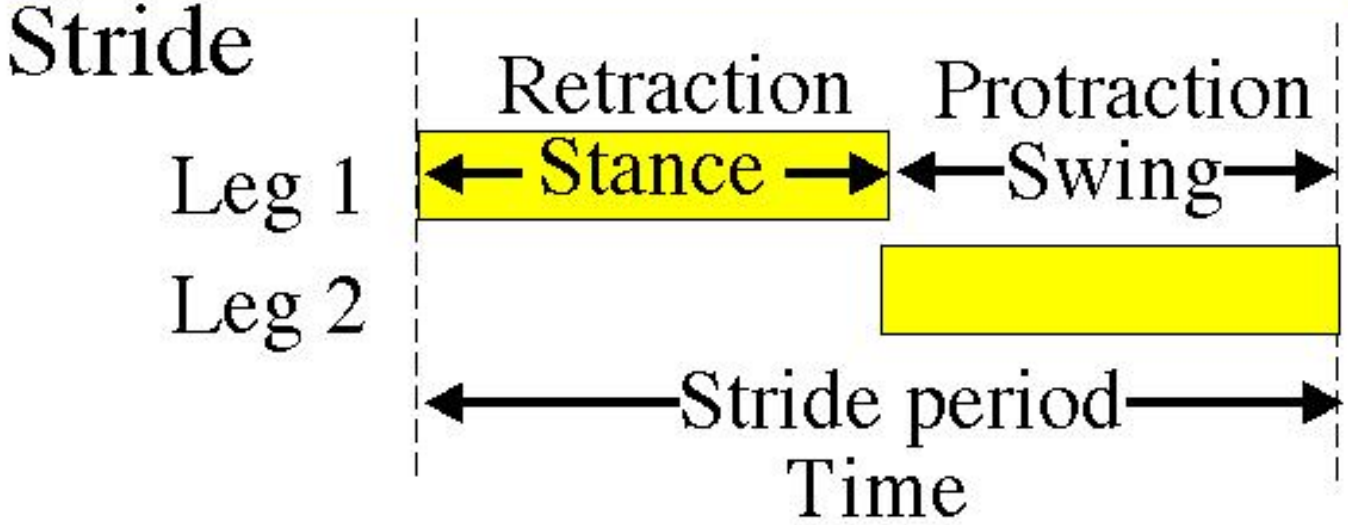
Biomotion

Mystery of Motion

Why do animals change gait?

Terms Used in Gait Analysis



Stride - one complete cycle of leg movements

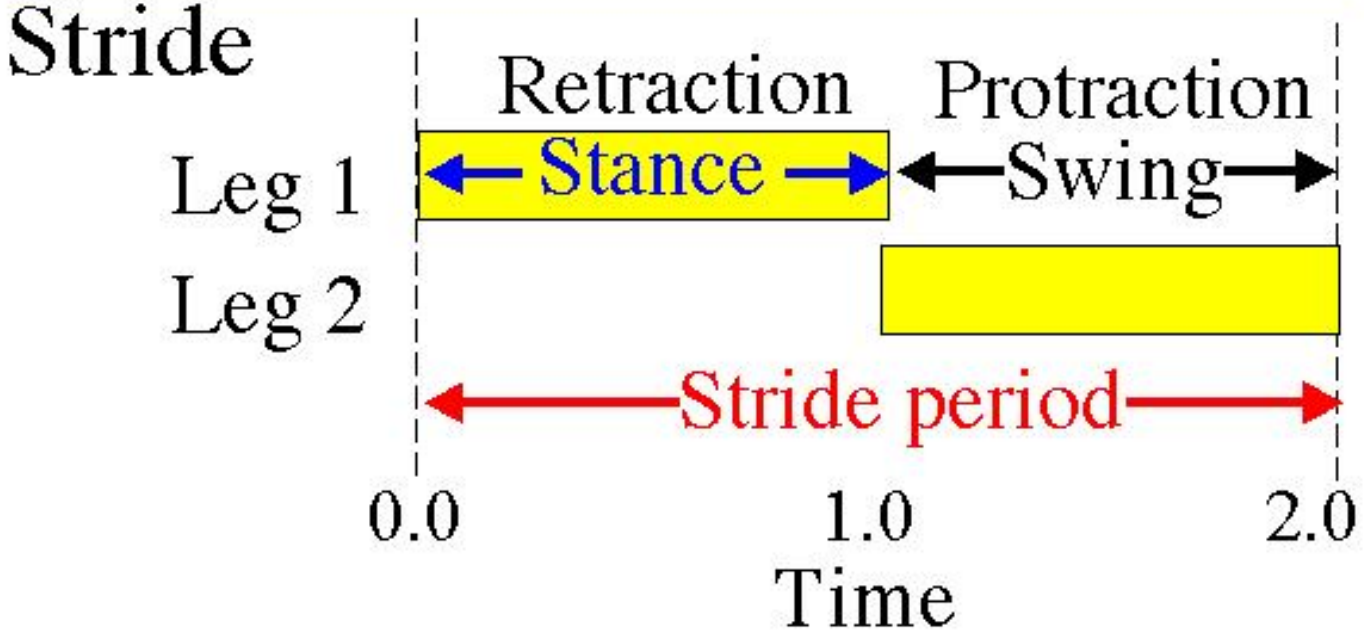
Stride period- time to complete one stride

Stride frequency - strides / time (cycles/sec or Hz)

Stride length - distance traveled / stride

Speed = stride length * stride frequency

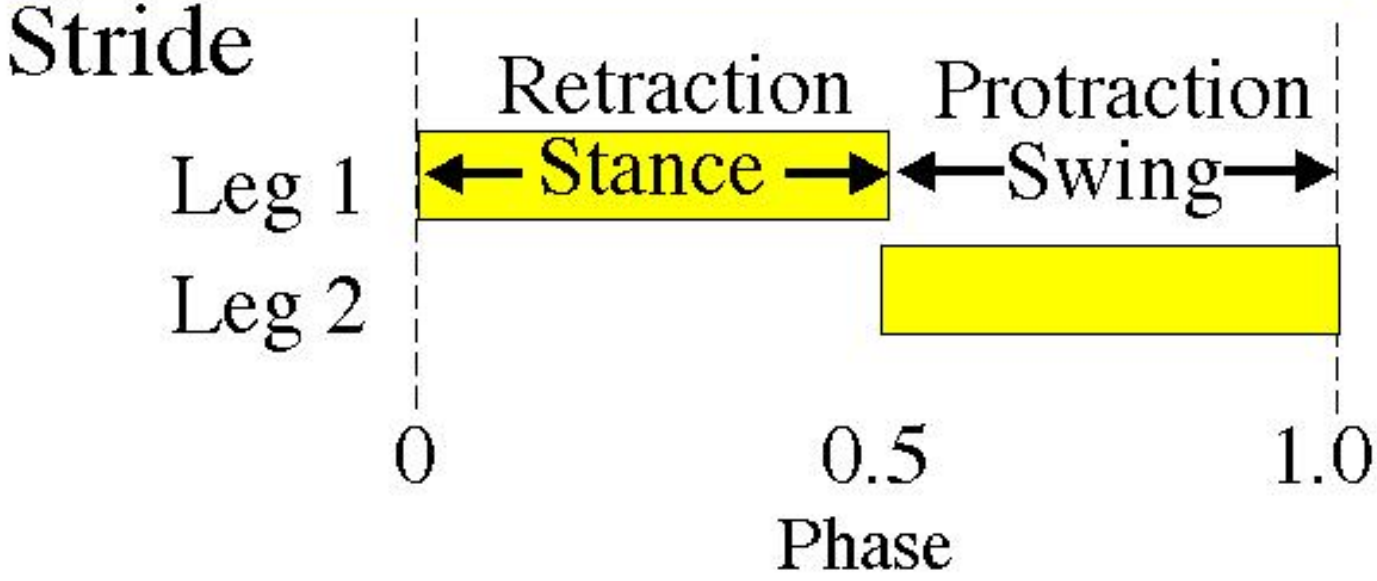
Terms Used in Gait Analysis



Duty factor - stance or contact time /stride period

What is the duty factor? 1.0/2.0 = 0.5

Terms Used in Gait Analysis

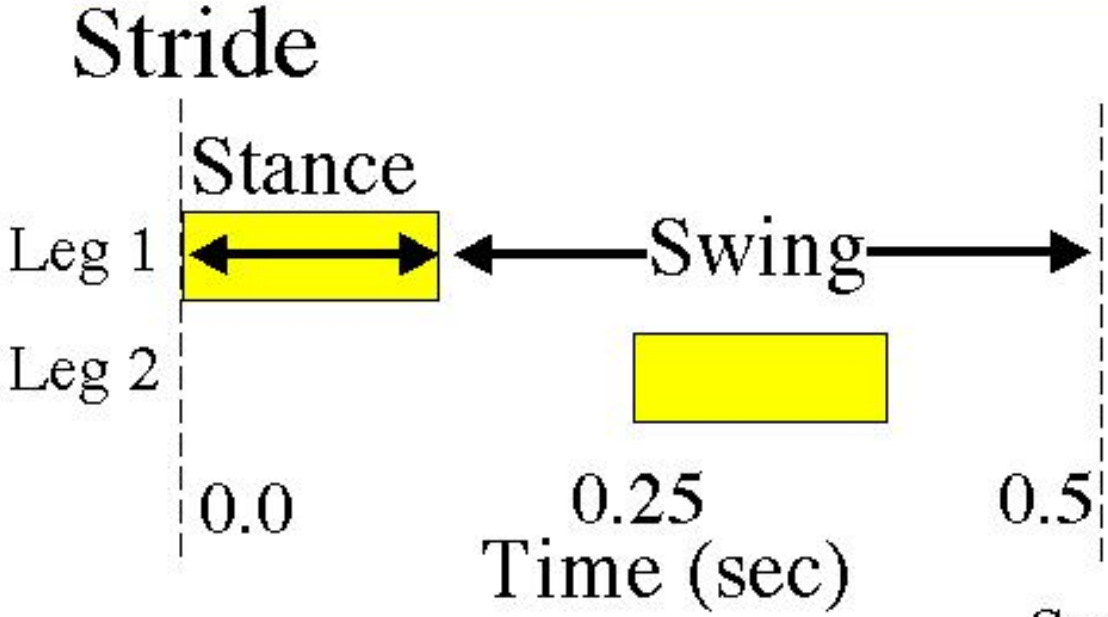


Phase - place in the cycle where an event occurs

Define a complete stride from 0 to 1.0

Where does Leg 2 touch down? 0.5

Gait Analysis of Biped



Speed = 5 meters/second

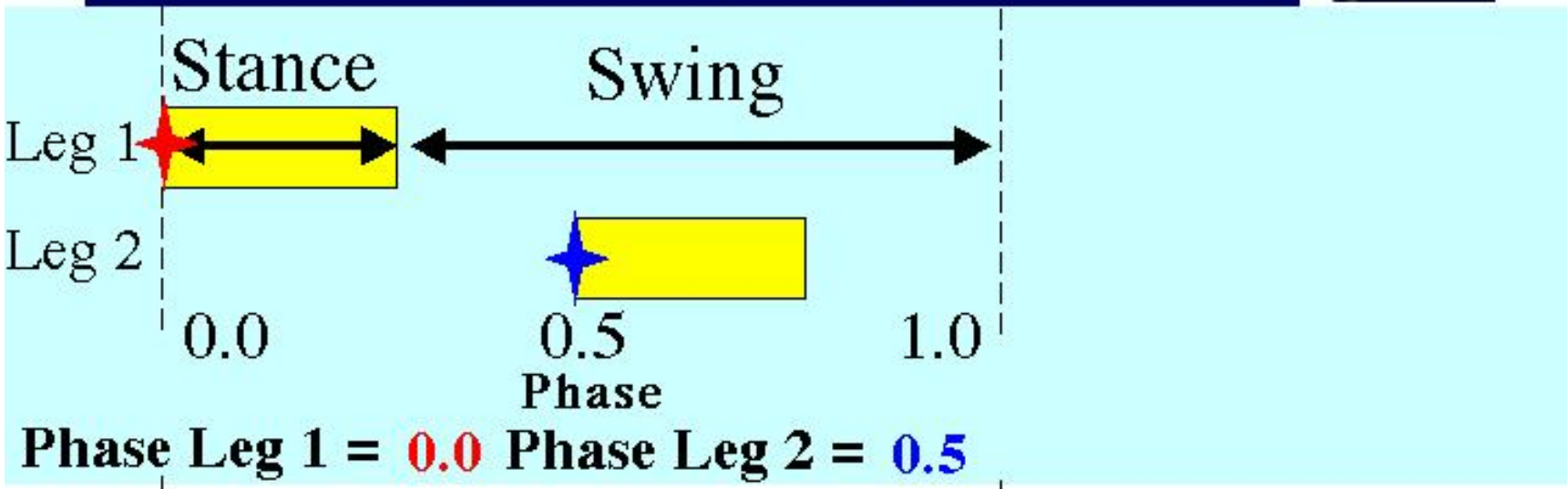
Stride period = 0.5 seconds

Stride frequency = 1/stride period = 2 Hz

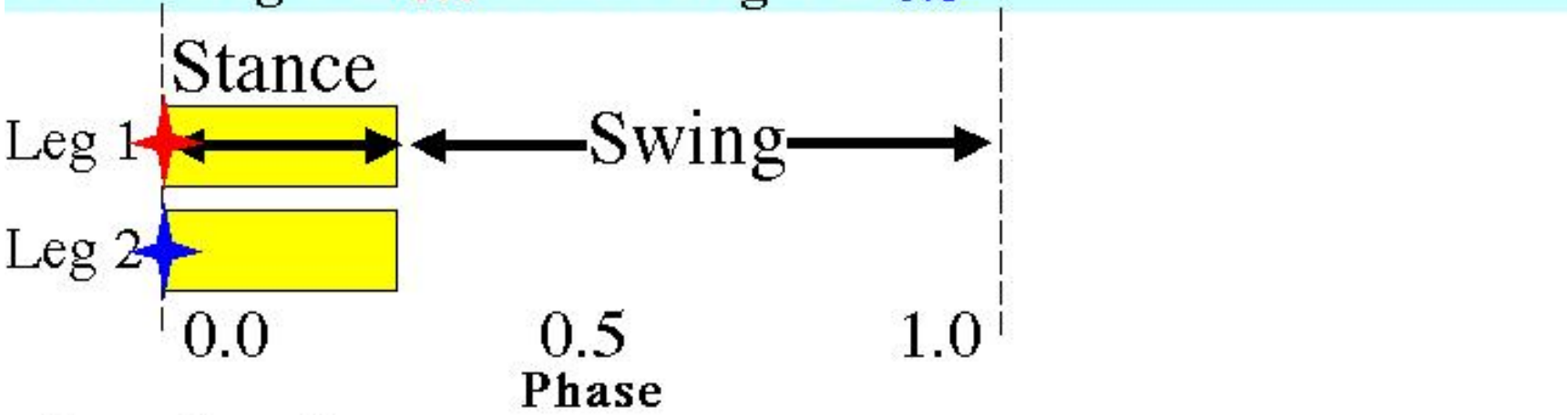
Stride length = speed/stride frequency = 5/2 = 2.5 m

Duty factor = 0.125/0.5 = 0.25

Gait Analysis of Biped

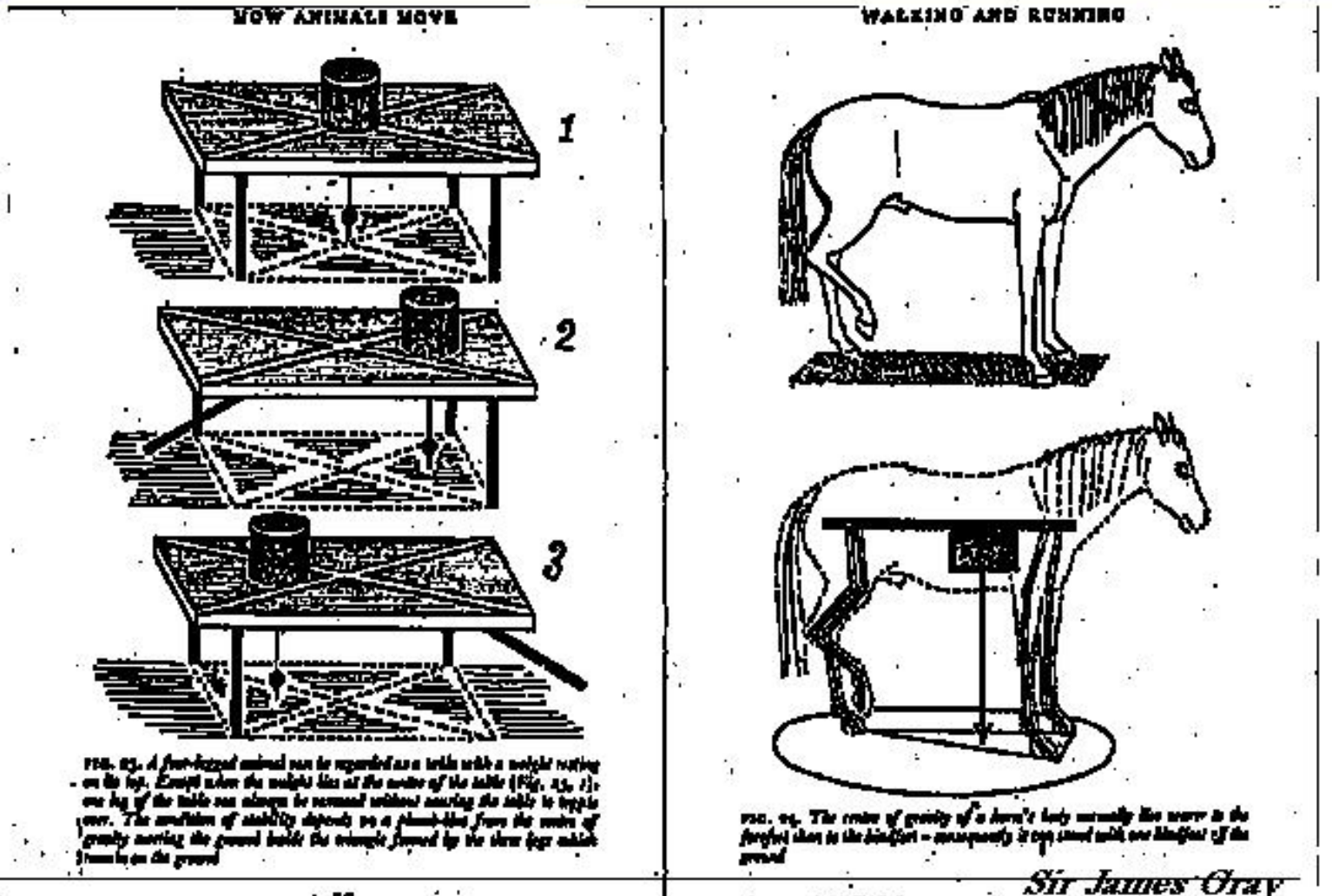


Phase Leg 1 = 0.0 Phase Leg 2 = 0.5



Phase Leg 1 = 0.0 Phase Leg 2 = 0.0

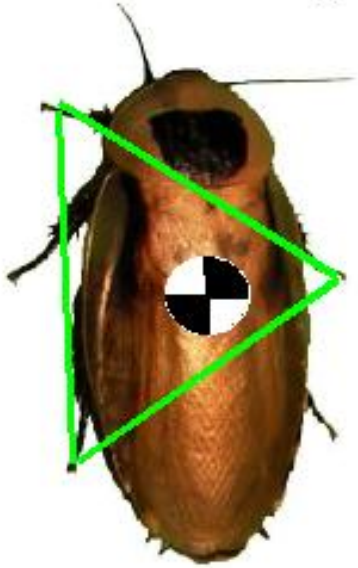
Static Stability

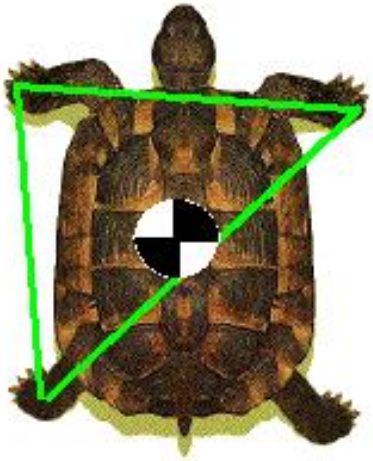


Static Stability

Keep Body within Tripod of Support

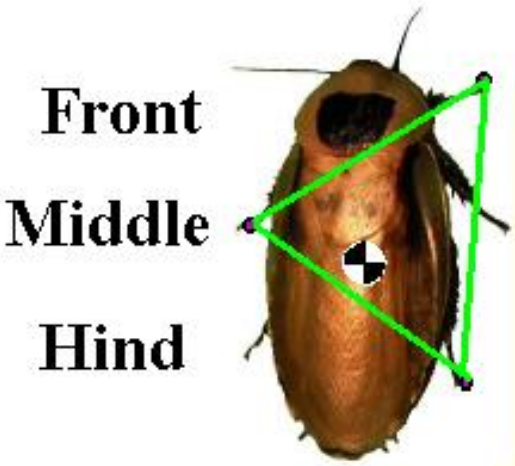
More Legs **Greater Sprawl** **Leg Order**

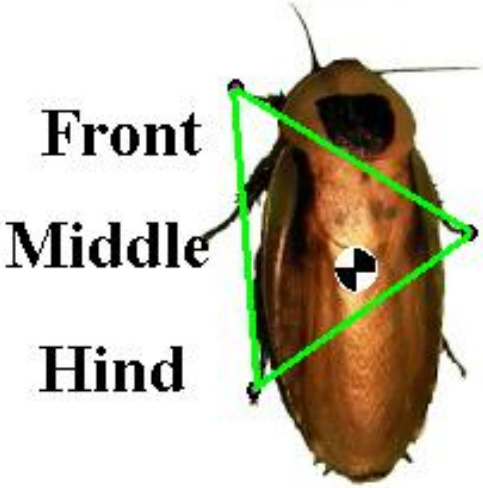




Leg Number Posture Gait

Static Stability

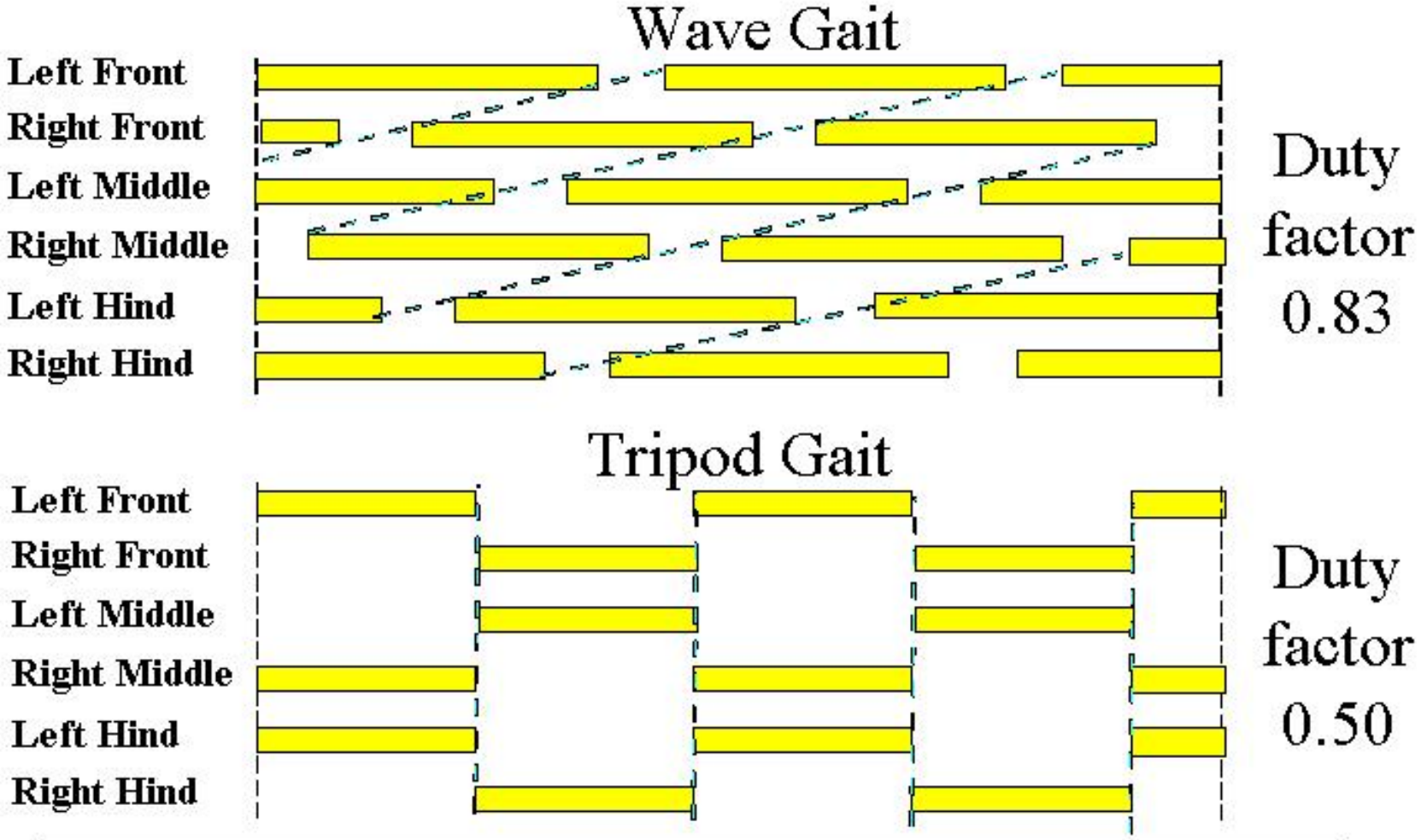




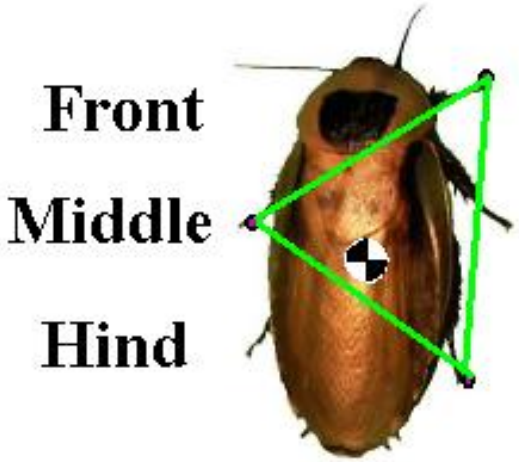
Hexapedal animals use an Alternating Tripod over a wide range of speeds.

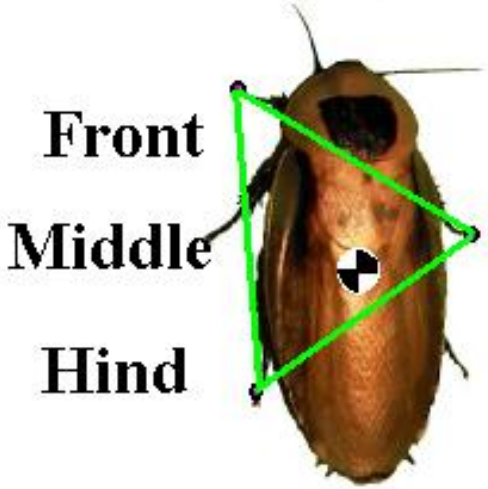
The body or center of mass remains within a tripod of support.

Hexapod Gait Analysis



Static Stability



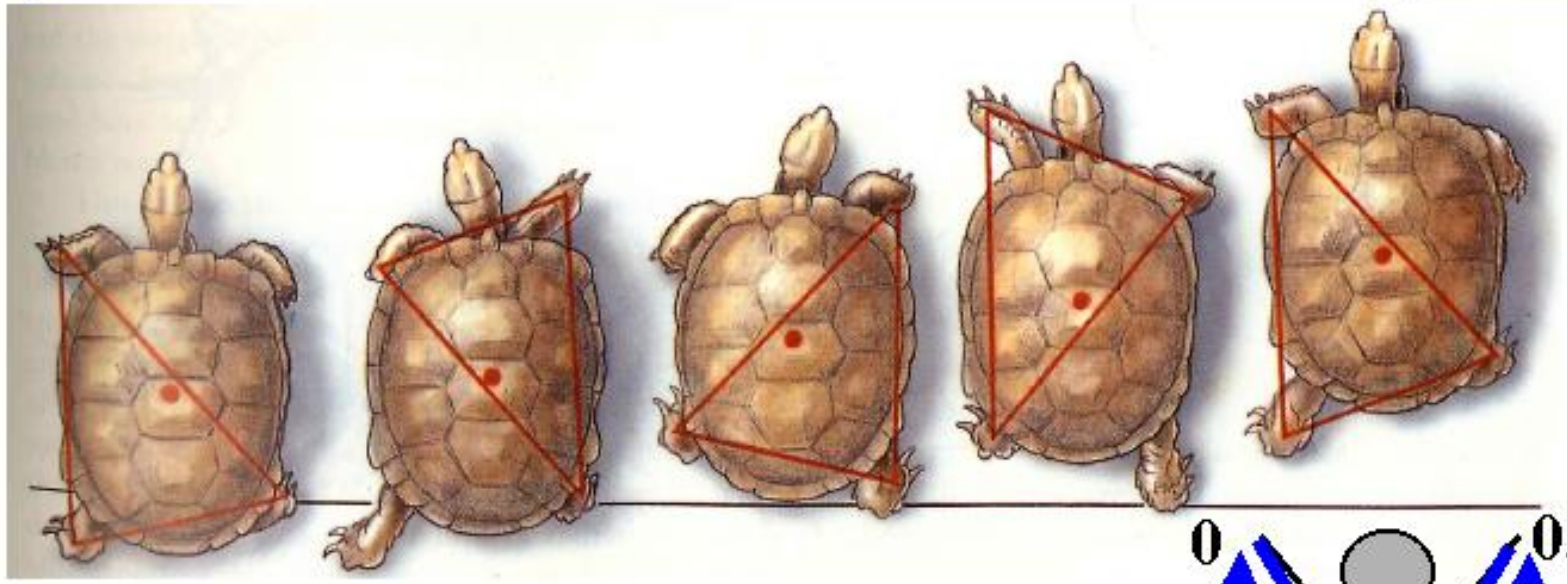


What gait do quadrupeds use to maintain static stability?

Quadrupedal Stability

Demos

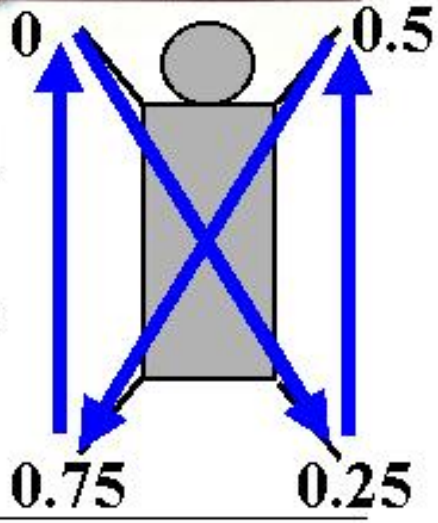
Statically Stable Quadrupedal Walking



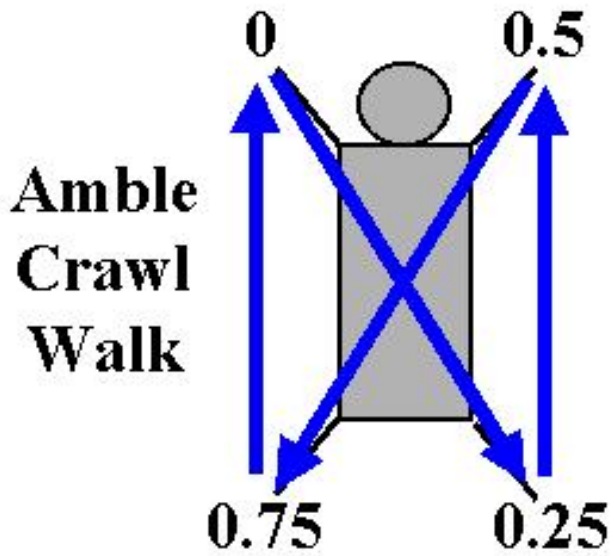
Duty factor must be at least 0.75 to have 3 legs on the ground at once.

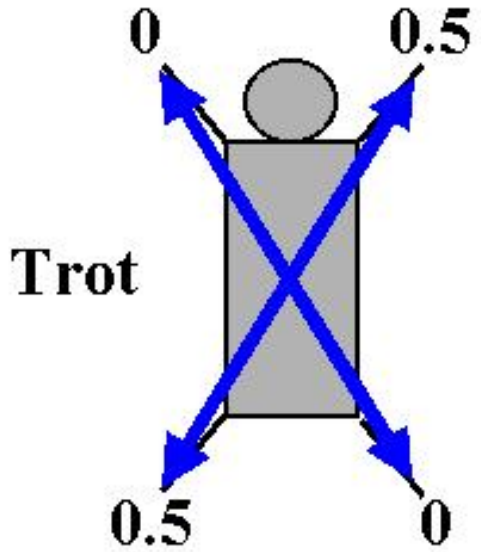
Only one gait is possible for static stability.

Crawl
Walk
Amble

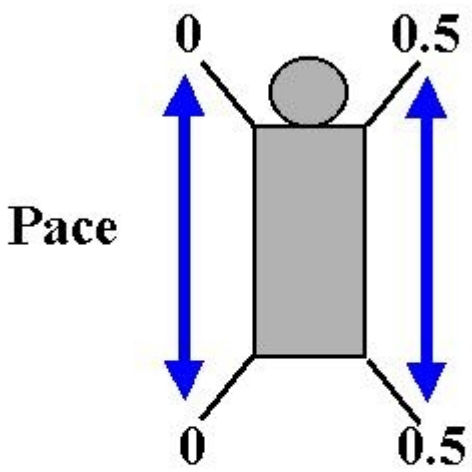


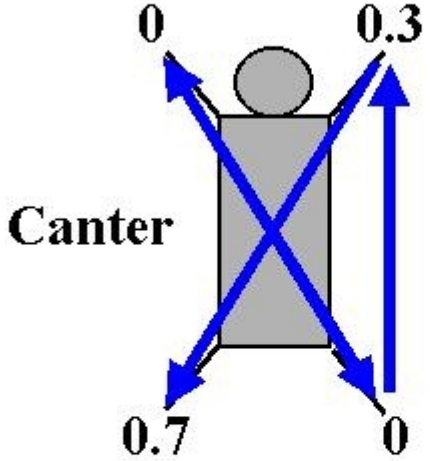
Quadrupedal Gaits



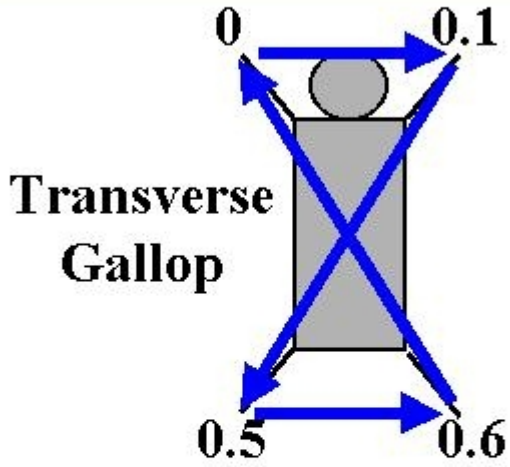


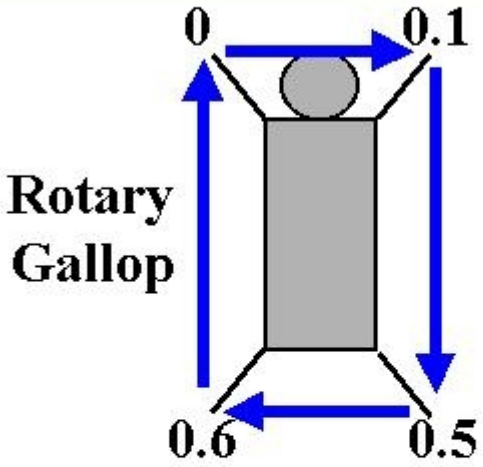
Faster Quadrupedal Gaits



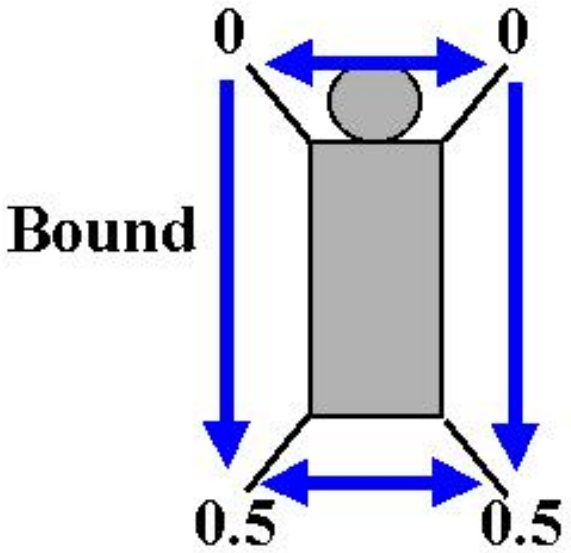


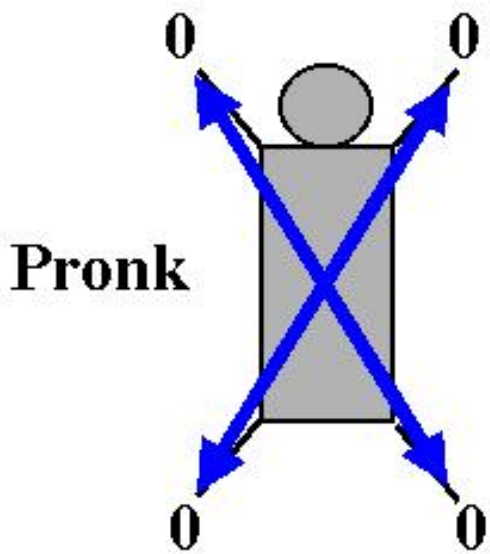
Faster Quadrupedal Gaits





Faster Quadrupedal Gaits





Dynamic Stability

Quadrupeds often have less than a tripod of support, but don't fall down.

Why?

Dynamic stability

- stable over a complete cycle, but need not be stable at any instant

- use the energy of motion

Bipedal Lizards

Dynamic stability allows quadrupeds to run on two legs

Video

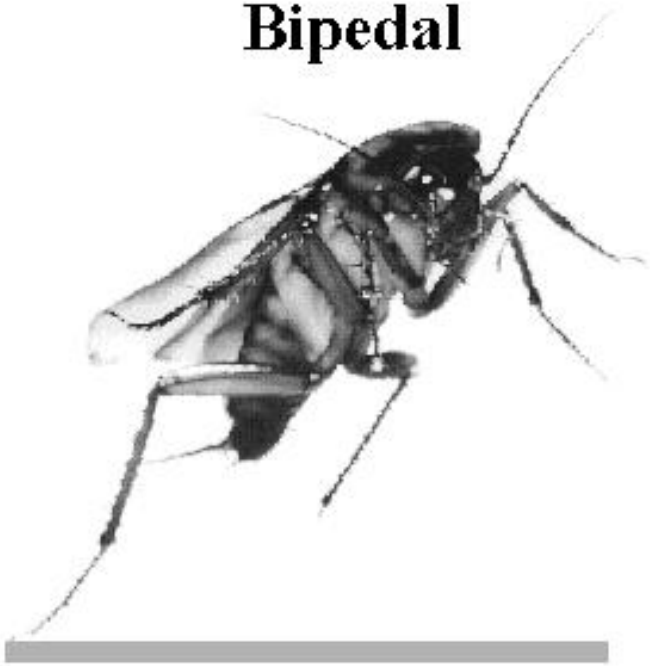
Discovery by *Cal* Undergraduate in PolyPEDAL Lab

Michael Tu

Dynamic Stability

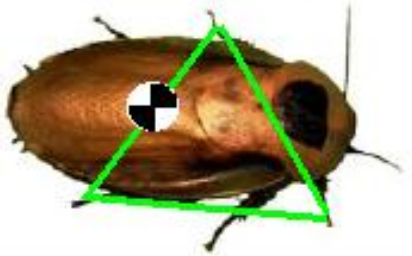
Highest Speeds

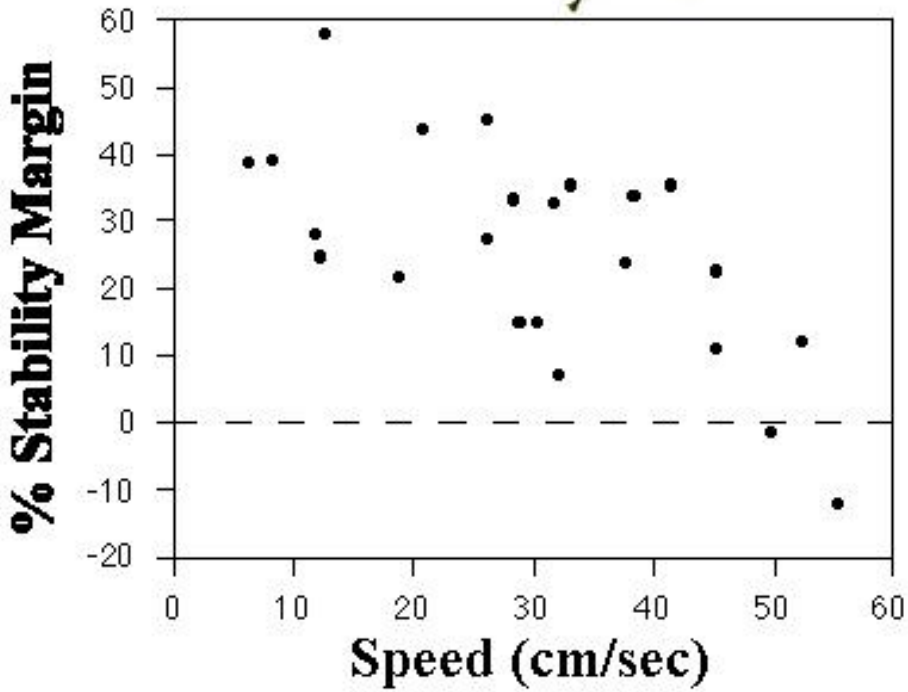
Bipedal



Aerial Phase

Full and Tu, 1991





Ting, Blickhan and Full, 1994

Back Springs

Back Spring

Cheetah

Alexander et al. 1985

Lateral Back Spring

Gecko

New Discovery - Juliann Chen *Cal* Undergraduate in PolyPEDAL Lab!

Mystery of Motion

Why do animals change gait?

1. Increase speed - static stability requirements at slow speed limits gait choice

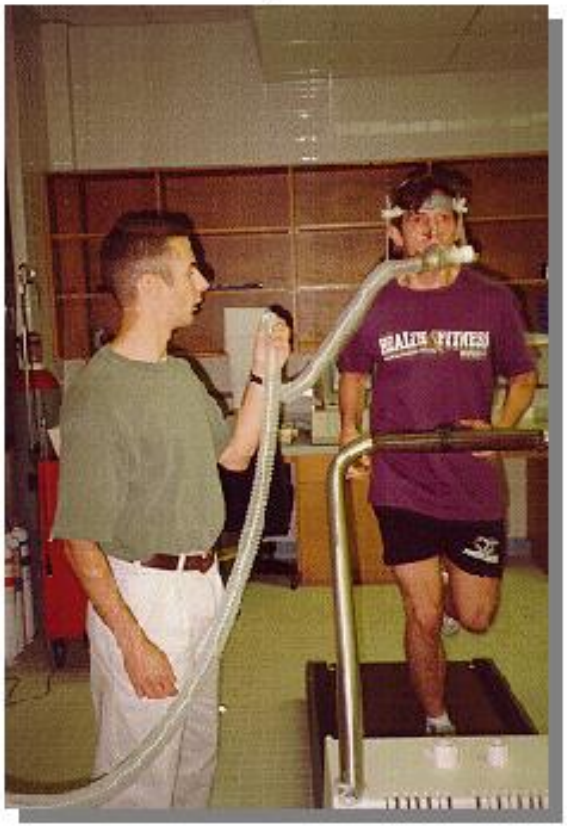
- an increase in speed allows faster, dynamically stable gaits

Do Gaits Differ in Cost?

Does it cost more energy or fuel to walk fast or run slowly?

Measure Oxygen consumed.

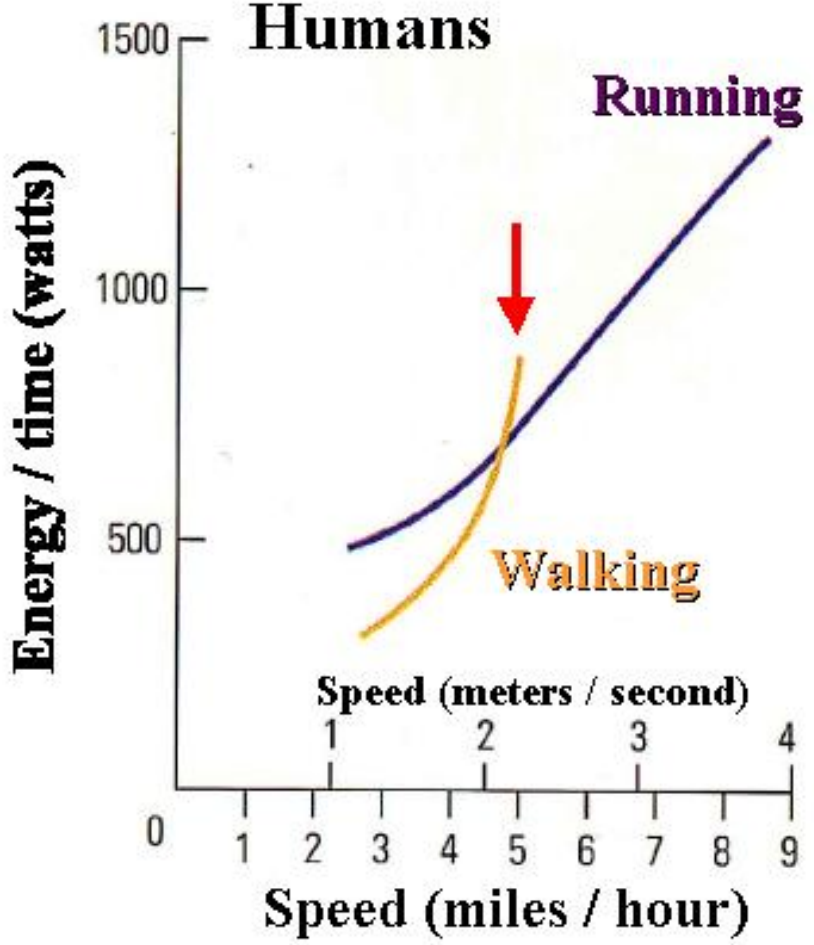
1 ml O_2 = 5 Cal



Energy Cost of Walking and Running

Costs more energy to walk fast than to run.

Change gait to reduce energy cost.



Energy Cost of Horse Locomotion

Fast walking costs more than slow trotting. Fast trotting costs more than slow galloping.

Horses select the gait that reduces energy cost.

Mystery of Motion

Why do animals change gait?

1. **Increase speed** - static stability requirements at slow speed limits gait choice
   - an increase in speed allows faster, dynamically stable gaits
2. **Reduce energy** - decrease cost per distance

Hypothesis of Gait Change

Bone bending increases as an animal moves faster using the same gait.

Changing gait decreases forces on bone and tendons.

Does an animal change gait to decrease the force on bone and tendons or to reduce energy cost?

Test Gait Change Hypothesis

Add a weight to horse.

Increase peak forces at same speed.

Does weighted horse change gait at slower speeds?
Supports gait change to reduce force.

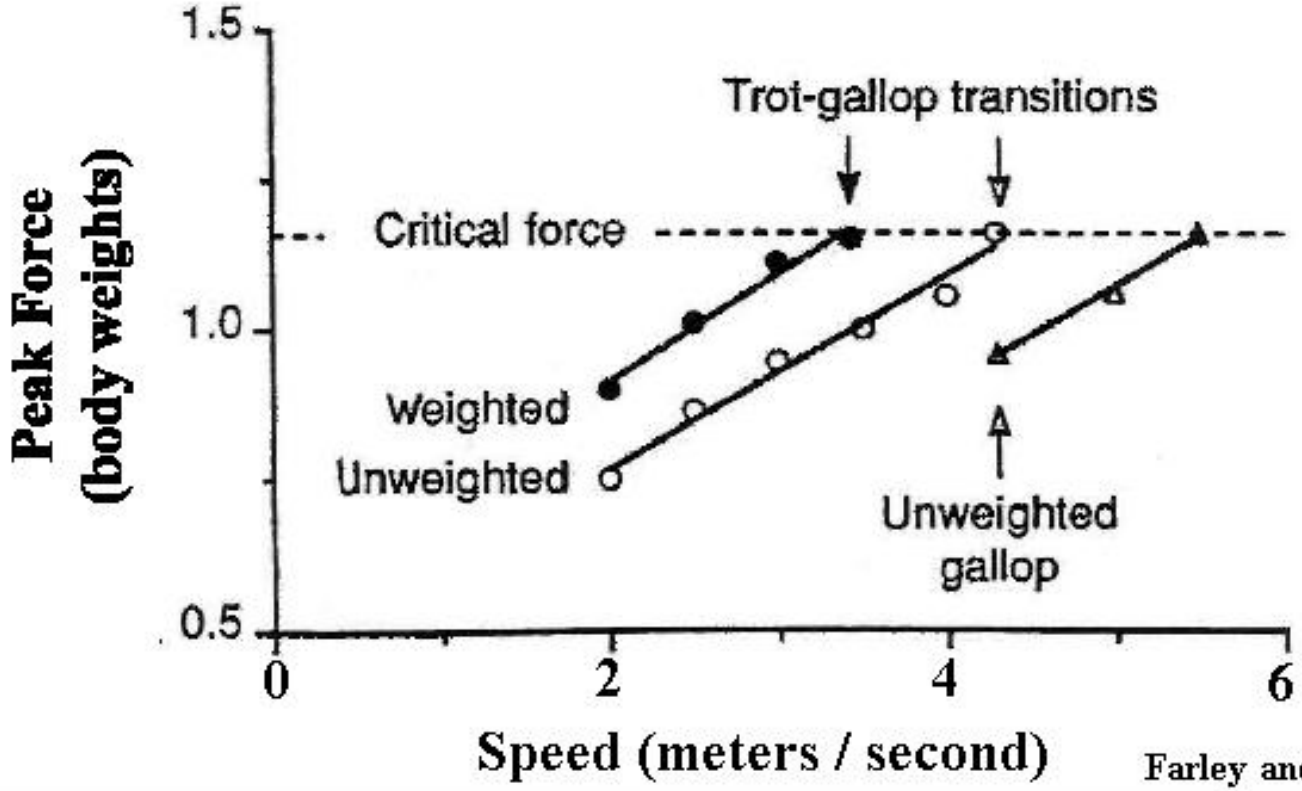
Does weighted horse change gait at same speed as unweighted?
Supports gait change to reduce energy cost.

Prof. Claire Farley from *Cal*

Integrative Biology

Mechanical Trigger of Gait Change

Horses change gait to decrease forces on bones and tendons. Reduce chance of injury.



Farley and Taylor 1991

Mystery of Motion

Why do animals change gait?

1. **Increase speed** - static stability requirements at slow speed limits gait choice
   - an increase in speed allows faster, dynamically stable gaits
2. **Reduce energy** - decrease cost per distance
3. **Decrease skeletal strain** - reduce bone bending and tendon forces

General Principles of Gaits

How similar are gait changes among diverse animals?

Animals differ in body size, speed, leg number, leg position.

How can we make comparisons?

Compare a Camel to a Dog

A dog runs at speeds a camel walks.

At what speed might they move in a similar way ? with the same gait?

The camel's body and leg is 3 times longer than the dog's.

Speed / Leg length

Compare a Camel to a Dog

Speed / Leg length

Dog

$$\frac{\text{3.5 m/sec}}{\text{0.5 m}}$$

Camel

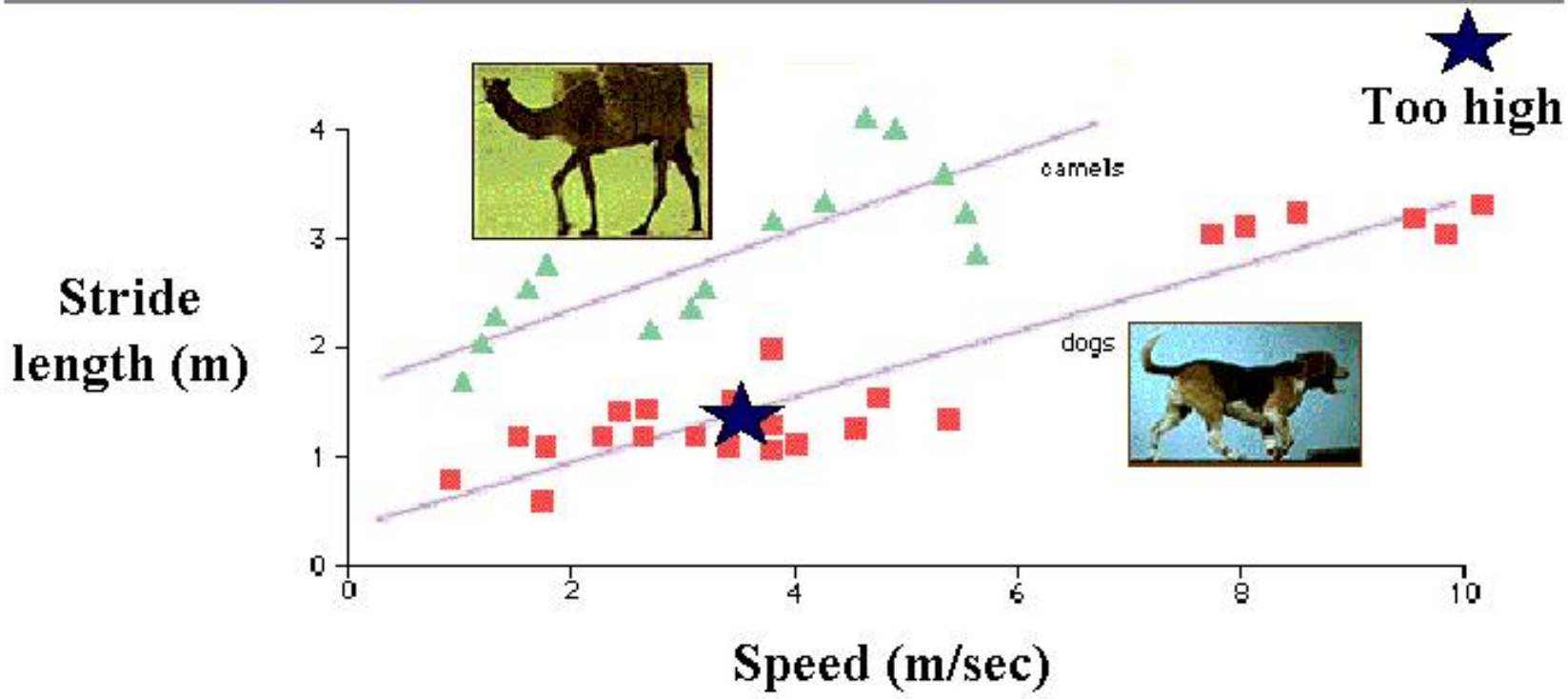
$$\frac{\text{10.5? m/sec}}{\text{1.5 m}}$$

3 times the leg length

3 times the speed?

Compare a Camel to a Dog

Equivalent speeds not directly proportional to leg length.



Scaling - Geometric Similarity

Animals are similar if the large one is an enlarged picture of the small one.

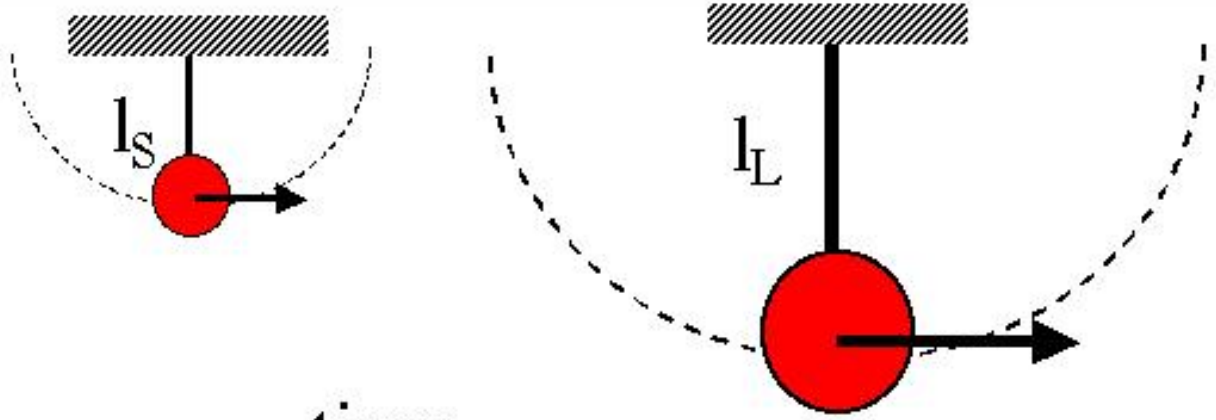
$$\frac{\text{length}_L}{\text{length}_S} = \text{CONSTANT}$$

Ratio of any two corresponding lengths

CONSTANT

Scaling - Dynamic Similarity

Motions are similar if the large animal is a slowed down movie of a small animal.



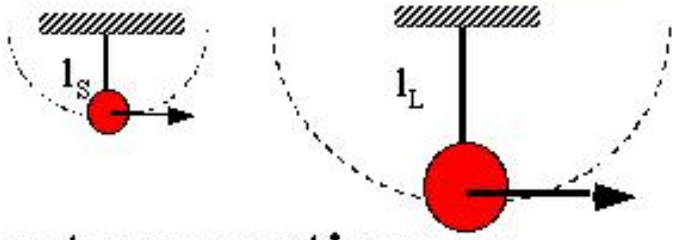
$$\frac{\text{time}_L}{\text{time}_S} = \text{CONSTANT}$$

Ratio of any two corresponding times

CONSTANT

Froude Number

If you move in an arc then:
speed^2 / length = acceleration



If lengths and times are in constant proportions so are speeds and accelerations, therefore:

$$\textbf{Froude number} = \frac{\text{speed}_L^2}{\text{acceleration}_L \, \text{length}_L} = \frac{\text{speed}_S^2}{\text{acceleration}_S \, \text{length}_S}$$

Froude number is a dimensionless speed

Dynamically similar behavior has similar Froude numbers

Compare a Camel to a Dog

Speed^2 / (gravity *Leg length)

Dog

$$\text{Froude \#} = \frac{(3.5\ \text{m/sec})^2}{9.8\ \text{m/sec}^2 * 0.5\ \text{m}} = 2.5$$

Camel

$$\text{Froude \#} = \frac{(6.1\ \text{m/sec})^2}{9.8\ \text{m/sec}^2 * 1.5\ \text{m}} = 2.5$$

3 times the leg length

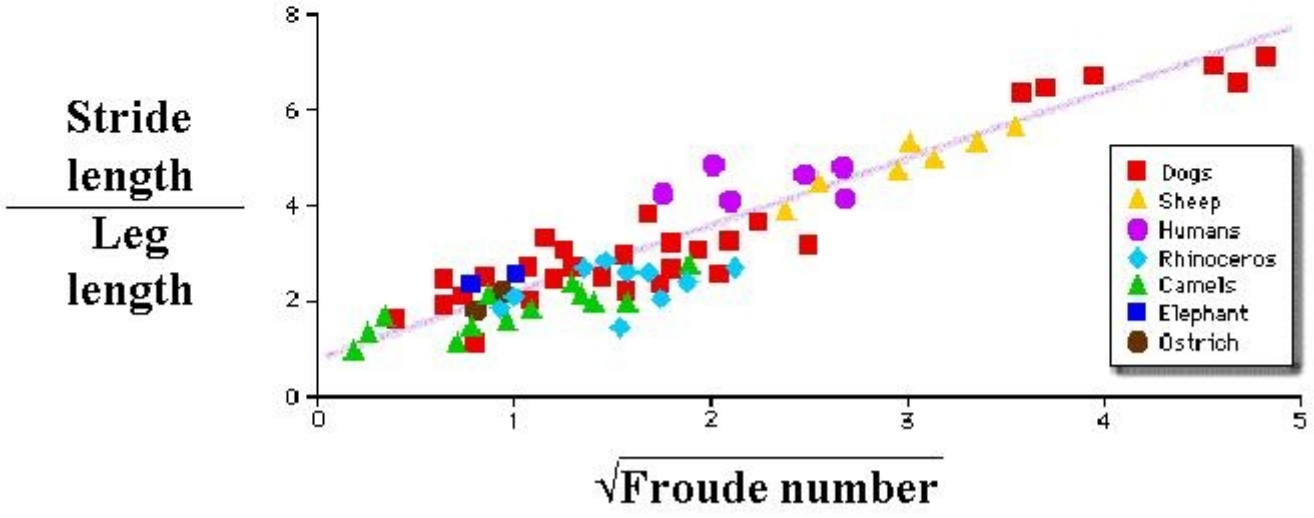
1.7 times the speed

Similarity in Gaits

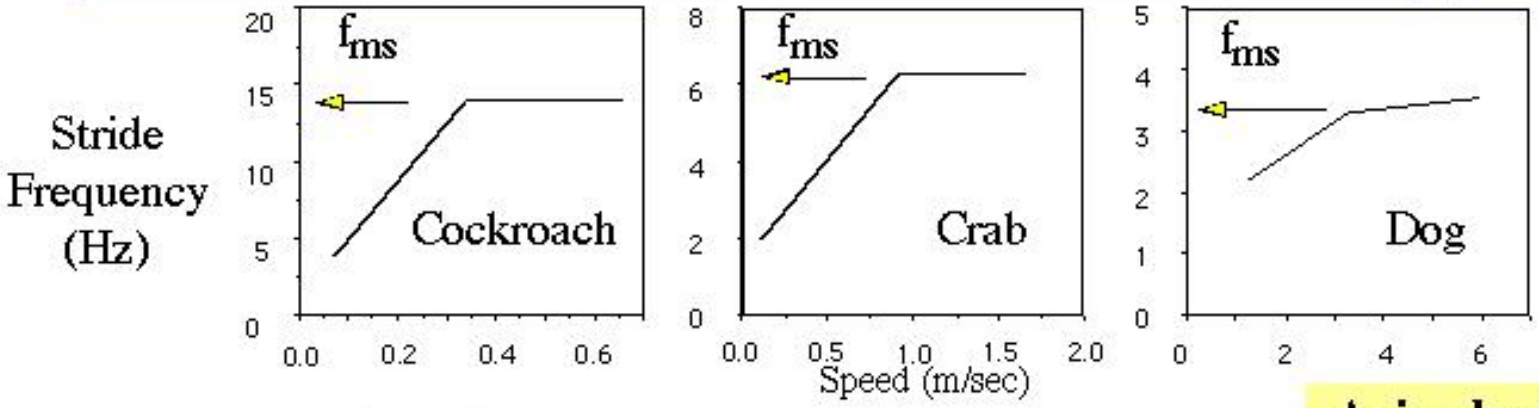
Most mammals move in a dynamically similar way!

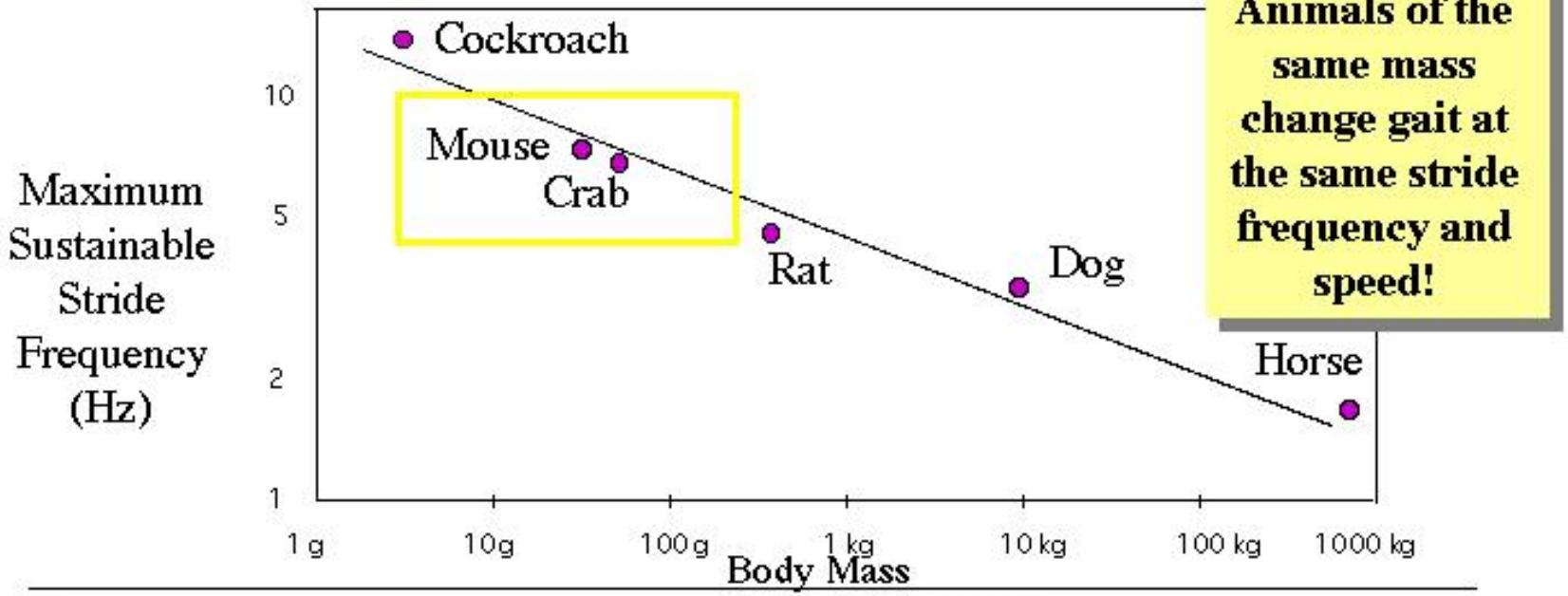
Change from a walk to a trot at Froude # = 0.5

Change from a trot to a gallop at Froude # = 2.5



Stride Frequency





Animals of the same mass change gait at the same stride frequency and speed!