Using simple nervous systems to investigate the neural basis of behavior

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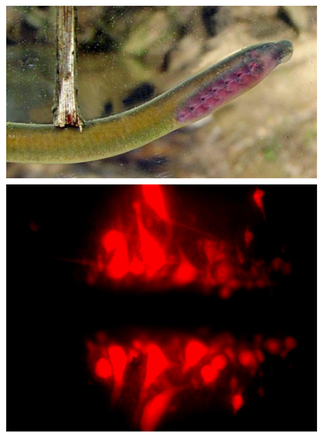
Introduction

The human brain is remarkable, both in the sense that it helps us with a lifetime of decisions and memories, but also that it allows us to contemplate how the brain itself works. One concludes, however, pretty quickly that the human brain is quite complicated. The brain has an estimated 10^{11} neurons, and more than a thousand times more connections. How these neurons and connections work together in systems is a grand challenge in the neurosciences.

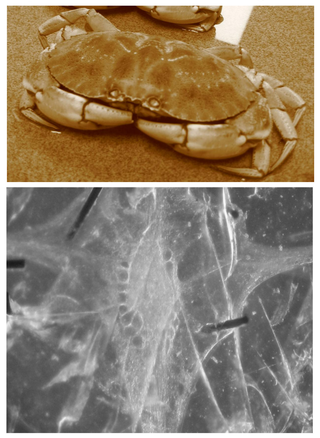
Fortunately, we can use organisms with simpler nervous systems to understand basic principles of nervous system function. Thus, one expects lessons learned in simpler nervous systems to have application in more complex organisms, including humans.

A successful approach in understanding nervous system function is to examine the role that different neural systems play in regulating behavior. Broadly speaking these include processes that support sensory encoding, motor activity, and multisensory and sensory-motor integration.

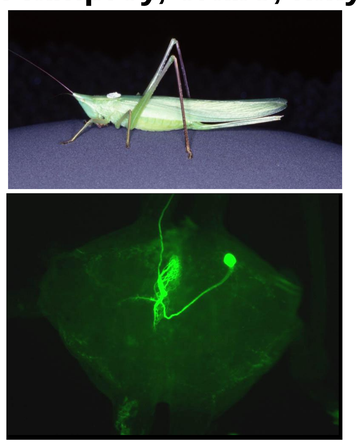
Model organisms with simple nervous systems: lamprey, crabs, katydids, and *Drosophila*



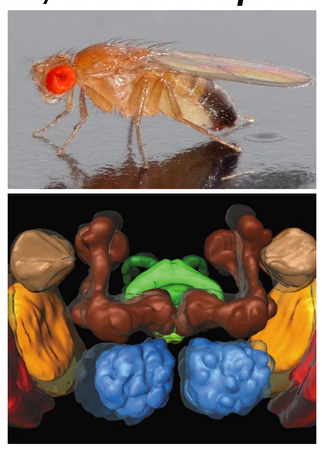
Lamprey
Attractive features: well understood motor system that regulates swimming behavior and a nervous system in which axons can regenerate after injury.



Crab
Attractive features: well characterized simple set of neurons in a stomatogastric ganglion that control gut behavior, this system can be studied *in vitro* for days.



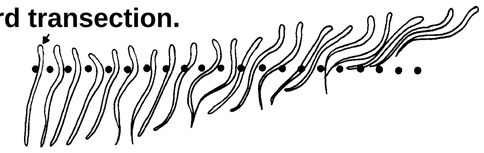
Katydid
Attractive features: Stereotypical acoustic behaviors and identified sensory neurons for comparative studies of signal recognition and detection.



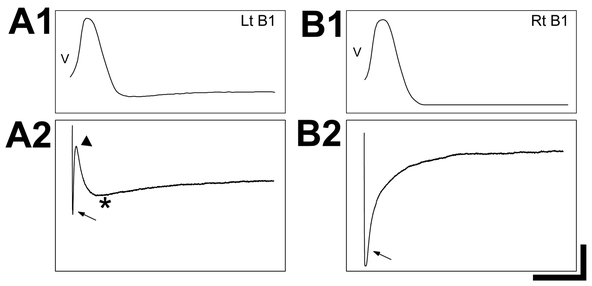
Drosophila
Attractive features: small nervous system, molecular genetic tools for manipulation, simple learning tests.

Motor systems in Lamprey

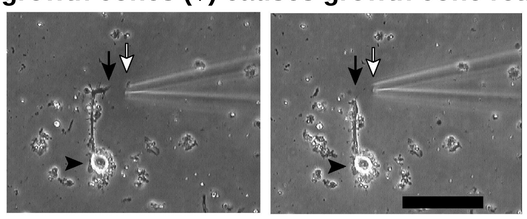
Lamprey recover locomotor function within ~8 wks following spinal cord transection.



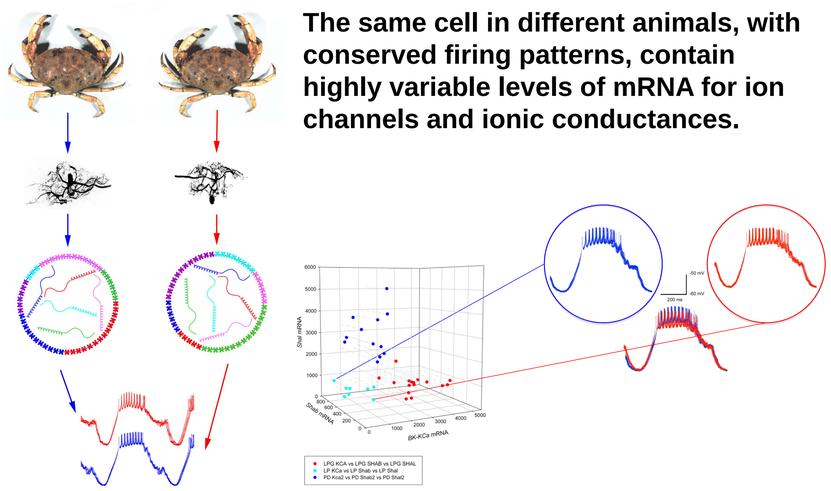
Intracellular recordings from reticulospinal (RS) neurons showing that a component of action potentials (*, Lt B1), due in part to Ca^{2+} channels, is missing in injured neurons (Rt B1).



RS neuron in cell culture ( ) showing that induction of Ca^{2+} influx into growth cones (↓) causes growth cone retraction.



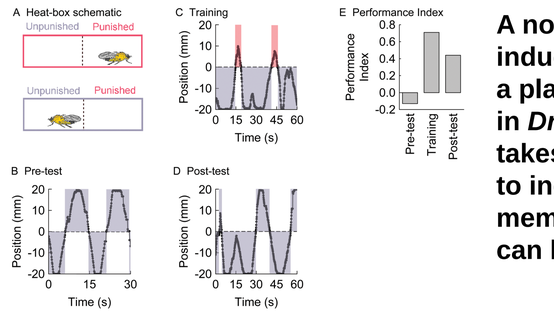
The STG of the Crab



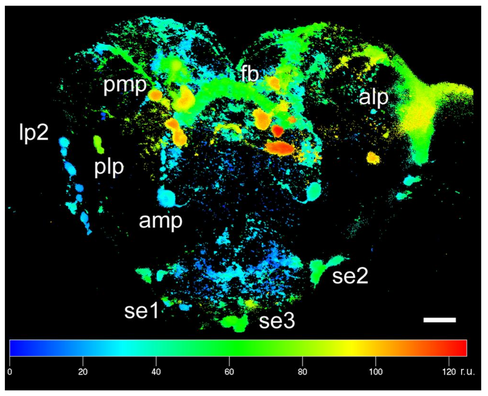
The same cell in different animals, with conserved firing patterns, contain highly variable levels of mRNA for ion channels and ionic conductances.

How can a conserved output arise from a disparate set of underlying building blocks (i.e., voltage-gated ion channels)? Working hypothesis: all channels "balanced" around a set point for activity.

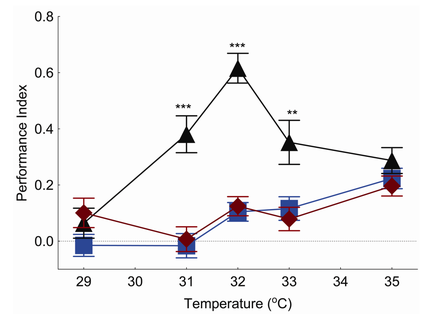
Learning in *Drosophila*



A novel way to induce and test a place memory in *Drosophila*, takes minutes to induce a memory that can last hours.



Serotonergic neurons are found in characteristic positions and innervate specific parts of the brain.

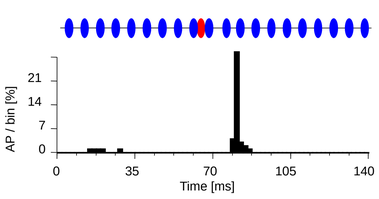


Serotonin neuron activation paired with place can induce memory formation

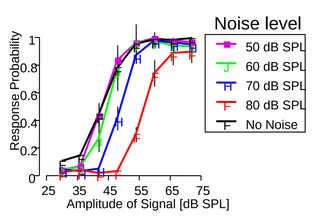
Hearing and communication in Katydids

A single neuron detects change of the auditory scene

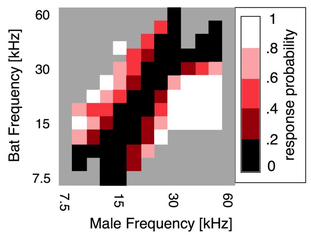
… with high reliability (> 80 %)



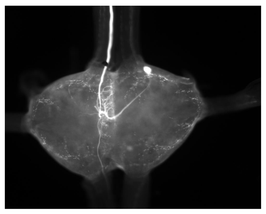
… with high sensitivity



… independent of signal frequency

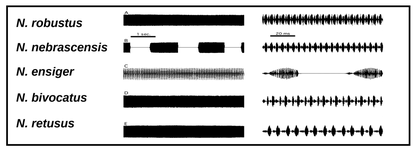


… based on a dendritic mechanism

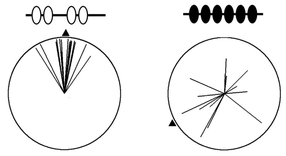


Katydids recognize specific patterns

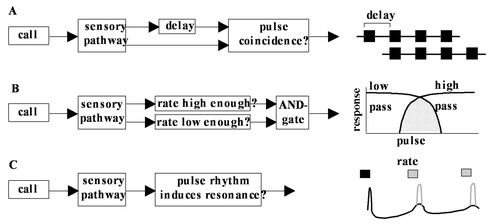
… each species has a distinct pattern

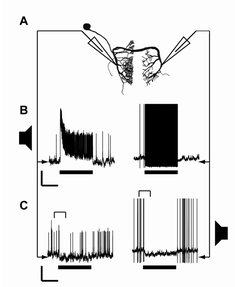


… females respond to one pattern, but not others



… pattern recognition mechanisms vary among species; model to study neuronal basis of pattern recognition





Conclusions

Investigation of simpler nervous systems allows for discovery of principles in nervous system function.

We discovered that (1) control of Ca^{2+} flux in regenerating neurons is a critical for axon extension, (2) variation in ion channel expression levels can give rise to a common physiological output, (3) neural coding mechanisms that allow for hearing in a noisy background, and (4) that activation of an aminergic circuit can be sufficient for reinforcing a memory.

These general principles are expected to greatly advance our understanding of more complex nervous systems.