nobel Prize in Physiology or Medicine  
1963

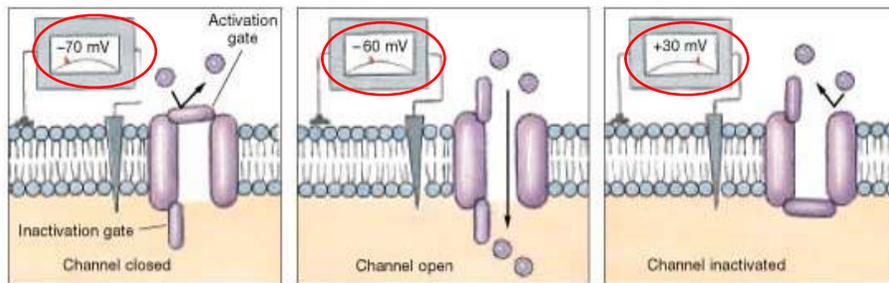
“for their discoveries concerning the ionic mechanisms involved in excitation and inhibition in the peripheral and central portions of the nerve cell membrane”

### Measurement of separated ionic currents



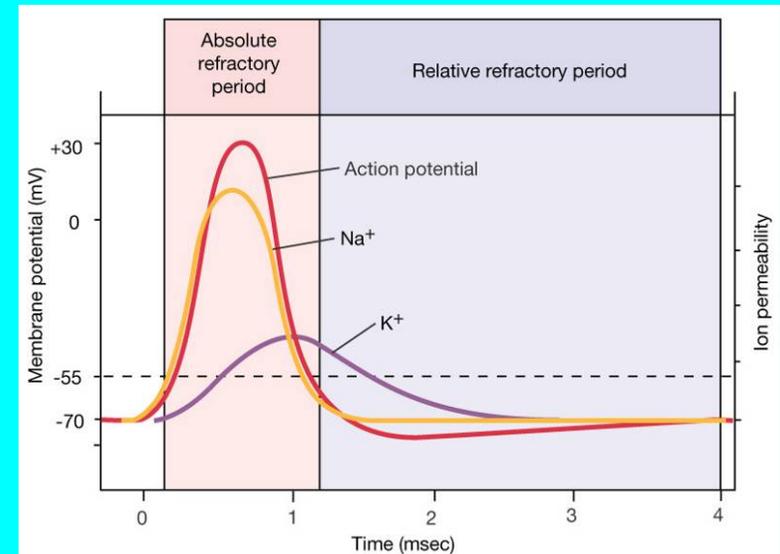
Voltage-Gated  $\text{Na}^+$  and  $\text{K}^+$  Channels

### States of voltage-gated sodium channels



(c)  
at depolarization threshold

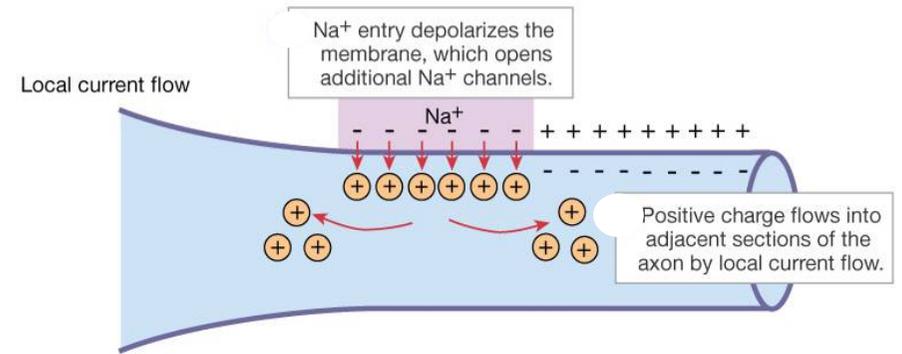
### Conductivities during action potential



## Factors Influencing Conduction Direction and Velocity

The evolutionary need for the fast and efficient transduction of electrical signals

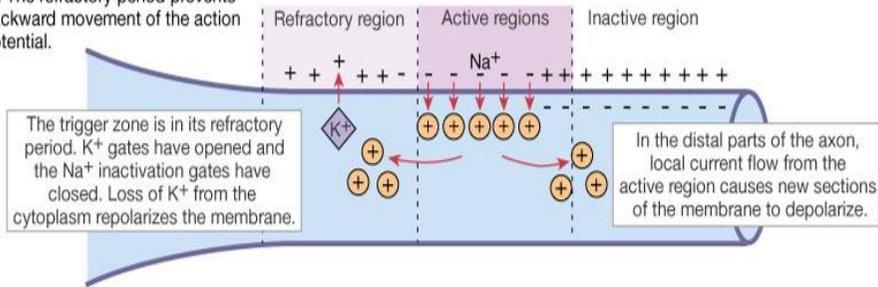
## Propagation of action potential (1)



based on local current flow and depolarization of adjacent membrane area

## Propagation of action potential (2)

(c) The refractory period prevents backward movement of the action potential.

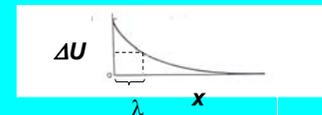


Speed and distance of propagation?

How are the *time constant* and the *space constant* related to propagation velocity of action potentials

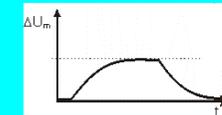
Generation of the next peak potential

Where?



The greater the space constant, the more rapidly distant regions will be brought to threshold and the more rapid will be the propagation velocity

When?



The smaller the time constant, the more rapidly a depolarization will affect the adjacent region.

Velocity is the function of passive properties –  $\tau$  and  $\lambda$  – of membranes

### Effect of axon diameter:

$r \uparrow \Rightarrow R_i \downarrow (\sim 1/r^2)$   
 $R_m \downarrow (\sim 1/r)$

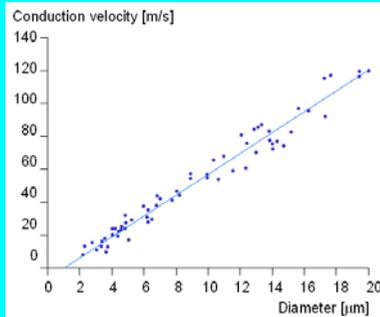
$\tau \downarrow$   
 $\lambda \uparrow$

$$\tau = C_m R_m$$

$$\lambda \sim \sqrt{\frac{R_m}{R_i}}$$

Squid giant axon  $r=250\mu\text{m}$   
 $v=25\text{m/s}$

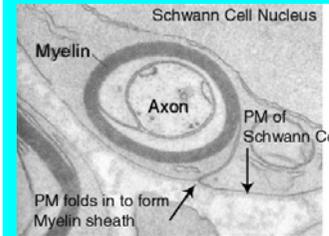
human nerve cell  $r=10\mu\text{m}$   
 $v \neq 0.5\text{m/s} ?$



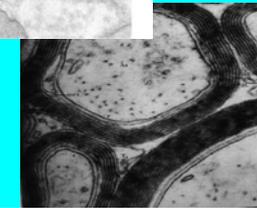
### Myelination!

$R_m$  – very high  $\Rightarrow$  big space constant

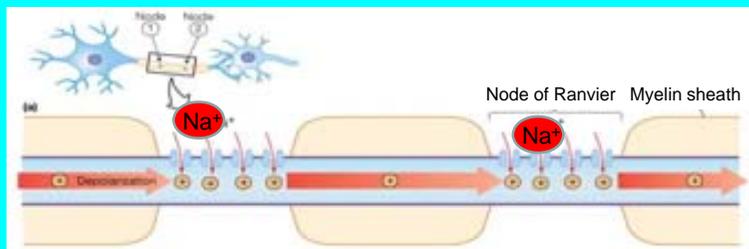
$C_m$  – very small  $\Rightarrow$  small time constant



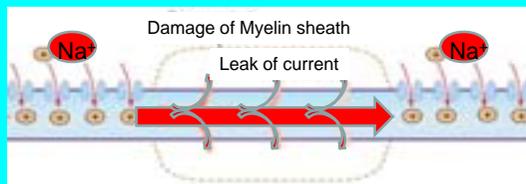
human nerve cell  $r=10\mu\text{m}$   
 $v \sim 100\text{m/s}$



### Saltatory conduction - quick, energy saving



Myelin prevents ions from entering or leaving the axon along myelinated segments.



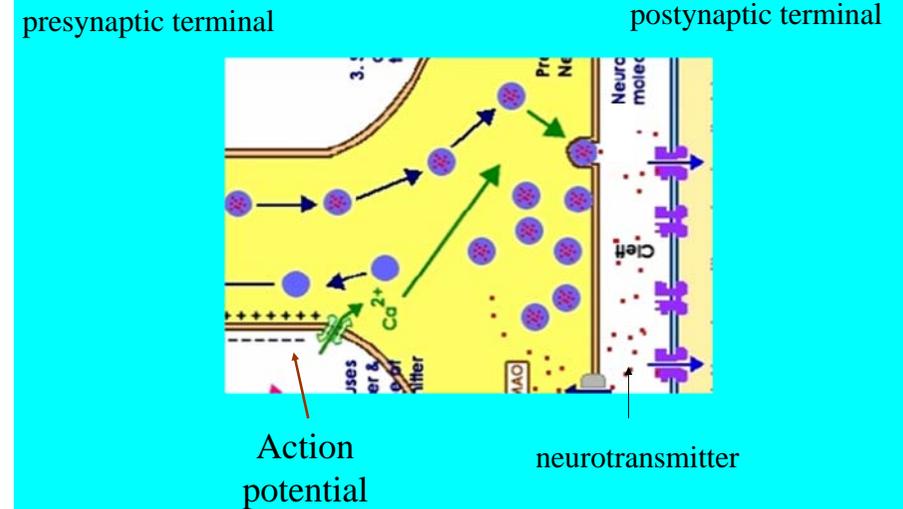
### Effect of axon diameter and Myelination

The diameter of frog axons and the presence or absence of myelination control the conduction velocity.

Fiber type	Average axon diameter ( $\mu\text{m}$ )	Conduction velocity ( $\text{m} \cdot \text{s}^{-1}$ )
<b>Myelinated fibers</b>		
A $\alpha$	18.5	42
A $\beta$	14.0	25
A $\gamma$	11.0	17
B	Approximately 3.0	4.2
<b>Unmyelinated fibers</b>		
C	2.5	0.4–0.5

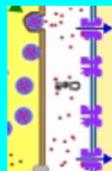
## Effect of passive electric properties on signal transduction in synapses

## Signal transmission in synapses

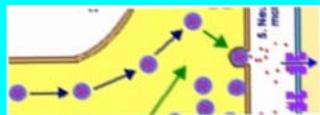


How can neurons transmit information from presynaptic to postsynaptic cells **if most synaptic effects are subthreshold?**

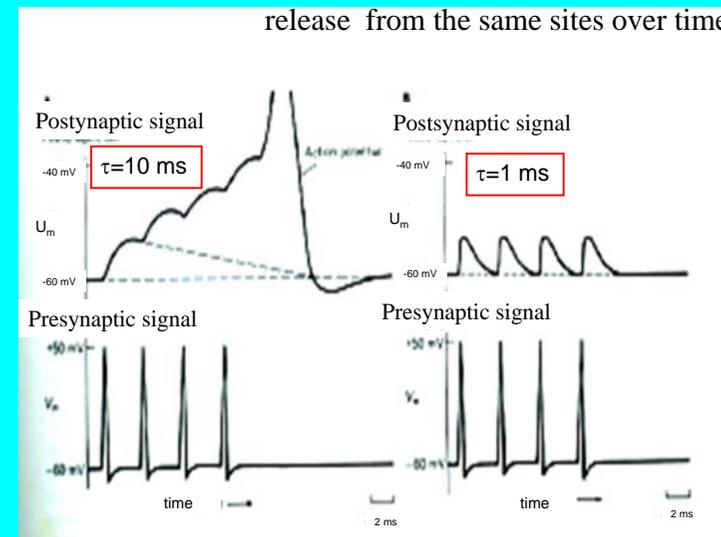
**Spatial Summation** : combined influences at the same cell at a particular moment in time



**Temporal Summation** : combined effects of neurotransmitter release from the same sites over time



**Temporal Summation** : combined effects of neurotransmitter release from the same sites over time



## Temporal and spatial summation

