Herbert Wertheim
College of Engineering
UNIVERSITY of FLORIDA

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Department of Electrical & Computer Engineering

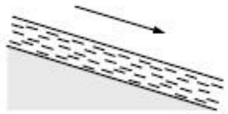
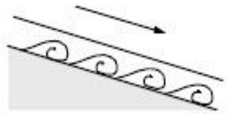
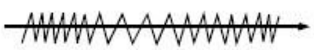
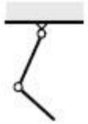
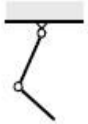
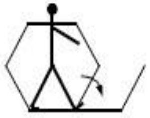
Summer Robotic Research Experience

Introduction

Dr. Christophe Bobda

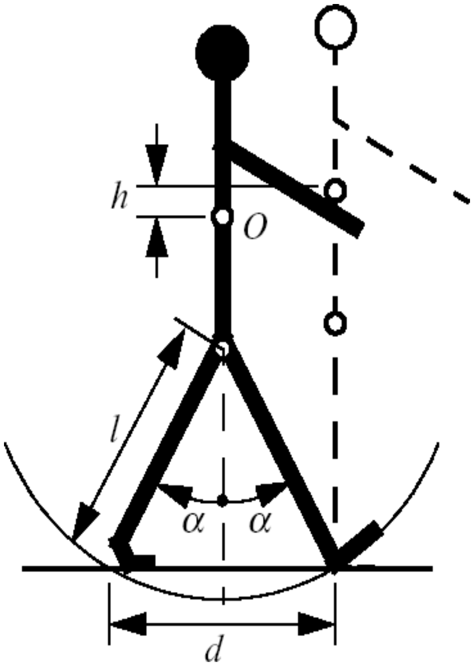
Legged Locomotion

Locomotion Principles Found in Nature

Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel 	Hydrodynamic forces	Eddies 
Crawl 	Friction forces	 Longitudinal vibration
Sliding 	Friction forces	 Transverse vibration
Running 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Jumping 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Walking 	Gravitational forces	Rolling of a polygon (see figure 2.2) 

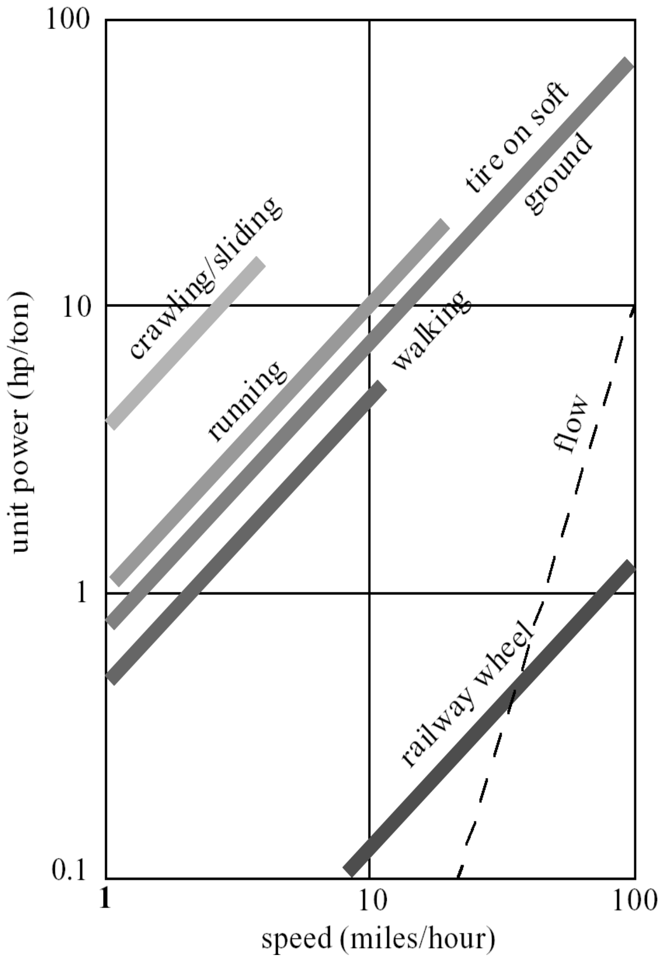
Biped Walking and Pure Rolling

- Biped walking mechanism approximates pure rolling via polygonal motion
- The smaller the step size, the more the polygon tends to a disk (wheel)
- Work against gravity is required
- Allows to overcome larger ob- stacles (compared to rolling)



Selection of Locomotion Concept

- Selection depends on
  - terrain properties
  - robot weight and complexity
  - desired operating speed
  - maximal energy expenditure
  - required energy efficiency
  - etc.



Degree of Freedom (DOF)

- The number of independent ways by which a dynamic system can move, without violating any constraint imposed on it, is called number of degrees of freedom.
- In other words, the number of degrees of freedom can be defined as the minimum number of independent coordinates that can specify the phase space, i.e., positions and momentum in classical mechanics, of the system completely.

Source: Wikipedia

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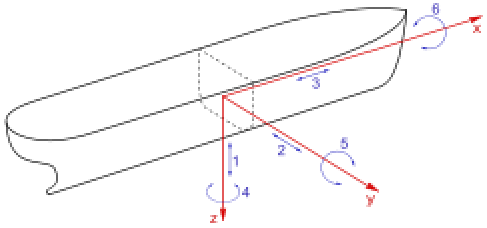
Source: Wikipedia

Dimensionality

- The Degree of Freedom (DOF) of a workspace is its overall dimensionality
  - On (flat) ground, DOF = 3
  - In the air or below water, DOF = 6

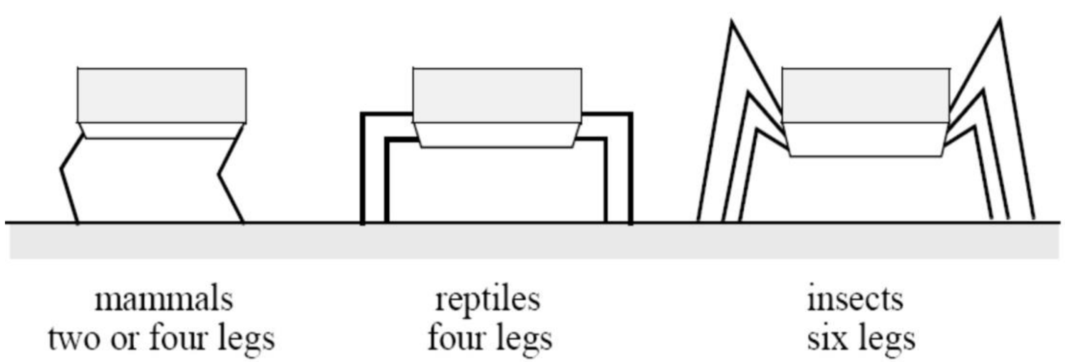


- For a robotic system
  - DOF is its ability to achieve various poses

Number of Legs vs. Control Complexity

- The number of legs influences
  - Mechanical complexity
  - Control complexity

- Insects can walk directly upon birth
- Most mammals require several minutes to stand
- Humans require more than a year to walk on two legs



Number of Distinct Gait Sequences

- The gait is characterized as a distinct sequence of **lift and release events** of the individual legs
- The number of possible events N for a walking machine with k legs is

$$N = (2k-1)!$$

- For a biped walker, the number of possible events becomes

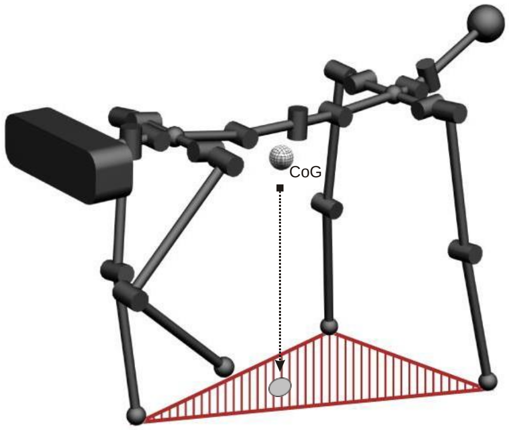
$$N = (2k-1)! = 3! = 6$$

- For a robot with 6 legs (hexapod)

$$N = 11! = 39'916'800$$

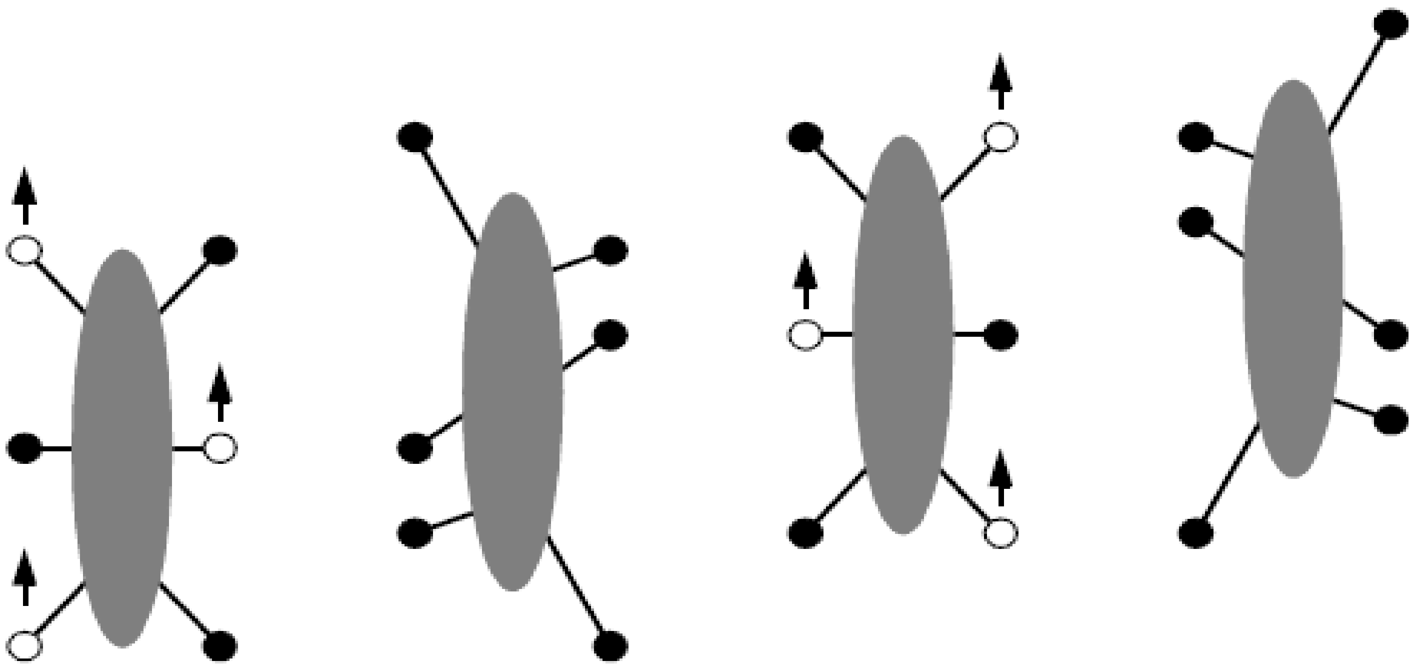
Static Locomotion

- Static Locomotion
- Characteristics
  - Body weight supported by at least three legs
  - CoG withing support triangle
  - Safe, slow and inefficient



Static Locomotion

Most widespread static sequence with 6 legs

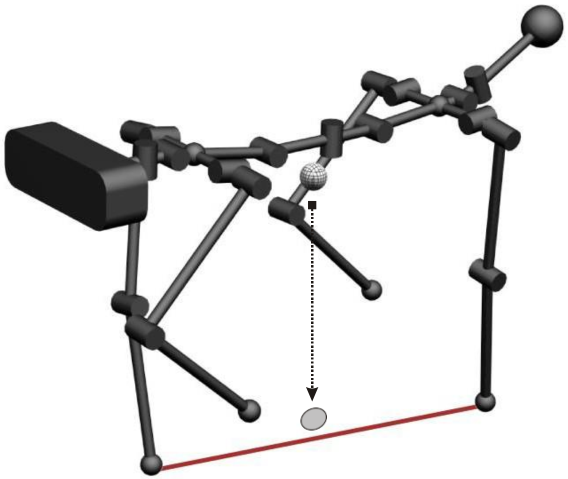


Dynamic Locomotion

- Dynamic Locomotion
- Characteristics
- The robot falls unless it moves

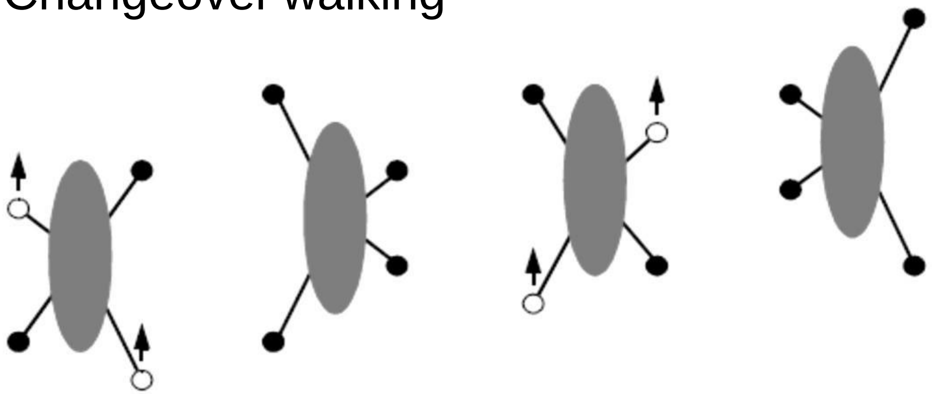
  <3 legs can be in ground contact

  Fast, efficient, but demanding for actuation and control

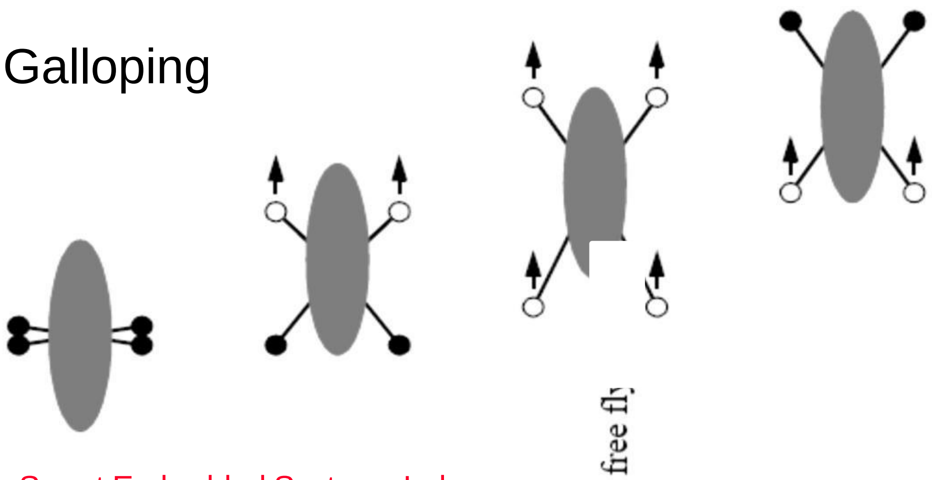


Dynamic Locomotion with 4 Legs

- Changeover walking



- Galloping



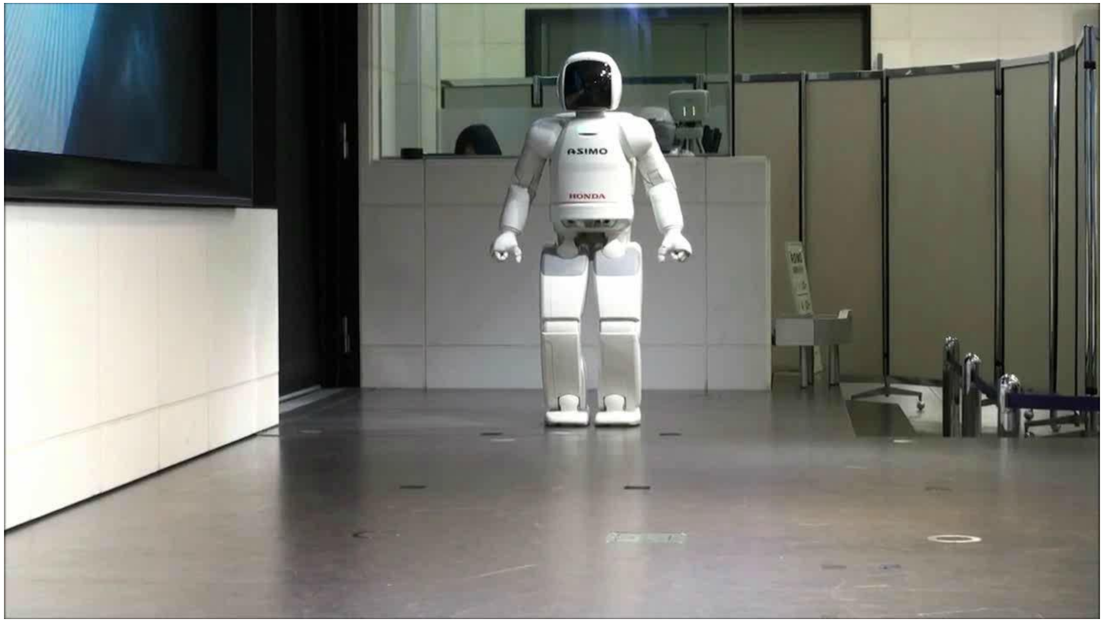
Dynamic Locomotion with 2 Legs

- In principle only dynamic walking feasible
- Large feet allow for static walking, however

- Two legs (biped) allow for four different states
  1. Both legs down ●/●
  2. Right leg down, left leg up ○/●
  3. Right leg up, left leg down ●/○
  4. Both leg up ○/○

Sequence	States	Description	Sequence	States	Description
1 → 2 → 1	●/● ○/● ●/●	*turning on right leg, or limping*	2 → 3 → 2	○/● ●/○ ○/●	*walking, running*
1 → 3 → 1	●/● ●/○ ●/●	*turning on left leg, or limping*	2 → 4 → 2	○/● ○/○ ○/●	*hopping on right leg*
1 → 4 → 1	●/● ○/○ ●/●	*hopping with two legs*	3 → 4 → 3	●/○ ○/○ ●/○	*hopping on left leg*

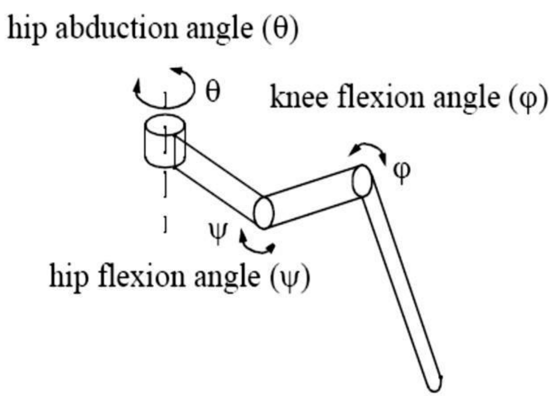
(Dynamic) Locomotion on ASIMO



Courtesy K. Moriyama

From Legs to Links and Joints

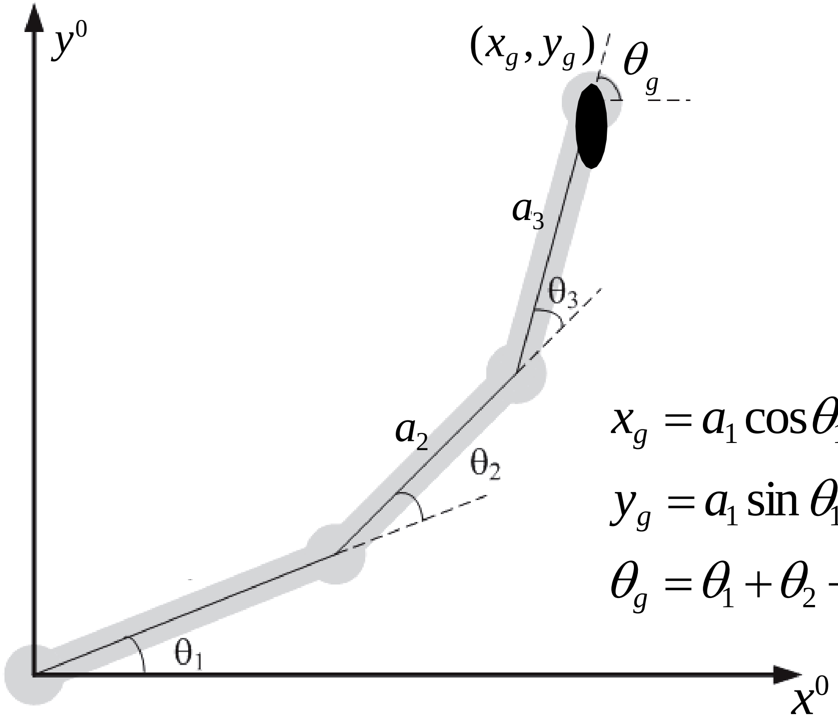
- A minimum of two DOF required to move leg
  - a **lift** and a **swing** motion.
  - Sliding-free motion in more than one direction not possible
- Three DOF for each leg required in most cases



- Additional joints (and thus DOF) increase the complexity of the design and especially of the locomotion control

Forward Kinematics

- Forward Kinematics
  - Given is a set of joint angles
  - Determine resulting end-effector position

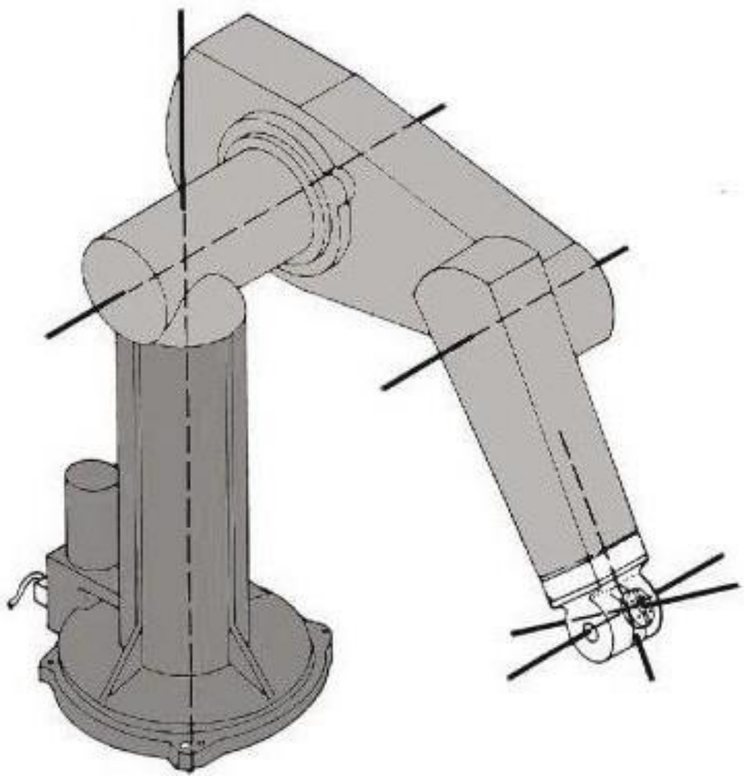


$$x_g = a_1 \cos\theta_1 + a_2 \cos(\theta_1 + \theta_2) + a_3 \cos(\theta_1 + \theta_2 + \theta_3)$$

$$y_g = a_1 \sin\theta_1 + a_2 \sin(\theta_1 + \theta_2) + a_3 \sin(\theta_1 + \theta_2 + \theta_3)$$

$$\theta_g = \theta_1 + \theta_2 + \theta_3$$

Forward Kinematics
DH Coordinate Frames on a PUMA Arm



Inverse Kinematics

- Inverse Kinematics
  - Given is a desired end-effector position
  - Determine corresponding joint angles

- Problem is non-trivial and generally not well-posed

No Solution | One Solution | >1 Solution

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