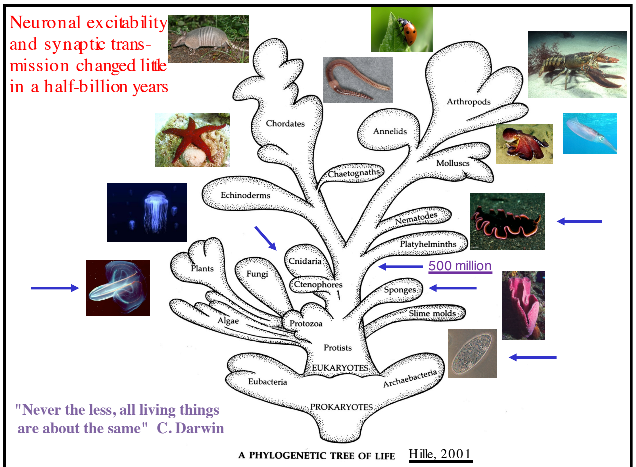
Evolution of Neural Excitability

May 9, 2016

Last day to hand in late assignments, Monday May16

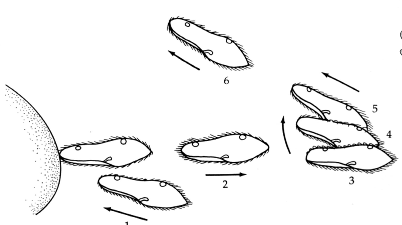
Neuronal excitability and synaptic trans-mission changed little in a half-billion years



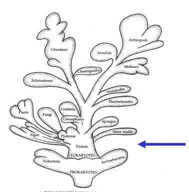
"Never the less, all living things are about the same" C. Darwin

Hille, 2001

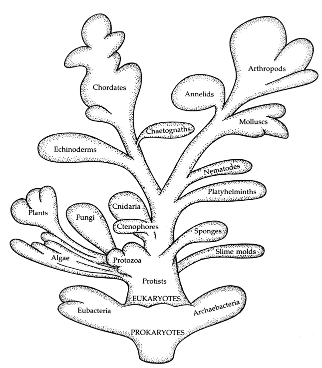
Early Beginnings of Behavior



AVOIDANCE RESPONSE OF *PARAMECIUM*

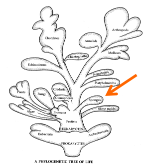


Where do we first see adaptive behavior in an animal?
Does adaptive behavior in a multi-cellular organism require a nervous system?



Sponges!
First Animals?

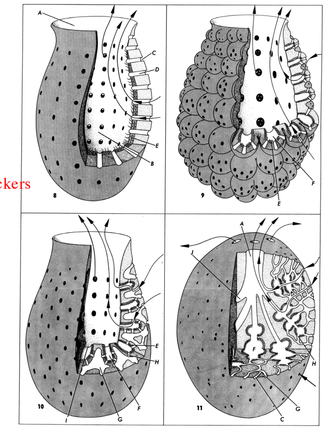
Does adaptive behavior in a multi-cellular organism require a nervous system?



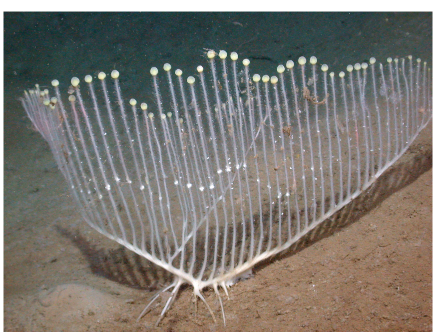
24-Isopropylcholesterol (24-IPC) found in rocks 640 million years old. Produced only by sea sponges and algae today.

Sponges can control direction and speed of water flow

3mm/s "conduction"
Blocked by Ca2+ channel blockers

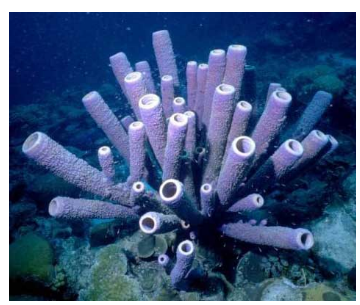


Harp Sponge



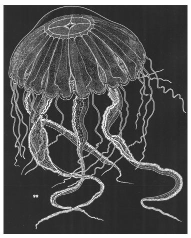
https://www.youtube.com/watch?v=VC3tAtXdaik

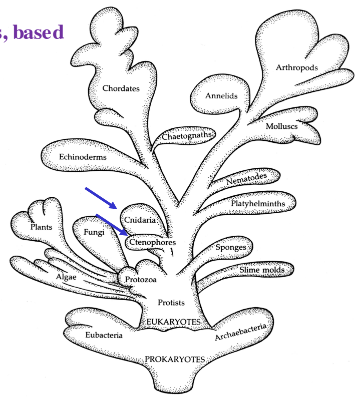
Sponges show that it is possible to be a multicellular animal responding, behavin and maintaining a well-regulated body form without having a nervous system of any apparent kind (plants too!)!



The early evolution of distinct conducting and contractile tissues allowed the rapid and coordinated movements that most animals make.

Early nervous systems, based on animals alive today

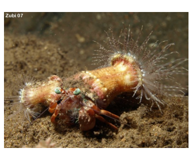


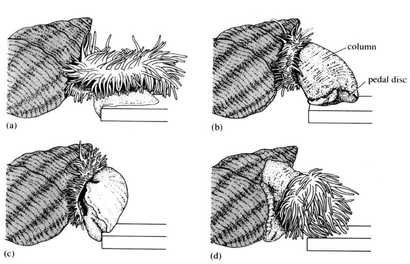


A PHYLOGENETIC TREE OF LIFE

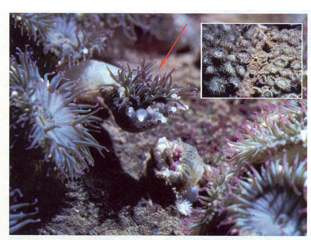
Coordinated “swimming”

Shell mounting

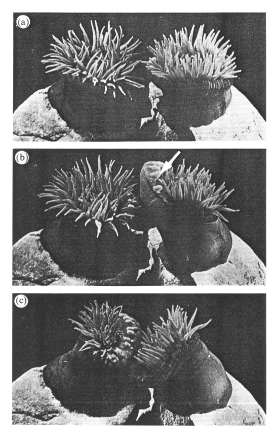




Clone Wars

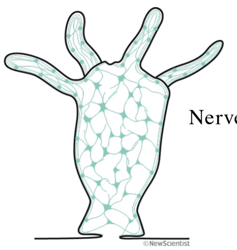


BORDER DEFENSE An anemone polyp (arrow) leans over to attack a small scout from the patch of clones next door. An empty zone (central swath in inset) separates patches of clones.

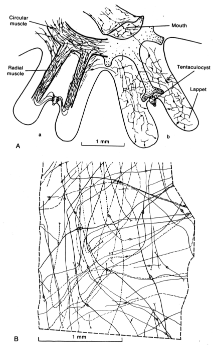


Cnideria: Starting point for neural evolution.

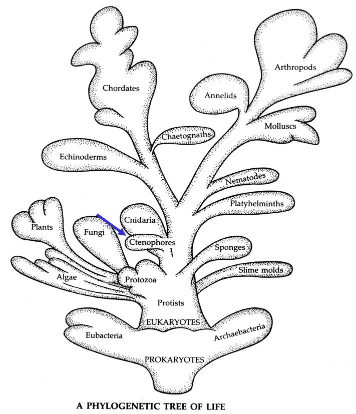
1. evolution of axons (giant axons),
2. chemical and electrical synapses,
3. neuroepithelial cells and myoepithelial cells.
4. pacemaker neurons



Nerve net

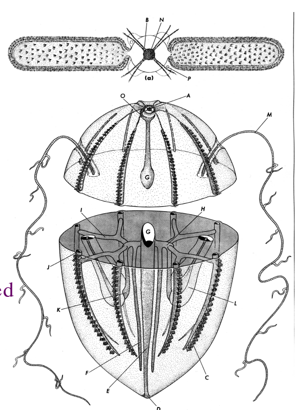


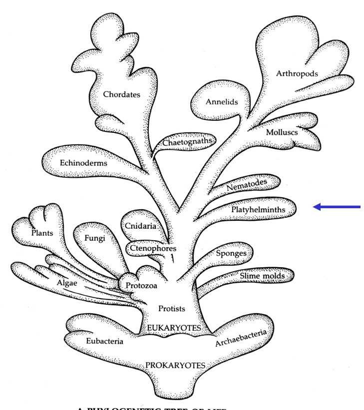
First "brains"??



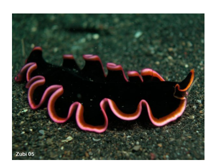
Ctenophore "Comb jellies"

May have evolved NS separately- new genetic data



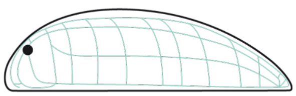


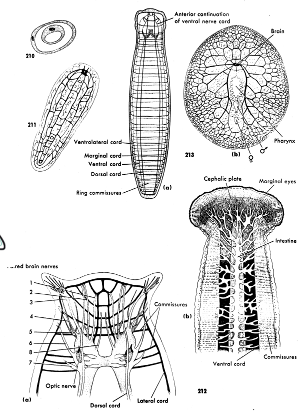
Next big event- modern NS blueprint



Platyhelminths

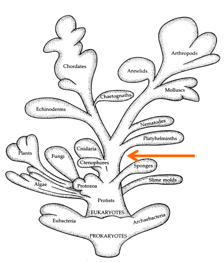
Neurons in distinct ganglia
Distinct muscle fibers
Nervous and Motor systems separated

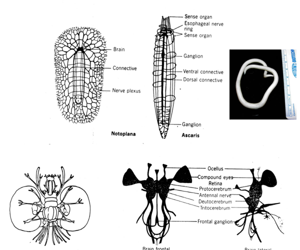


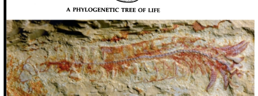


Platyhelminths: Basic plan for future nervous systems laid out her First centralized, anterior brains in flatworms: Then: continuing centralization and cephalization.

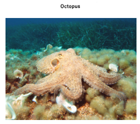
Nervous systems (and behavior) becomes more complex



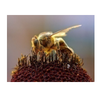




Chengjiangocaris kunmingensis
Shrimp-like 520 million years old
6 inches, 80 legs!

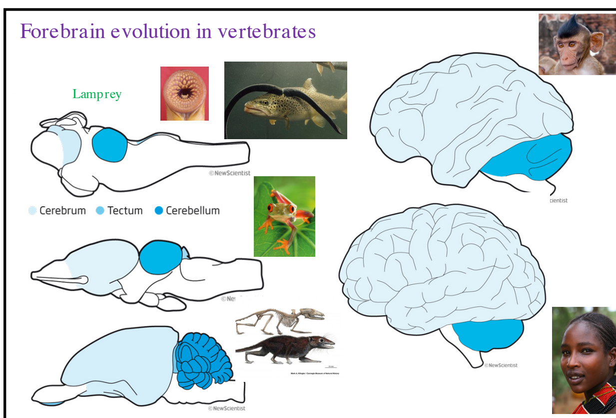


Problem solving, "play"
Consciousness?
Honorary Verts in UK



Abstract categorization?
Map learning

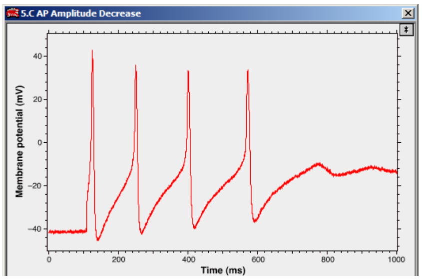
Forebrain evolution in vertebrates



Nervous systems have great differences in the degrees of complexity and organization. (Tectum- roof of midbrain- auditory and visual reflexes)

The ionic currents and mechanisms underlying excitability and synaptic communication are very similar in all nervous system.

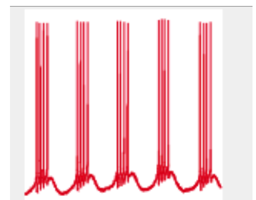
What are the requirements for excitability, for using electricity as a physiological messenger?



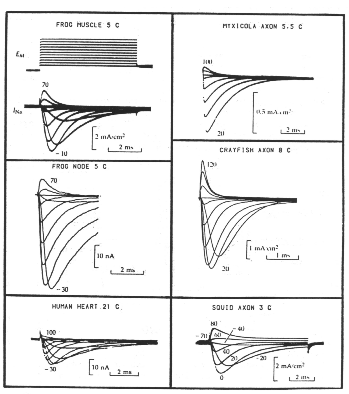
All cells have the basic requirements for excitability

1. Cell membrane
2. Ionic gradients (Na^+-K^+ ATPase), high $[Na^+]_o$
3. Gated permeability changes
4. Effecter system responding to signals (RP or changes in $[Ca^{++}]_i$)

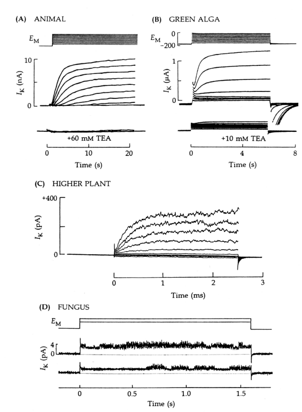
Neurons specialized in making electricity a messenger

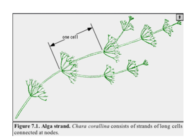


Action Potential I_{Na} similar across animals

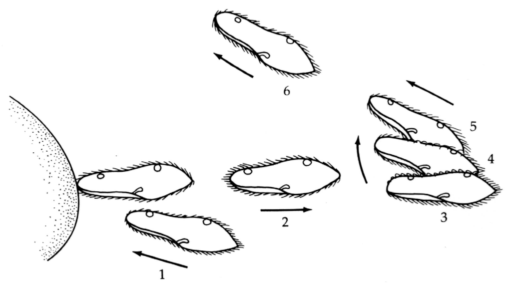


I_K similar across organisms



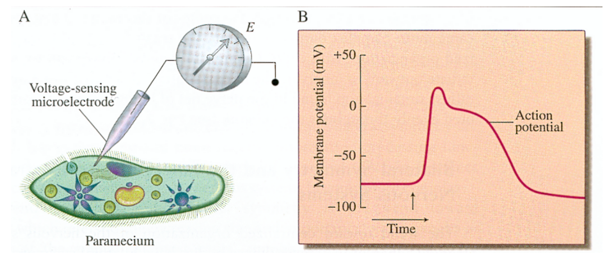


Channels driving behavior

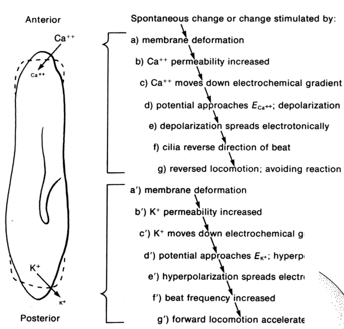


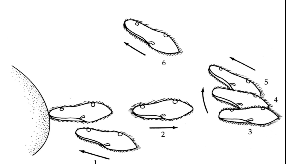
AVOIDANCE RESPONSE OF *PARAMECIUM*

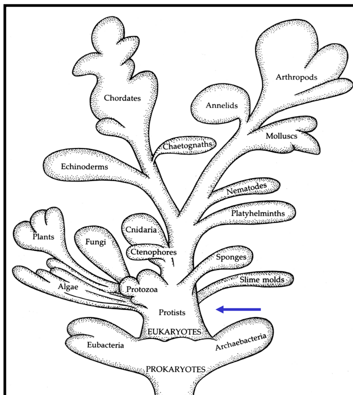
Channels driving behavior



Channels driving behavior







A PHYLOGENETIC TREE OF LIFE

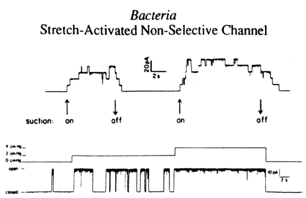
Swimming Neurons!

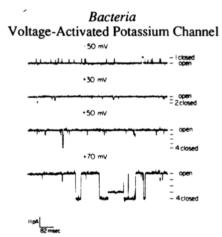
Two Types ICa

IK(v)
IK(Ca)
IK(A)
IK(mechano)
INa(Ca)

Spatial distribution of channels!!

Channels in bacteria





Channels in viruses???

SCIENCE VOL 287 3 MARCH 2000

A Potassium Channel Protein Encoded by Chlorella Virus PBCV-1

B. Plugge,[1]* S. Gazzarrini,[2]* M. Nelson,[3]* R. Cerana,[4] J. L. Van Etten,[5] C. Derst,[6] D. DiFrancesco,[2] A. Moroni,[2] G. Thiel[1]†

The large chlorella virus PBCV-1, which contains double-stranded DNA (dsDNA), encodes a 94-codon open reading frame (ORF) that contains a motif resembling the signature sequence of the pore domain of potassium channel proteins. Phylogenetic analyses of the encoded protein, Kcv, indicate a previously unidentified type of potassium channel. The messenger RNA encoded by the ORF leads to functional expression of a potassium-selective conductance in *Xenopus laevis* oocytes. The channel blockers amantadine and barium, but not cesium, inhibit this conductance, in addition to virus plaque formation. Thus, PBCV-1 encodes the first known viral protein that functions as a potassium-selective channel and is essential in the virus life cycle.

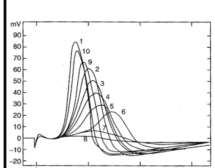
Why Na^+ as AP driving force?????

Ca^{++} AP = 100 μA/cm^2 current density= 10μM $[Ca^{++}]_i$

Cells made an irreversible investment in Ca as an internal messenger

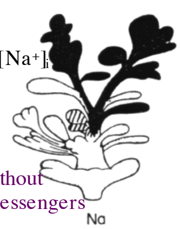
Greater current density for Na

Na^+ AP = 4 mA/cm^2 = 10 mM $[Na^+]_i$



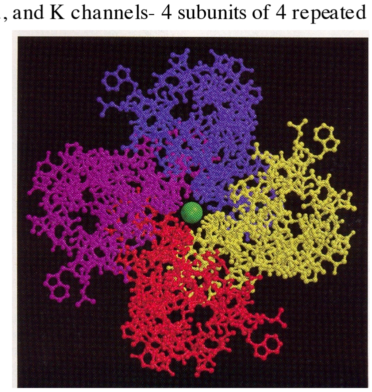
Reduced [Na]o

Powerful currents without a flood of internal messengers

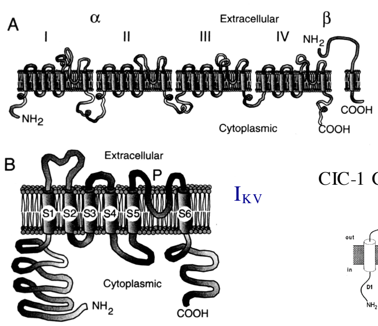


What does molecular biology tell us about channel evolution?

Na, Ca, and K channels- 4 subunits of 4 repeated domains



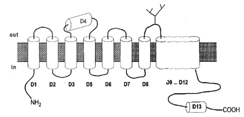
V-gated channels from same gene family



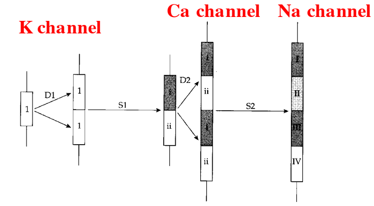
Na and Ca channels

I_{KV}

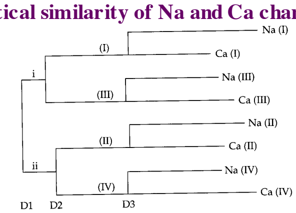
CIC-1 Cl channel (very different family)



Channel evolution by gene duplication

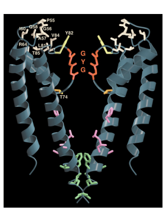


Statistical similarity of Na and Ca channel domains



What were the first channels?

K^+ and/or Cl^- needed for osmotic balance



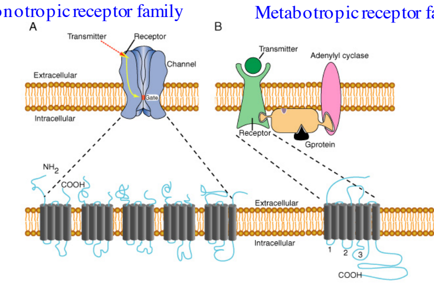
Ca^{++} channels- response to external stimuli, control of cellular functions, including AP generation. K channels for recovery of membrane potential

Na channels evolved from Ca channels

Receptor families suggest similar evolutionary origins

Ionotropic receptor family

Metabotropic receptor family



ACh- nicotinic
$GABA_{A,C}$
Glycine
$5HT_3$

ACh- muscarinic
α–adrenergic
beta- adrenergic
5HT, DA, HA, peptides
Rhodopsin

Multiple subtypes of each