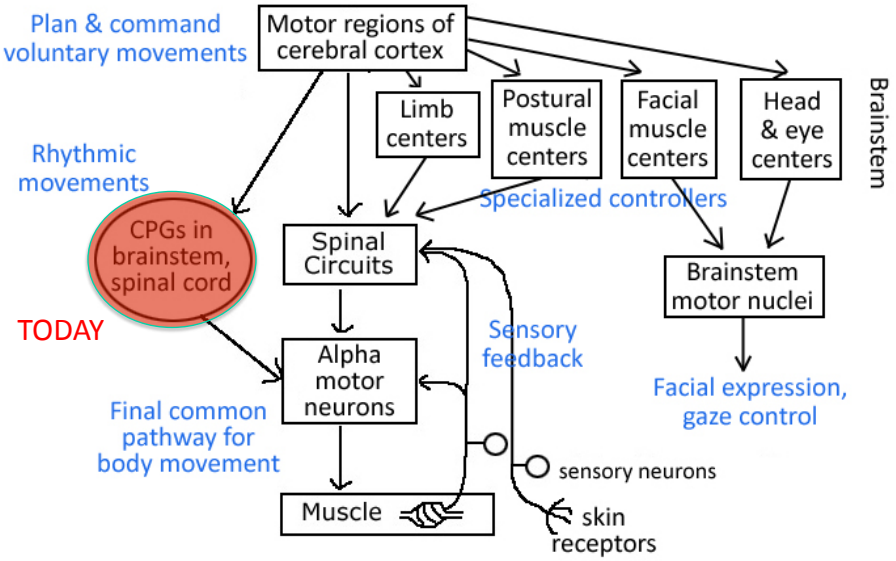
Central Pattern Generators (CPGs)



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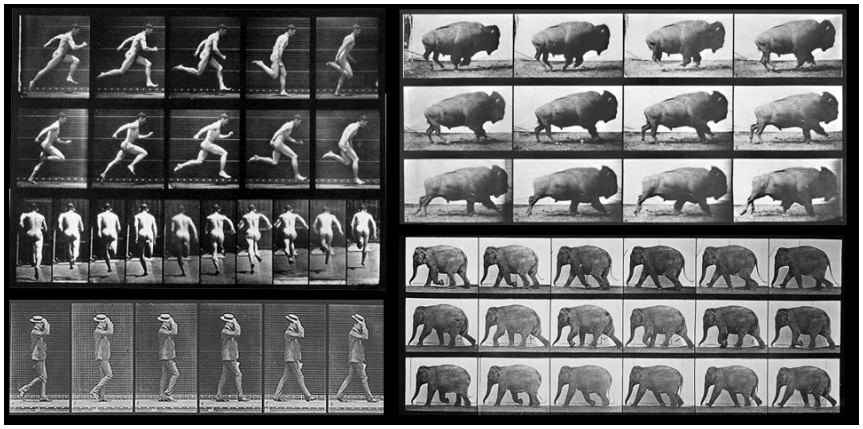
Central Pattern Generators (CPGs)

Walking, running, swimming, flying, chewing, and breathing are **stereotyped**, **rhythmic** behaviors. These are highly evolutionarily conserved, innate, and are controlled by specific spinal cord and brainstem networks called CPGs.

Eadweard Muybridge



Central Pattern Generators (CPGs)

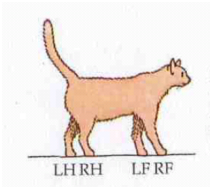
Definition

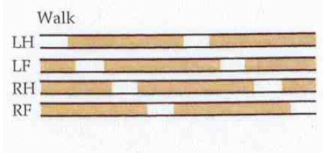
A central pattern generator is a self-contained neural circuit, usually at a low level of the CNS, that can autonomously* produce a simple, stereotyped, usually rhythmic motor behavior.

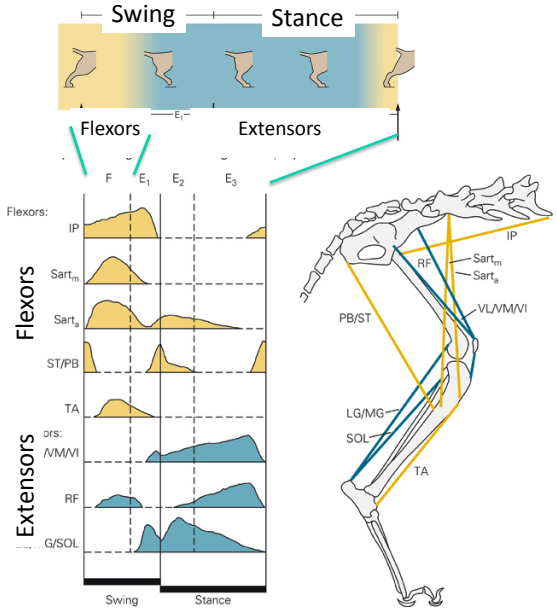
* without dynamic control from higher centers, and without the need for sensory feedback.

Walking in mammals

Walking involves activation of flexors and extensors in a right-left alternating pattern.



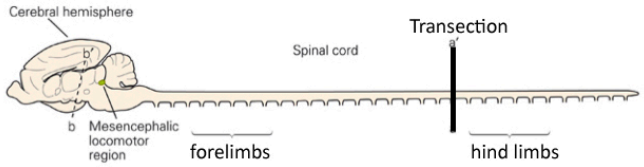


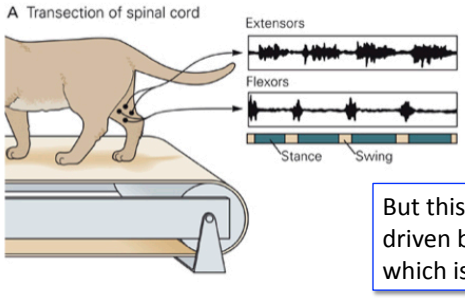


Walking in mammals

Early evidence that walking is controlled by a spinal CPG:

1. Walking persists after spinal cord transection when on treadmill.

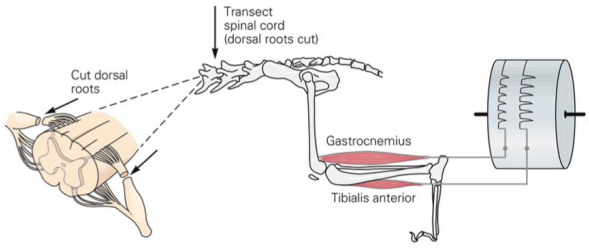


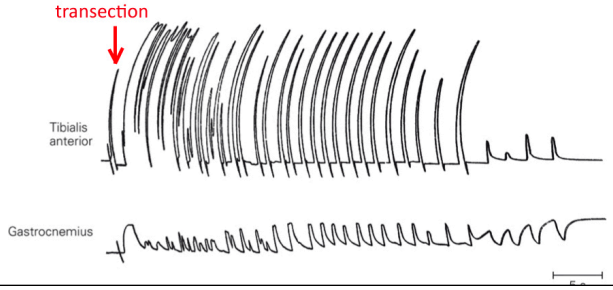


But this could be reflexes driven by proprioception, which is intact..

Walking in mammals

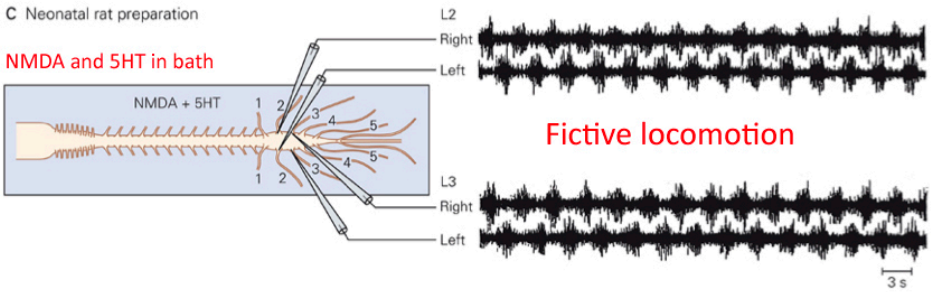
2. Basic alternating stepping occurs even when dorsal roots are cut.





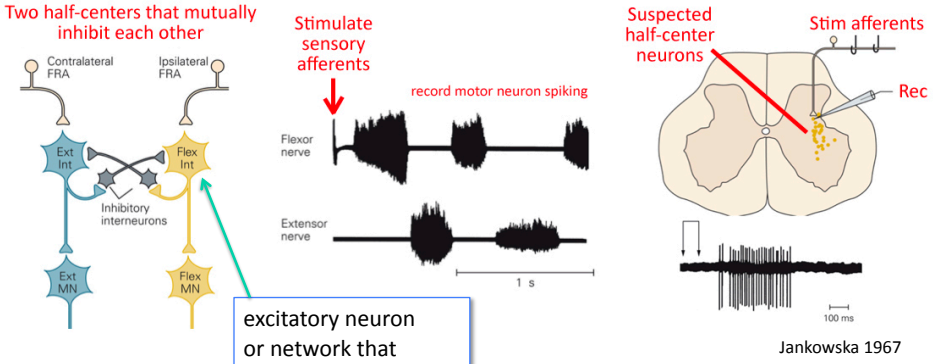
Walking in mammals

3. The isolated rat spinal cord can produce 'fictive locomotion'.



Half-center oscillator model

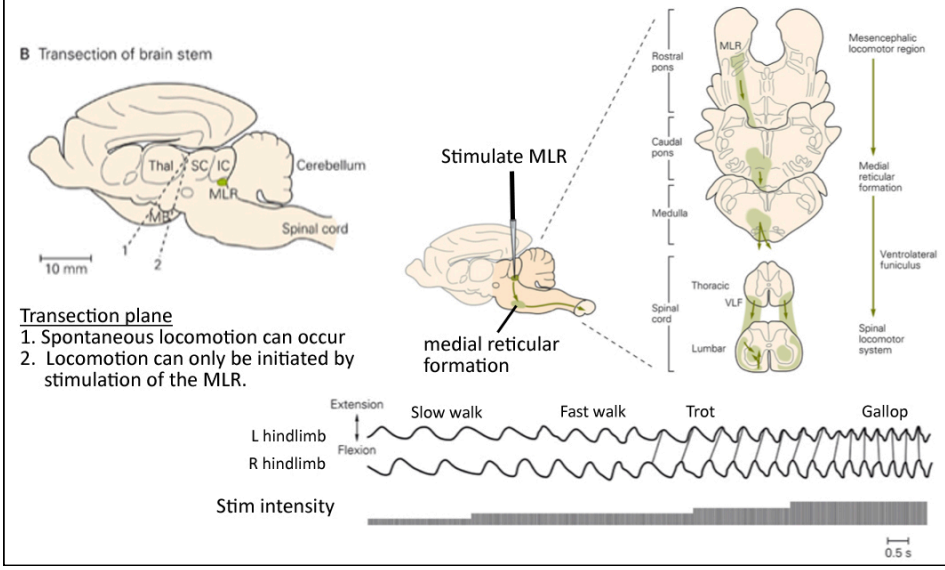
Graham Brown, 1911. Hypothesis: Contraction in the flexor and extensor muscles are controlled by two systems of neurons (termed "half centers") that mutually inhibit each other.



Jankowska 1967

The brainstem MLR activates locomotion

What turns locomotion on and off? Mesencephalic locomotor region (MLR) in brainstem reticular formation.

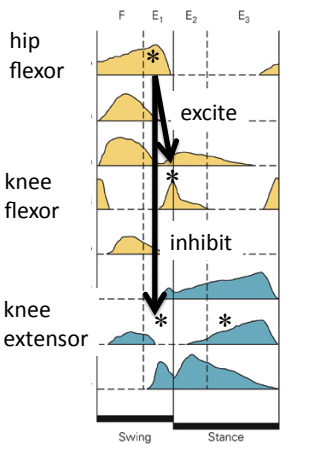


Transection plane
1. Spontaneous locomotion can occur
2. Locomotion can only be initiated by stimulation of the MLR.

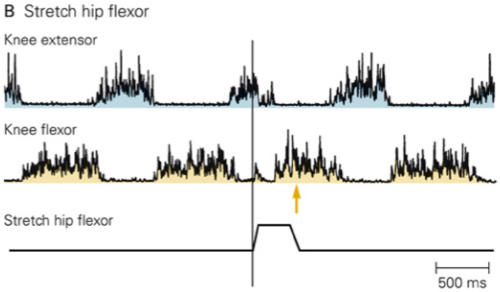
What is the role of sensory feedback?

Sensory feedback is not necessary for basic stepping, but it does modulate and fine-tune the rhythm—for example one muscle's stretch can entrain later elements of the pattern.

intact cat, normal gait

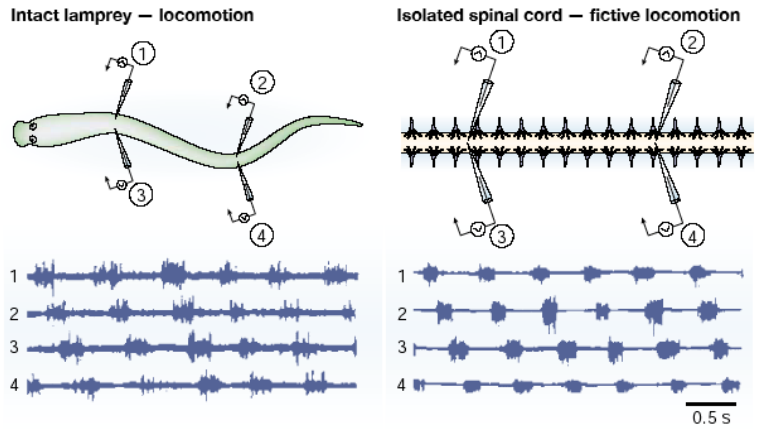


decerebrate cat walking on treadmill



Specific circuits and cellular mechanisms

Lamprey swimming is driven by a very similar spinal CPG

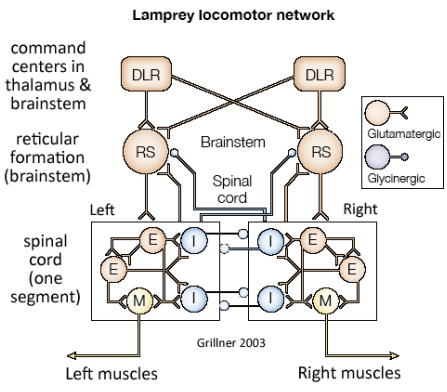


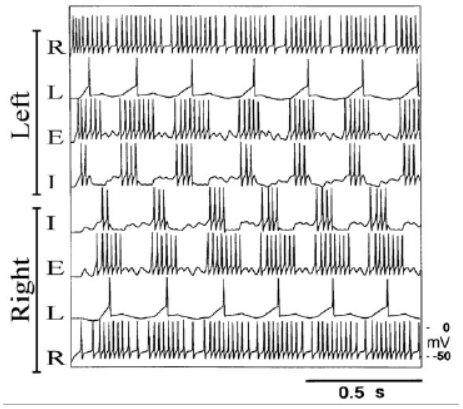
Speed is controlled by firing rate of command neurons in reticular nucleus (brainstem)

Driven by glutamate in bath; speed is controlled by concentration.

Specific circuits and cellular mechanisms

CPG network in one spinal cord segment.





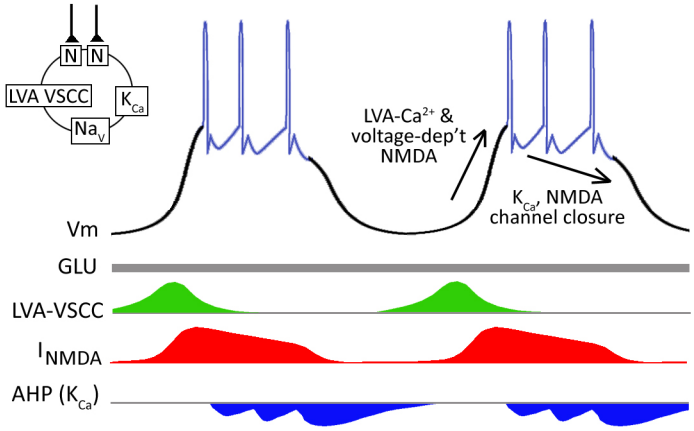
Muscle stretch inputs modulate the network but are ignored here.

Grillner 2006

Specific circuits and cellular mechanisms

Cellular mechanisms for oscillation in one segment

1. E and I cells are intrinsic pacemakers

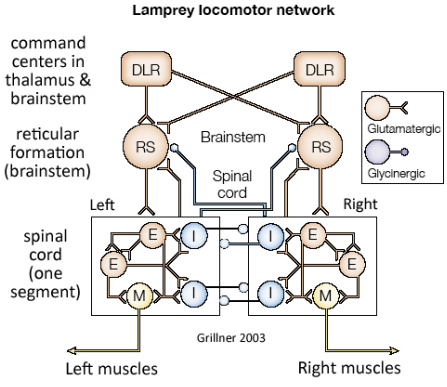


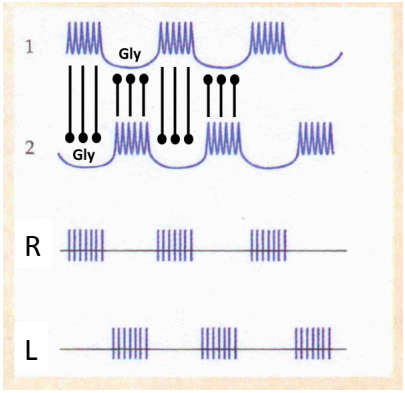
based on Grillner 2003

Specific circuits and cellular mechanisms

Cellular mechanisms for oscillation in one segment

2. Excitation couples all cells in each half-center to oscillate together; mutual inhibition causes R and L to oscillate in antiphase

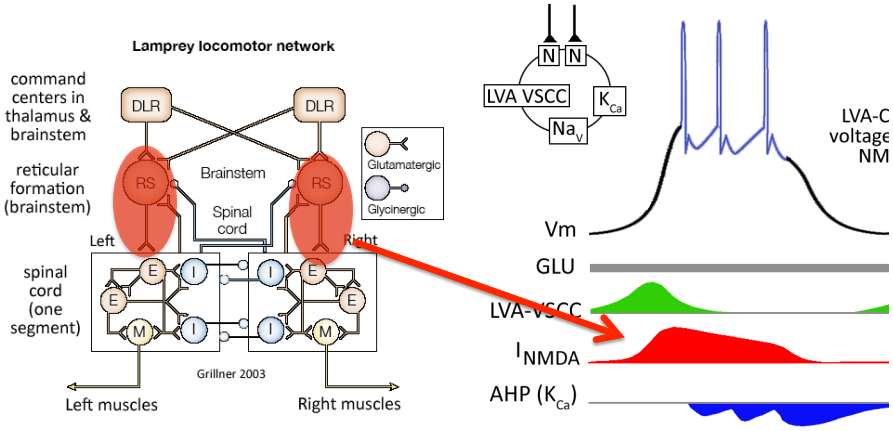




Specific circuits and cellular mechanisms

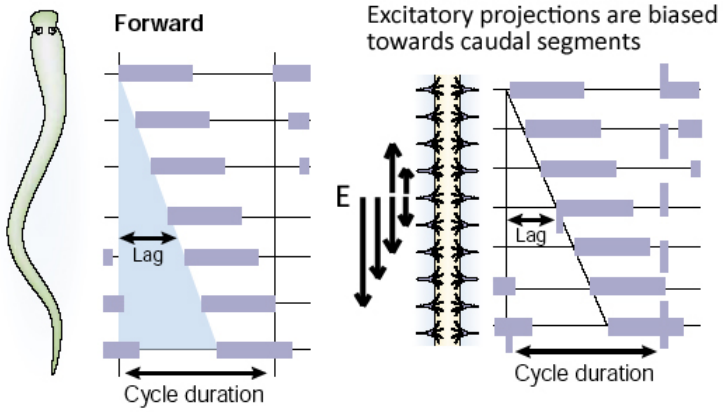
Speed of rhythm will increase with more descending excitation

3. More glutamate → stronger NMDA current → start next burst sooner



Specific circuits and cellular mechanisms

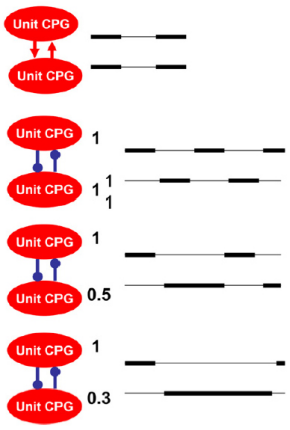
Segments are coupled by excitatory projections, leading to a propagating wave of contraction across segments



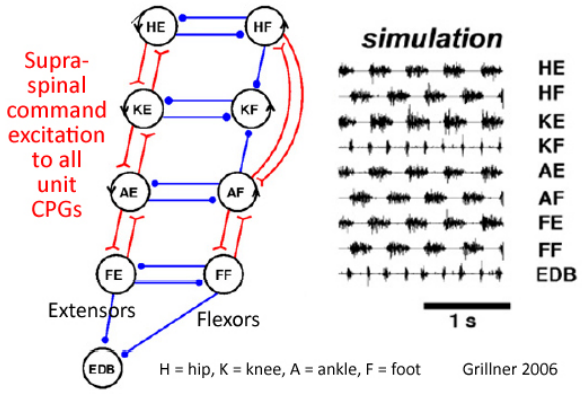
Grillner 2006

Relationship to mammalian walking

Lamprey half-center CPGs can be assembled to produce basic features of walking



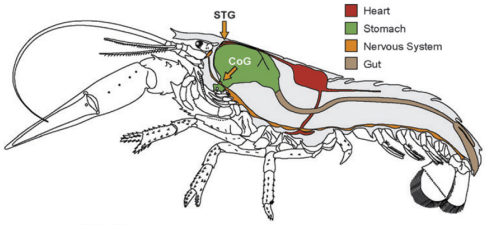
Leg model composed of coupled unit CPGs



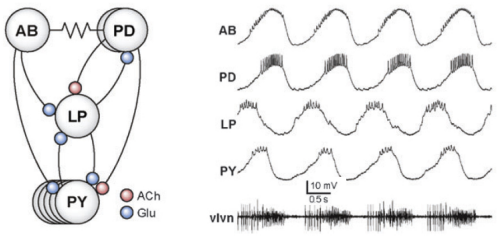
H = hip, K = knee, A = ankle, F = foot Grillner 2006

The best understood CPG: the stomatogastric ganglion

Lobster STG



Pyloric network



Every cell is known, its ion channels, connectivity, transmitter receptors, and how it shapes the rhythm.

Neuromodulation (dopamine) switches between multiple rhythms by altering almost all neurons in different ways.

Different animals produce the same motor pattern with different combinations of ion channels!!

Eve Marder

Summary: CPGs

CPGs have been identified for walking, swimming, chewing, breathing, and whisking (in rodents). Locomotor CPGs are in spinal cord. Facial and breathing CPGs are in brainstem.

CPGs autonomously produce rhythmic output, due to pacemaking by voltage- and calcium-gated ion channels, and network interactions that set rhythms across cells.

Sensory input and neuromodulators (serotonin, dopamine) regulate CPG function. This both helps shape the details of the rhythms, and allows a single CPG to produce different rhythms (e.g. walking, trotting, galloping).

High-level control of CPGs is accomplished by command centers in brainstem, which determine when rhythms are produced, and control key aspects of their output (e.g. locomotion speed).