

COMP417- Introduction to  
Robotics  
Locomotion

# Vehicle Locomotion

- Objective: convert desire to move  $A \rightarrow B$  into an actual motion:
  - How to arrange actuators (mechanical design)

# Vehicle Locomotion

- *Forward Kinematics:*
  - (actuators actions)  $\rightarrow$  pose
- *Inverse Kinematics (inverse-K):*
  - pose  $\rightarrow$  (actuators actions)

$$\text{pose} = \{x, y, \theta\}$$

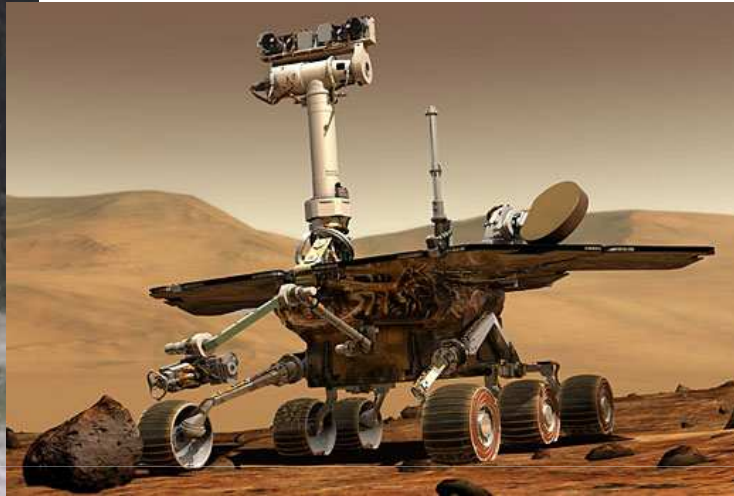
# Design Tradeoffs with Mobility Configurations

1. Maneuverability
2. Controllability
3. Traction
4. Climbing ability
5. Stability
6. Efficiency
7. Maintenance
8. Navigational considerations

# Navigational considerations

- Some mechanisms are more accurate and reliable.
- Some are mathematically more easily predicted and controlled.

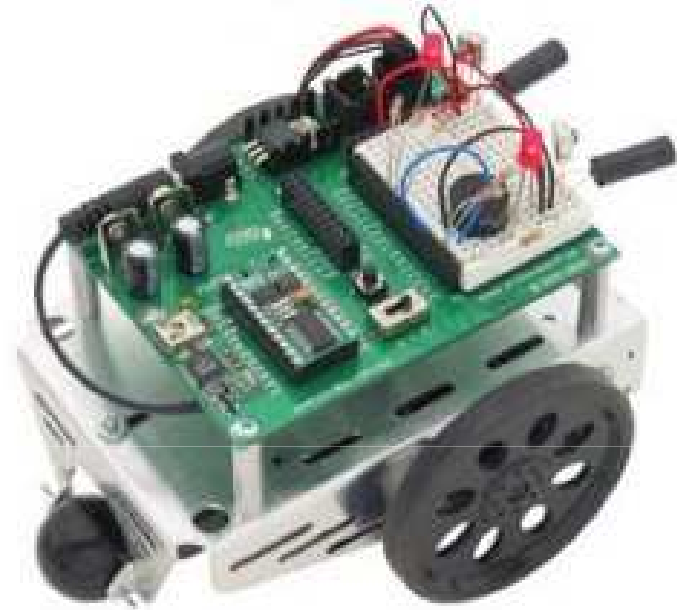
# Wheeled Vehicles



# Differential drive

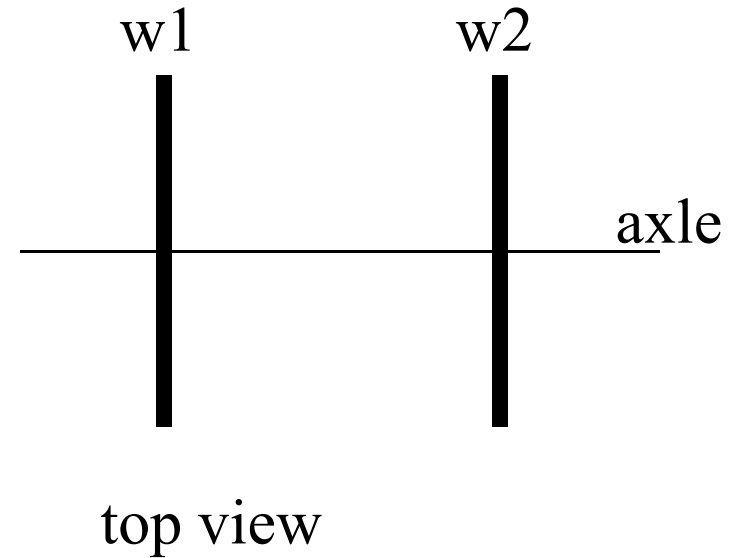
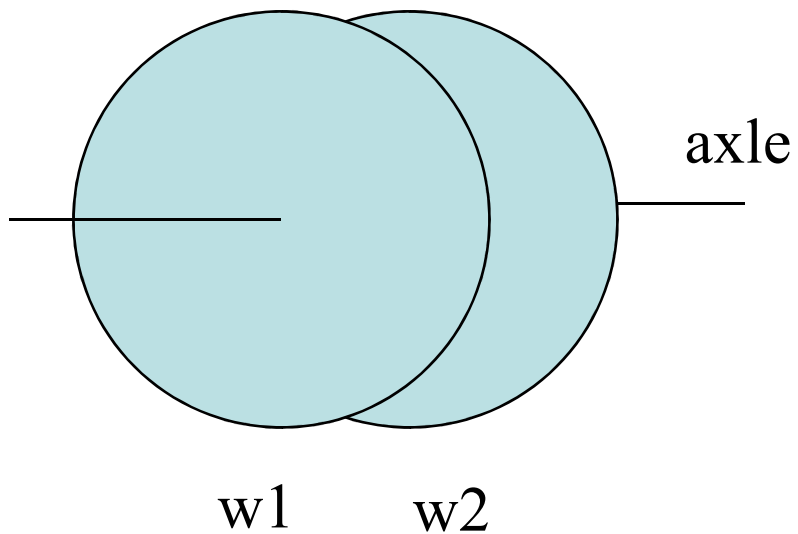
## Basic design:

- 2 motorized wheels
  - 2 DOF
- infinitely thin
- same diameter
- mounted along a common axis
- vehicle body is irrelevant (in theory).



# Idealized differential drive

side view



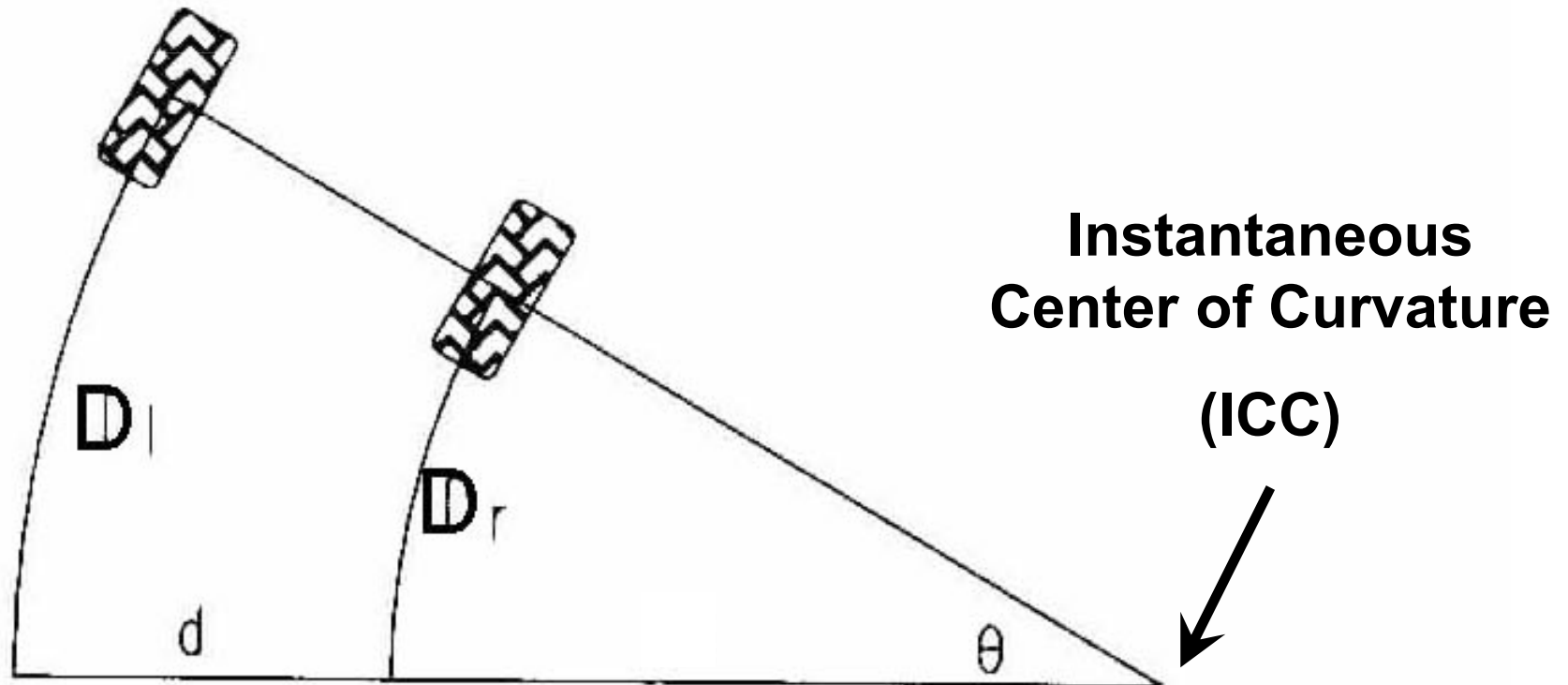


# Differential Drive Intuition

- Drive straight ahead?
- Turn in place?

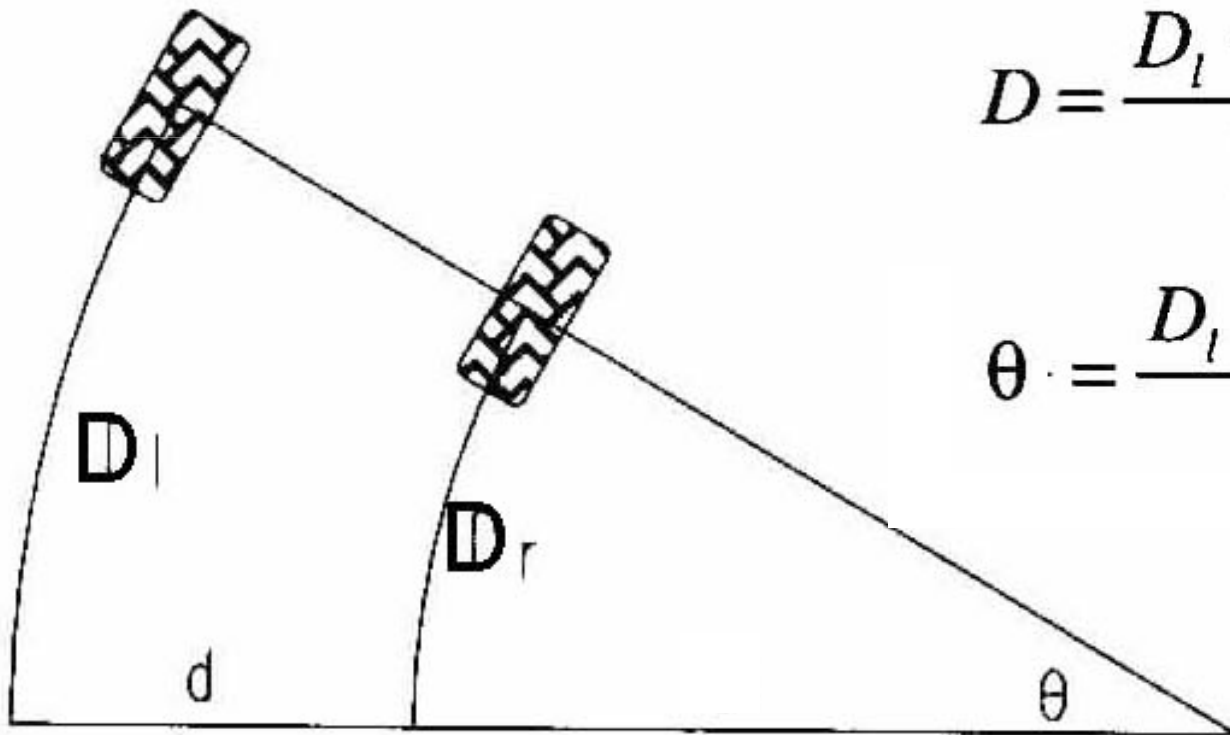
# Differential Drive Observation

- Vehicle rotation can be described relative to an axis running through the two wheels.



# Forward Kinematics of Differential Drive

- Wheel rotation by angle  $\phi_1, \phi_2$
- Distance of wheel motion  $D_i = \phi_i r$



$$D = \frac{D_l + D_r}{2}$$

$$\theta = \frac{D_l - D_r}{d}$$

# Forward Kinematics: Path Integration

- To get the path followed, you have to integrate over *time*.

$$x(t) = \frac{1}{2} \int_0^t [\dot{D}_r(t) + \dot{D}_l(t)] \cos[\theta(t)] dt$$

$$y(t) = \frac{1}{2} \int_0^t [\dot{D}_r(t) + \dot{D}_l(t)] \sin[\theta(t)] dt$$

$$\theta(t) = \frac{1}{d} \int_0^t [\dot{D}_r(t) - \dot{D}_l(t)] dt$$

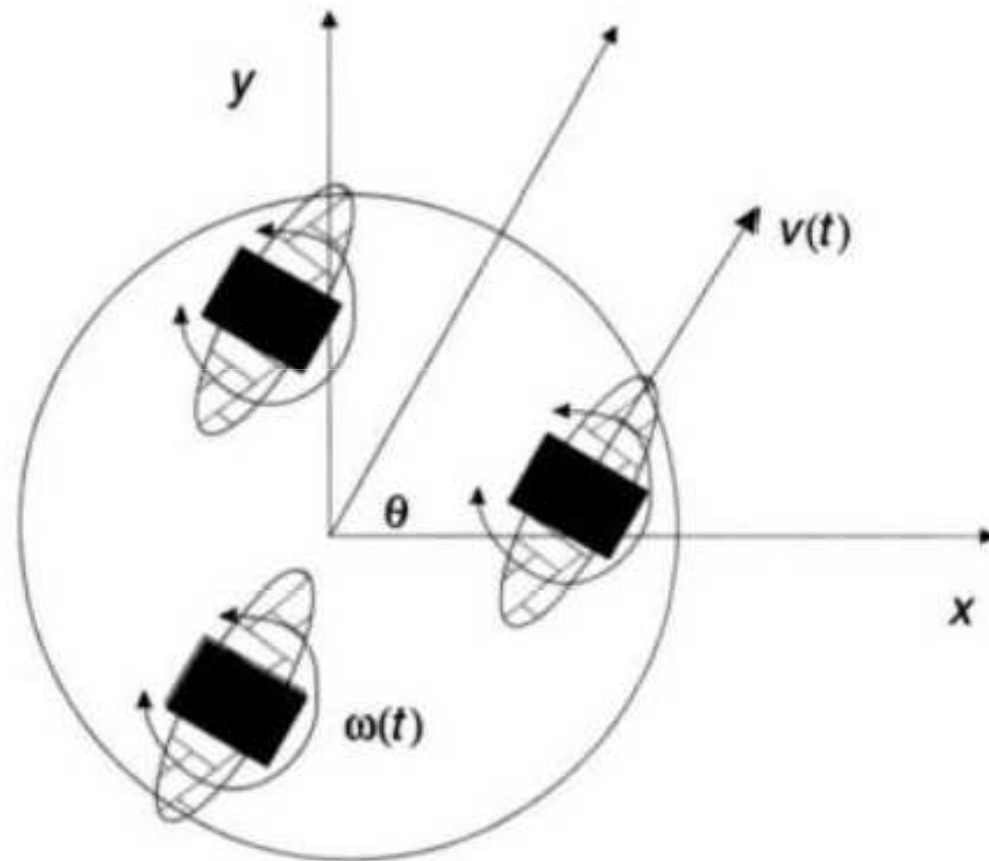
# Non-Holonomic Constraints

- Cannot change robot pose arbitrarily
- For differential drive:
  - Robot cannot move sideways
- Complicates planning:
  - Parallel parking...

# Differential Drive Issues

- Matching of drive mechanisms
  - Tire wear ( $r$  is wrong)
  - Motors ( $\phi$  is wrong)
  - Ground traction (rotation  $\phi r$  is not motion of  $\phi r$ )
- Balance
  - Castor (caster) wheel

# Synchronous Drive



# Forward Kinematic - Synchronous Drive

- Simpler:

$$x(t) = \frac{1}{2} \int_0^t v(t) \cos[\theta(t)] dt$$

$$y(t) = \frac{1}{2} \int_0^t v(t) \sin[\theta(t)] dt$$

$$\theta(t) = \int_0^t \omega(t) dt$$

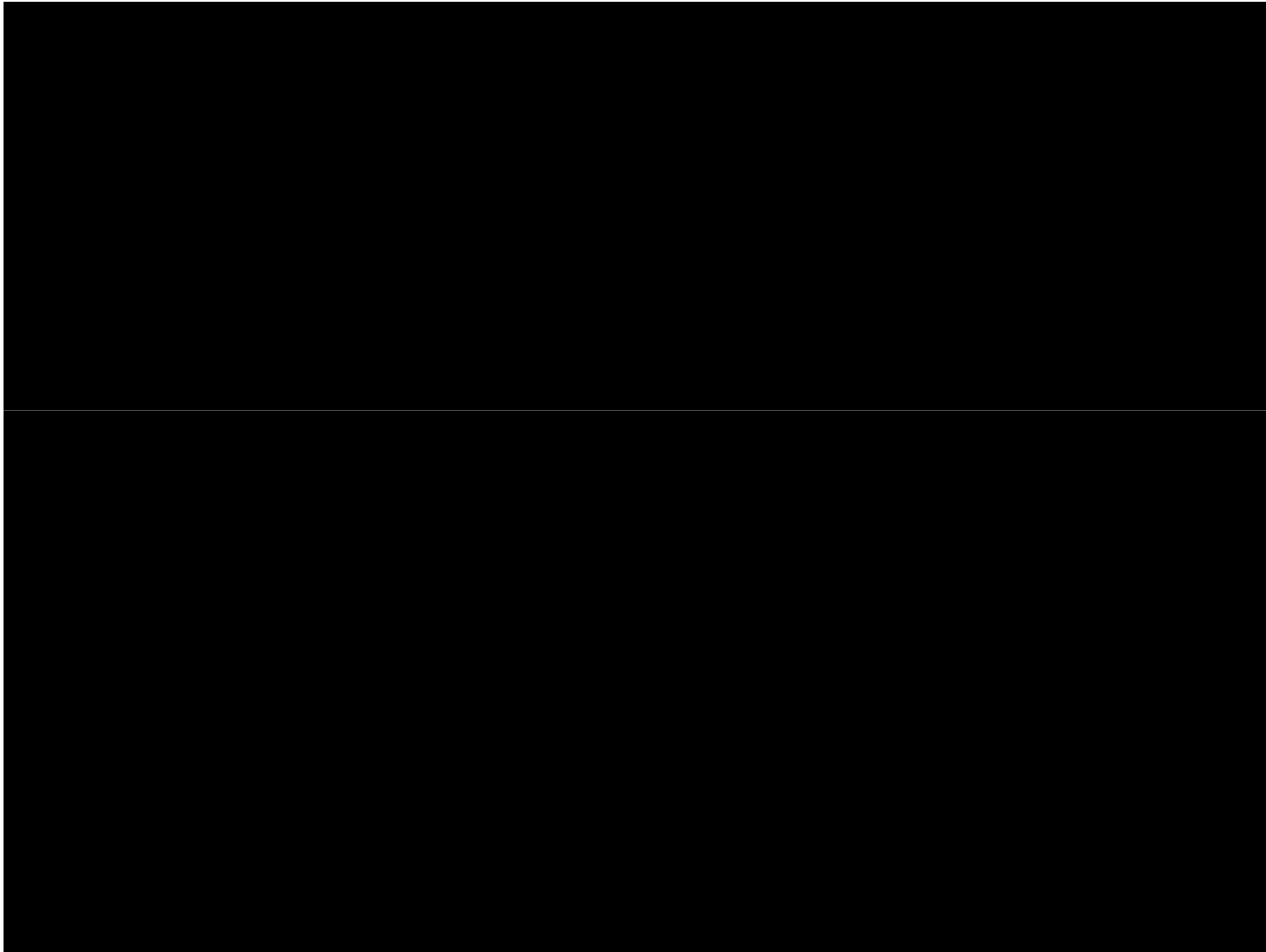
- Will not suffer from mechanical mismatch compared to Diff. Drive....
- .... But orientation of robot body stays same.



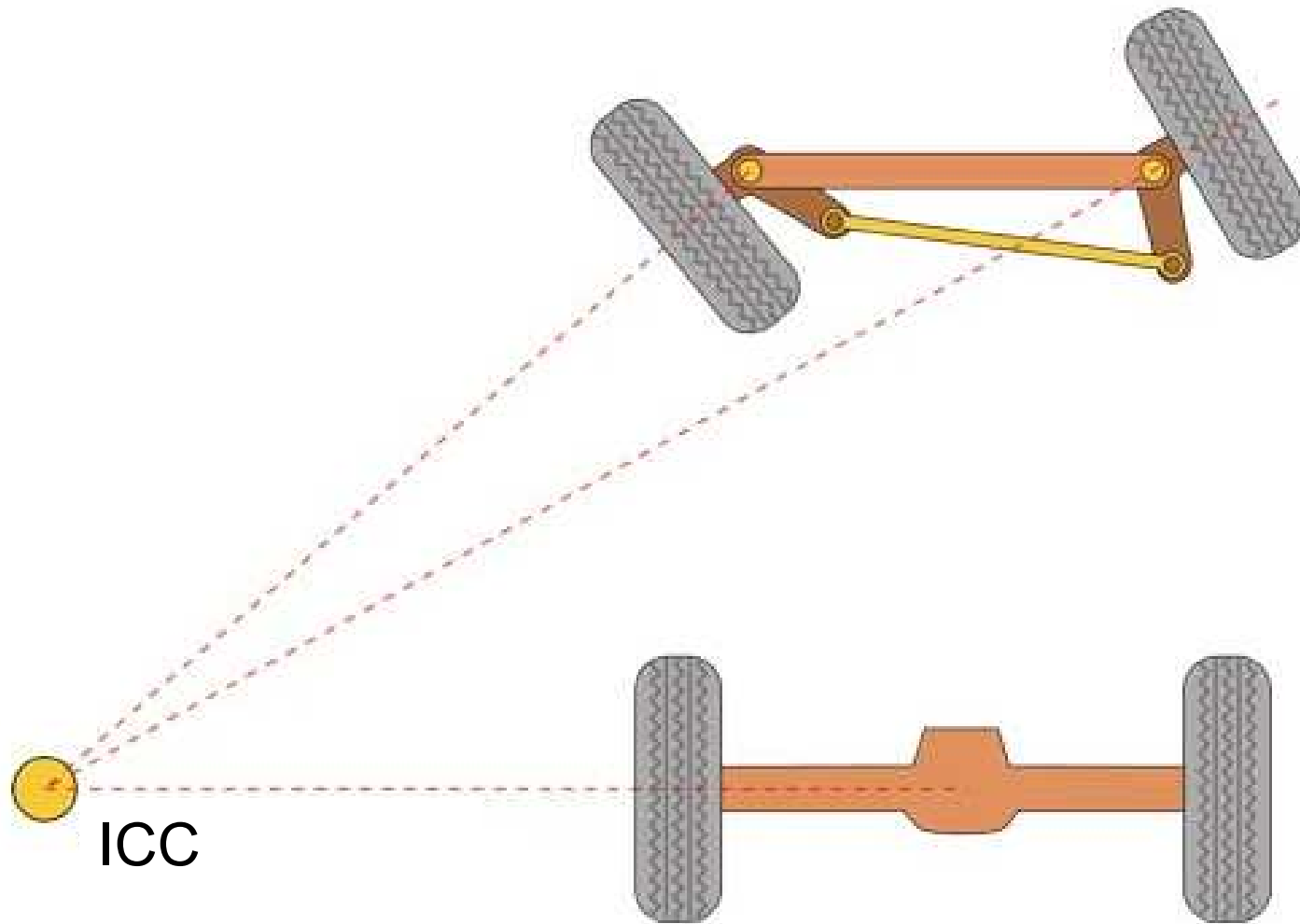
# Mecanum Wheels



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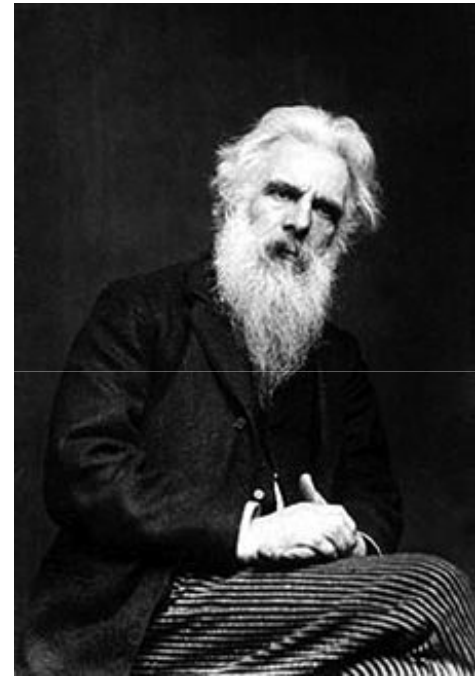


# Ackerman (Used in Cars)



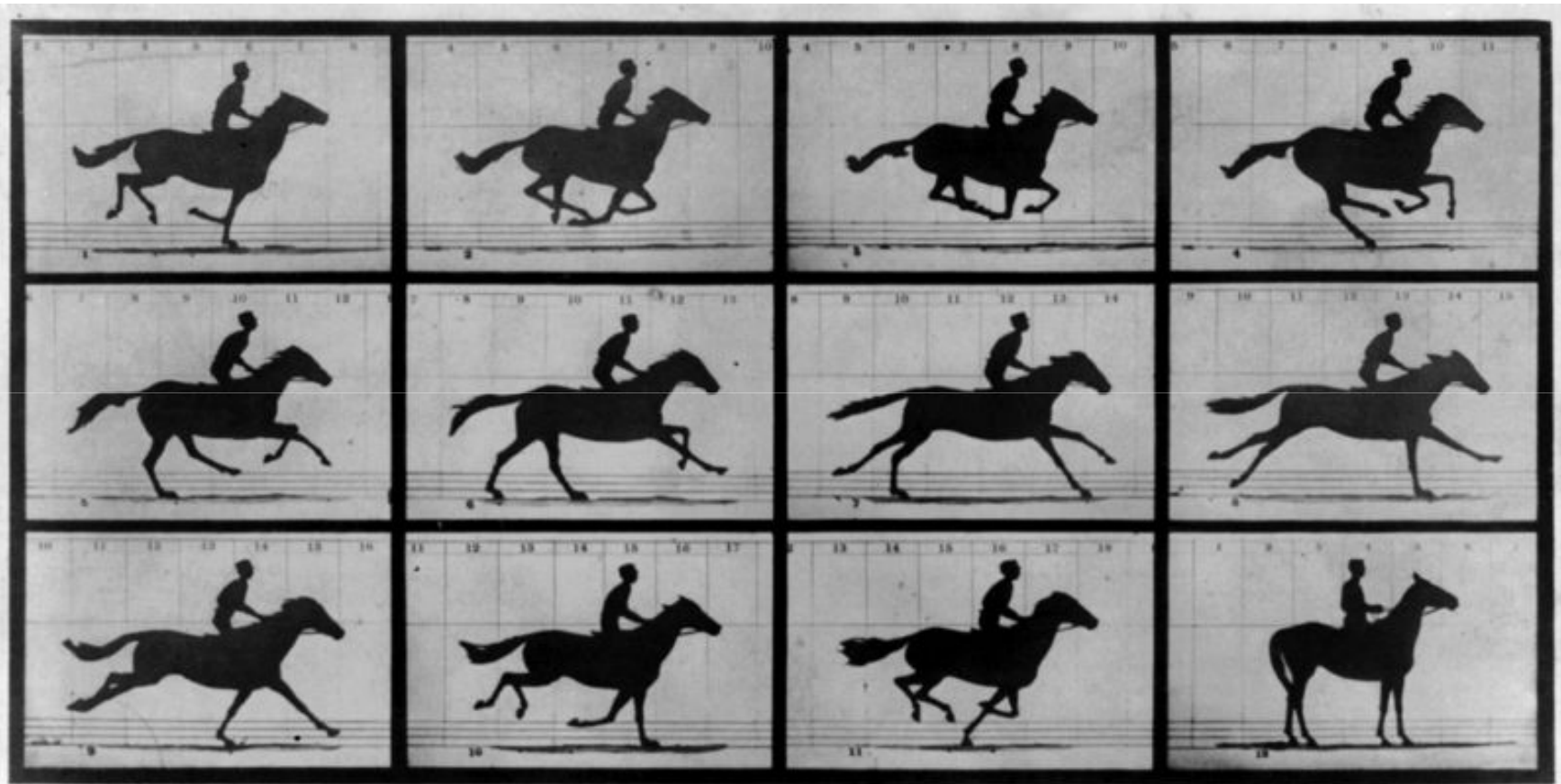
# Legged Locomotion

- Started to resolve a bet between Governor of California *Leland Stanford* and a friend, in 1872.
- Muybridge took the challenge



Eadweard Muybridge  
(*April 9, 1830 – May 8, 1904*)

# Legged Locomotion



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MORSE'S Gallery, 417 Montgomery St., San Francisco.

## THE HORSE IN MOTION.

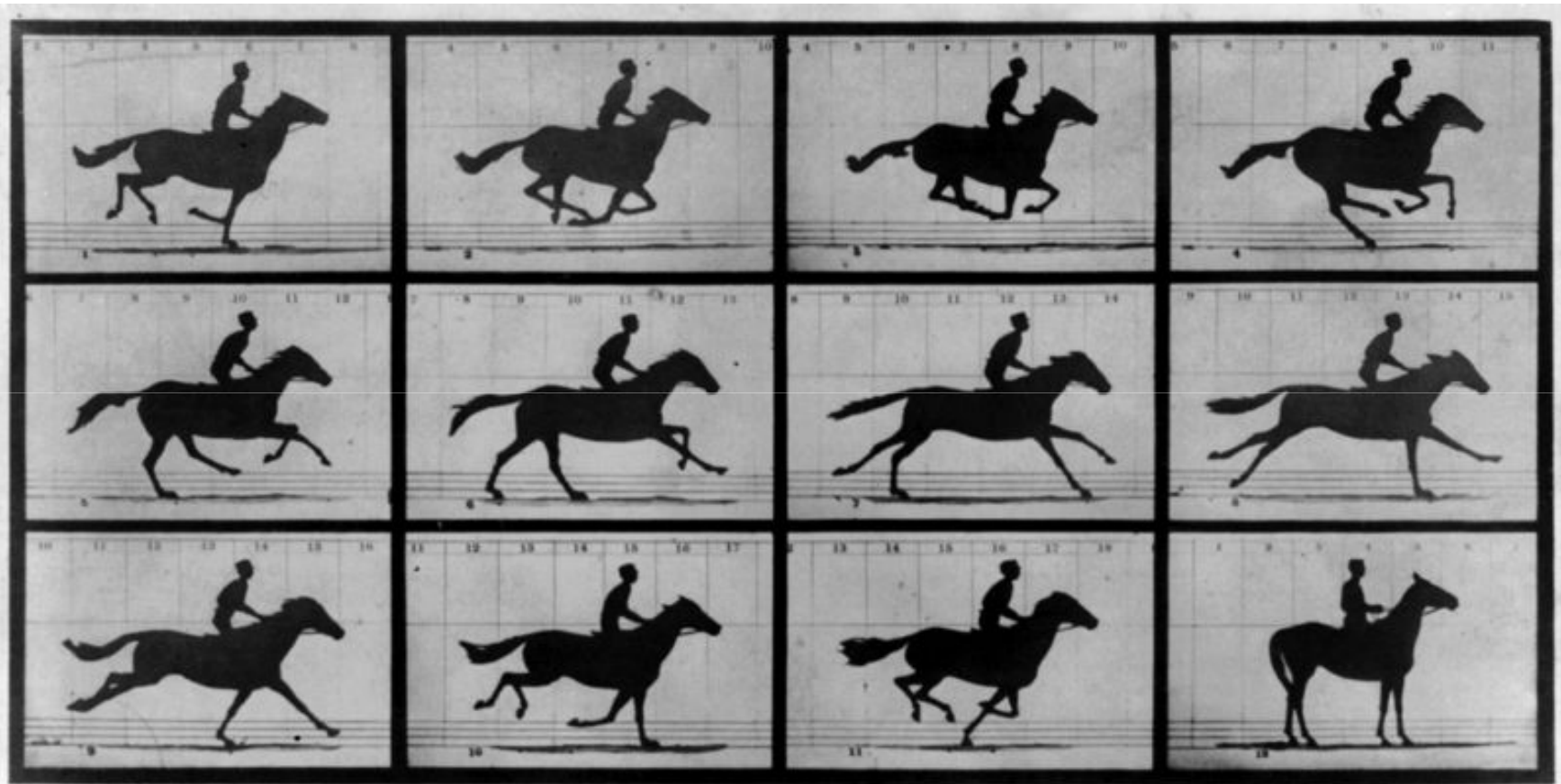
Illustrated by  
MUYBRIDGE.

AUTOMATIC ELECTRO-PHOTOGRAPH.

"SALLIE GARDNER," owned by LELAND STANFORD; running at a 1.40 gait over the Palo Alto track, 19th June, 1878.

The negatives of these photographs were made at intervals of twenty-seven inches of distance, and about the twenty-fifth part of a second of time; they illustrate consecutive positions assumed in each twenty-seven inches of progress during a single stride of the mare. The vertical lines were twenty-seven inches apart; the horizontal lines represent elevations of four inches each. The exposure of each negative was less than the two-thousandth part of a second.

# Legged Locomotion



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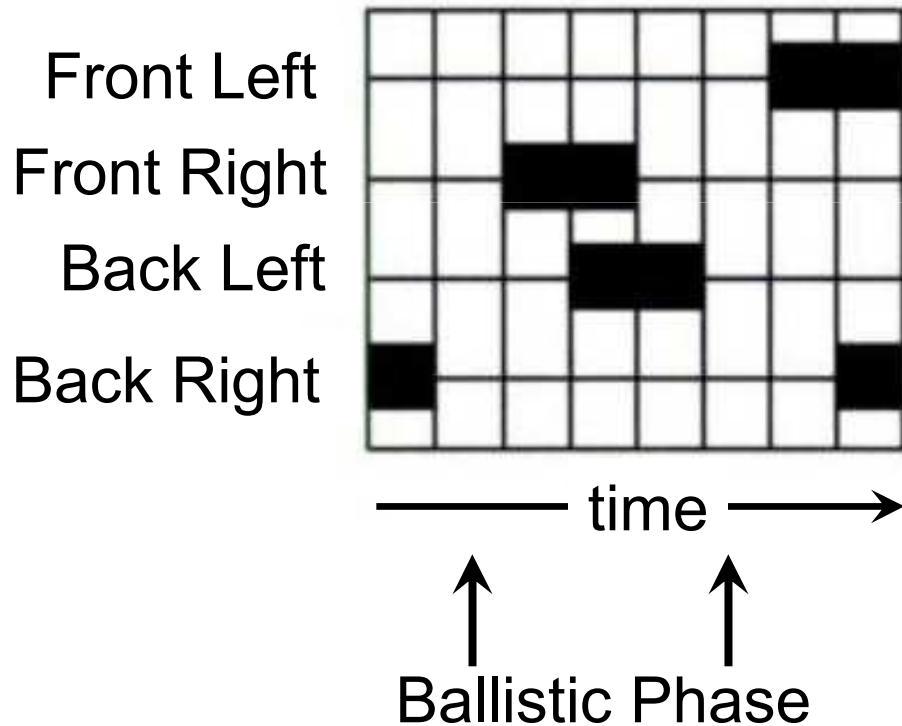
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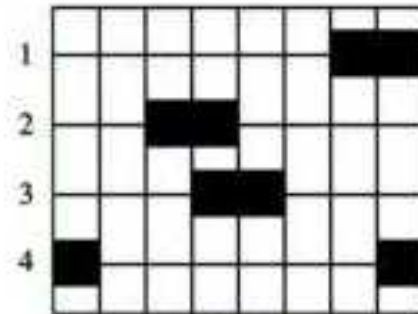
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# Hildebrand Gait Diagrams

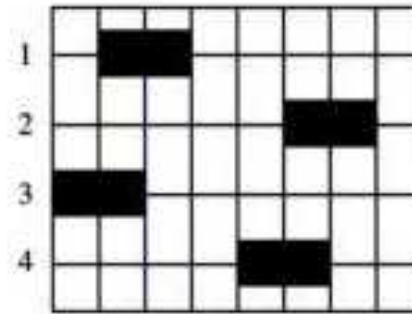
Trot



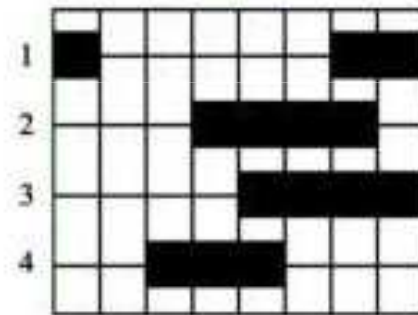
# Hildebrand Gait Diagrams



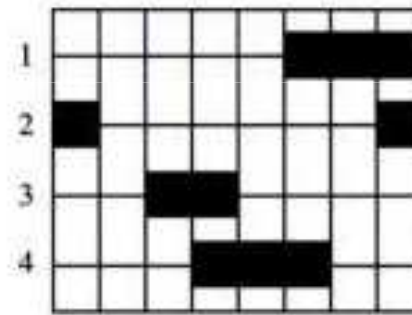
Trot



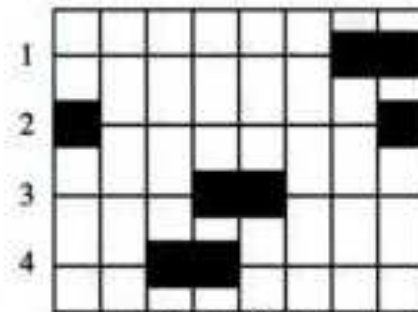
Rack



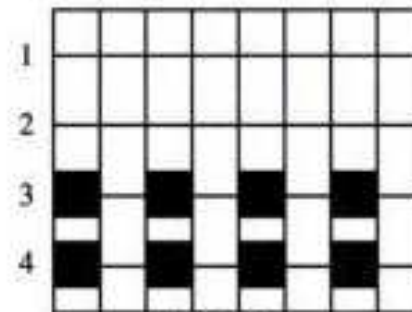
Canter



Transverse Gallop



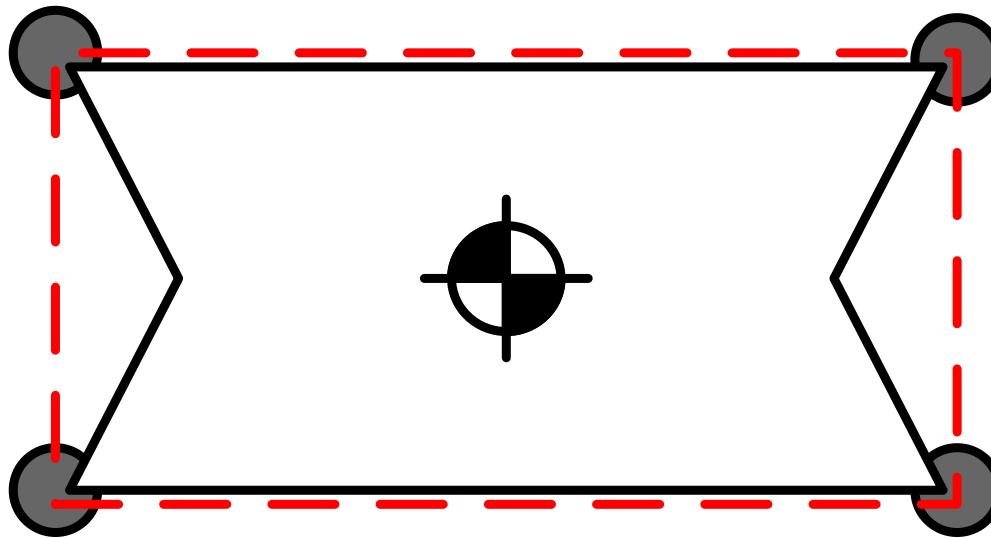
Rotary Gallop



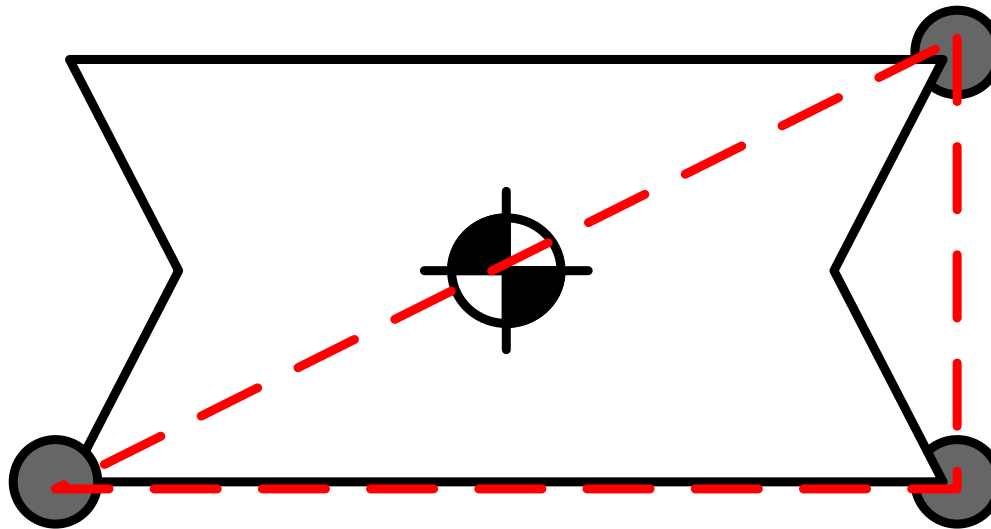
Ricochet



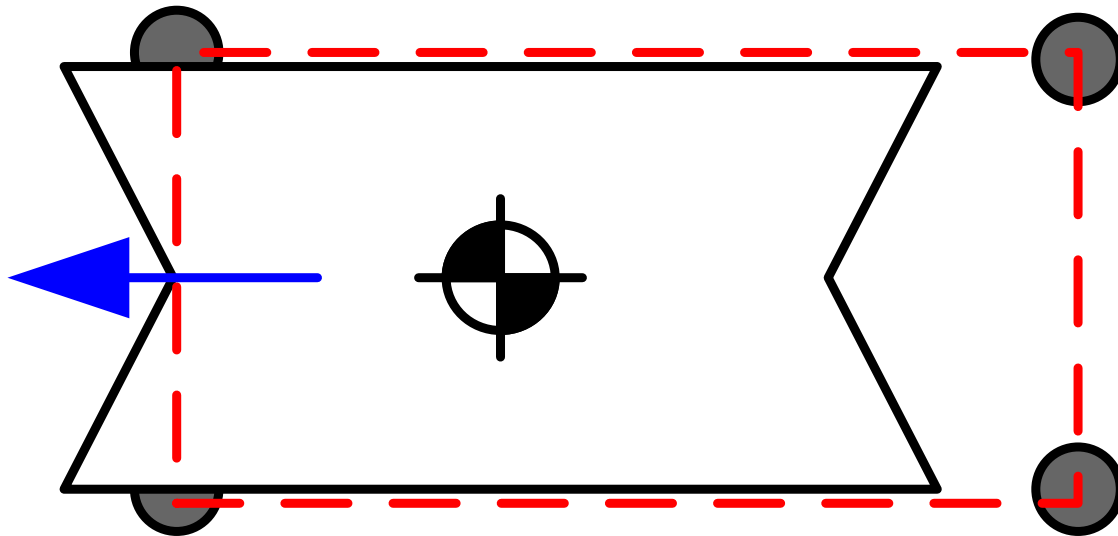
# Support Polygon



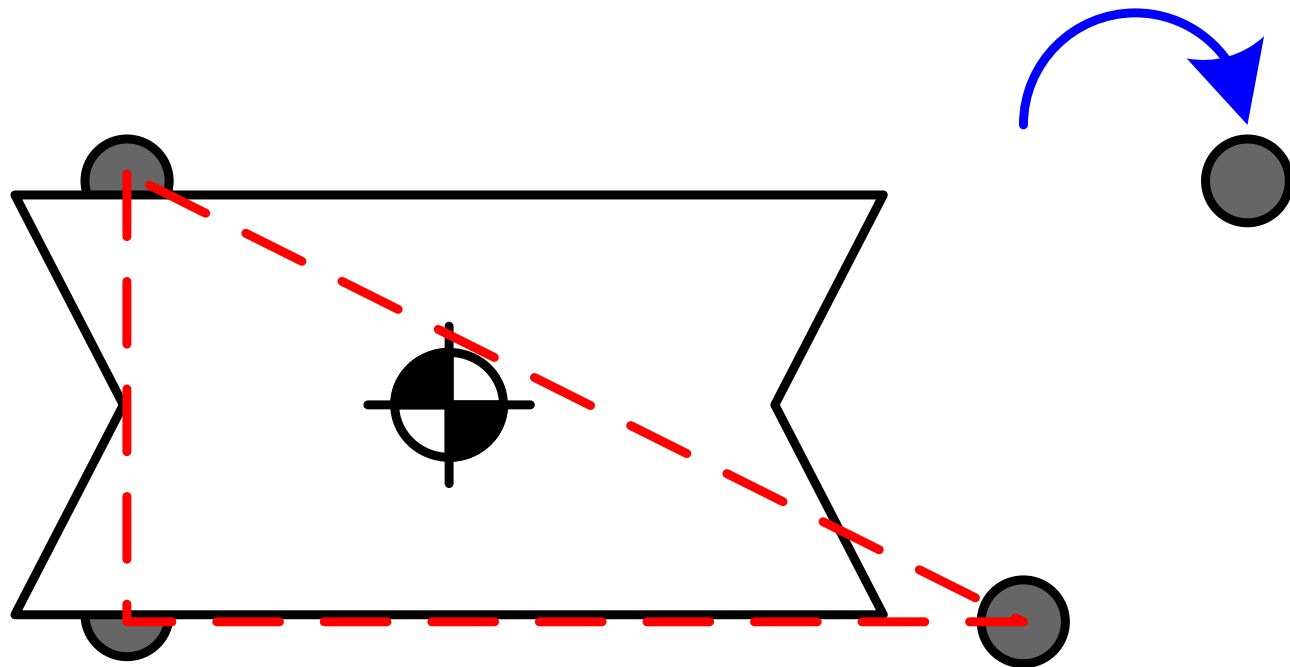
# Support Polygon



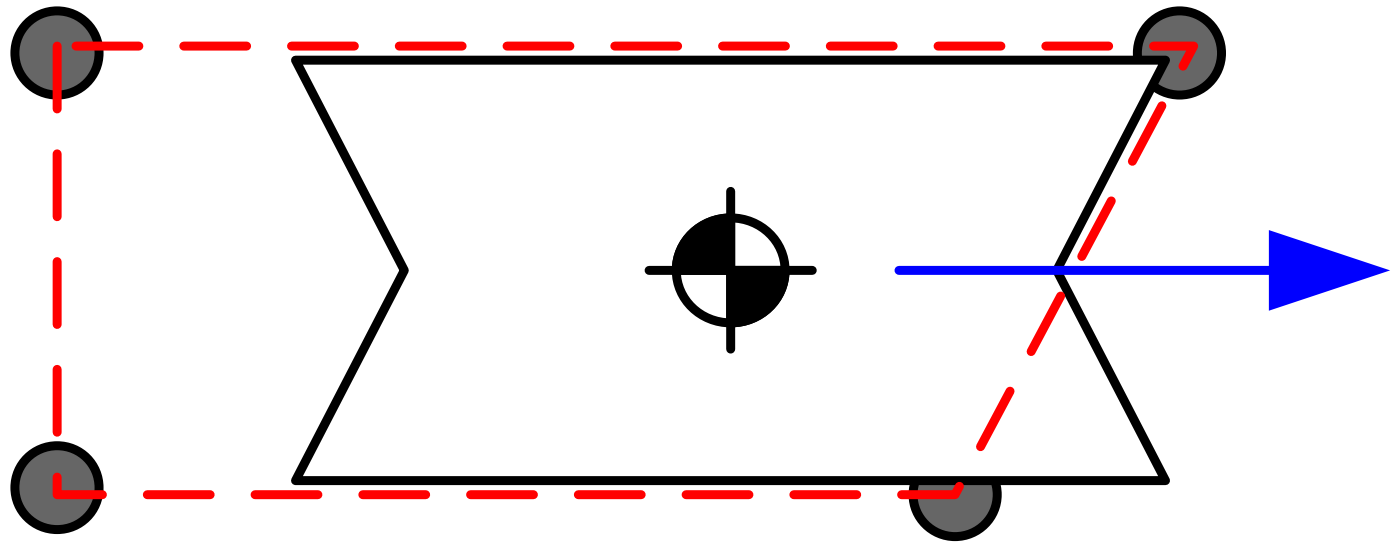
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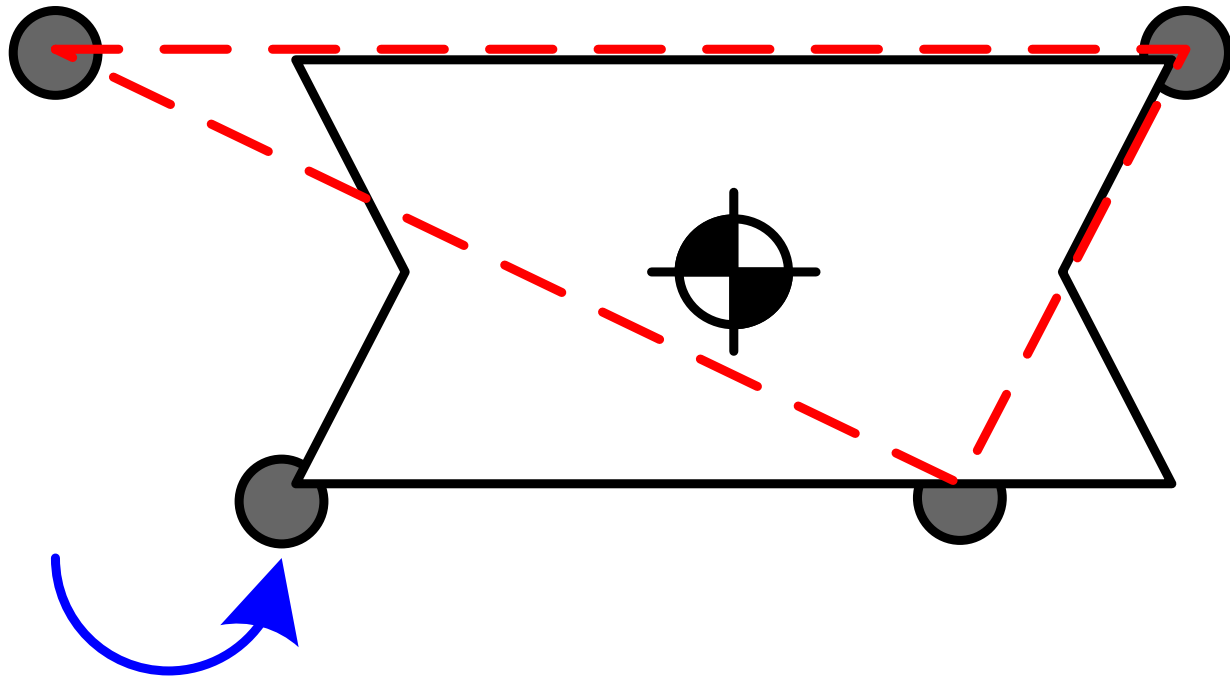
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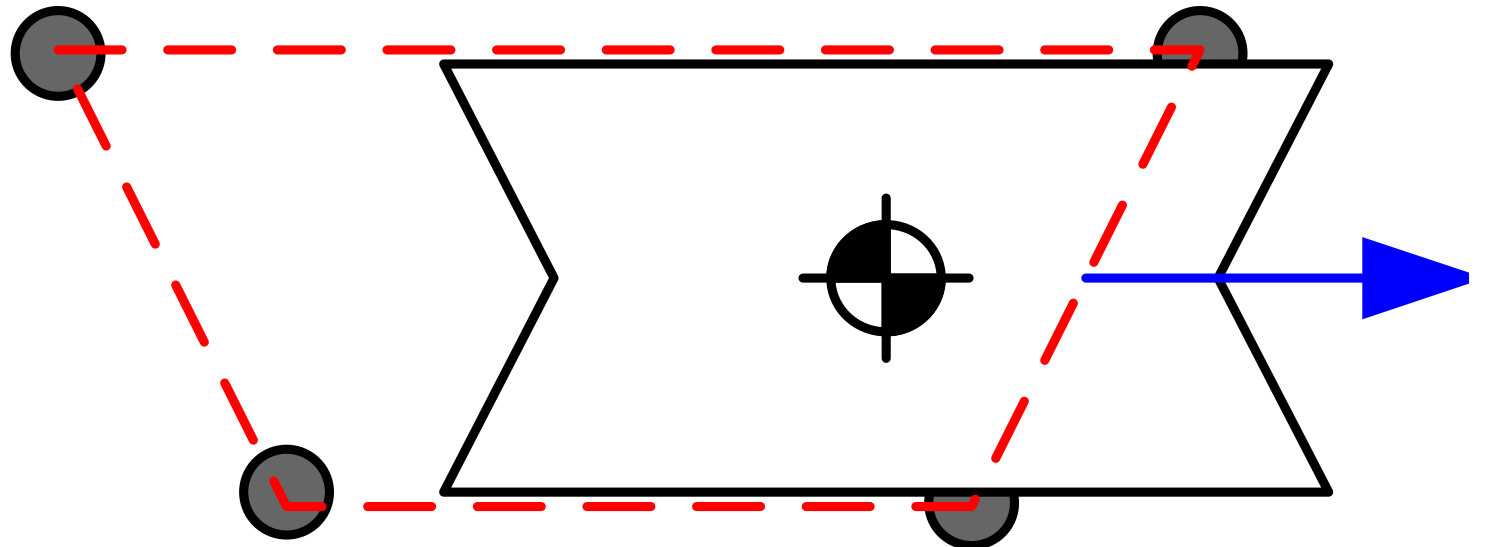
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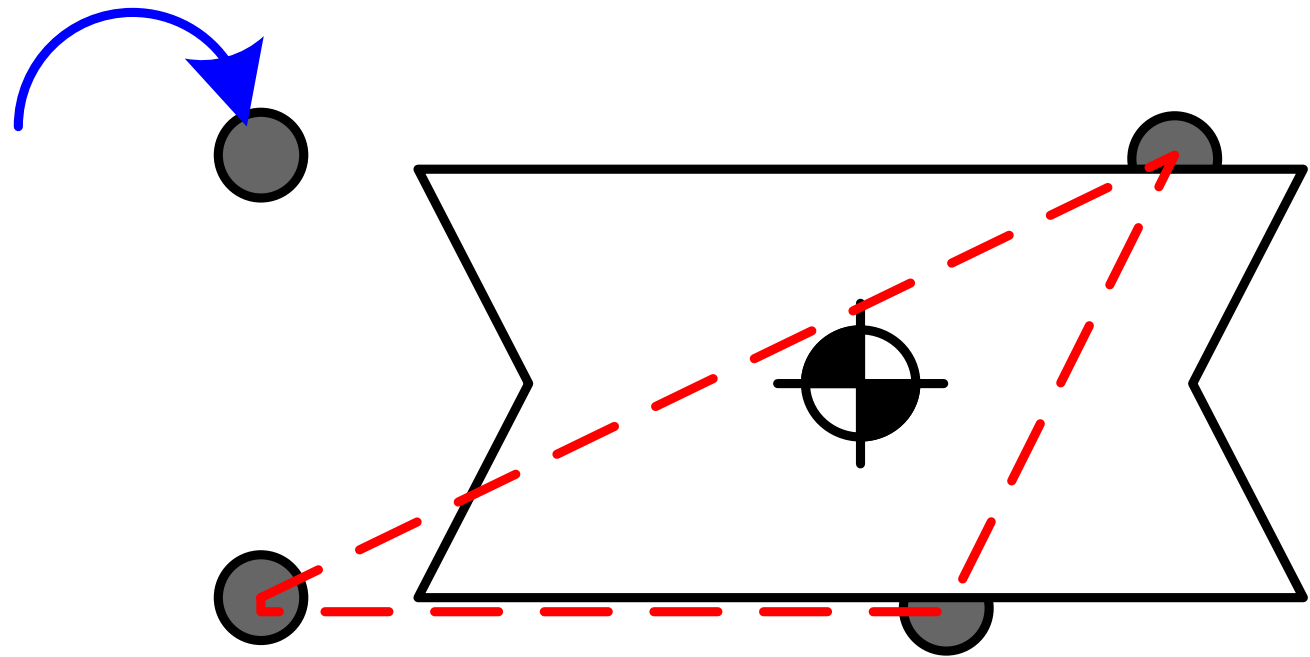
# Support Polygon



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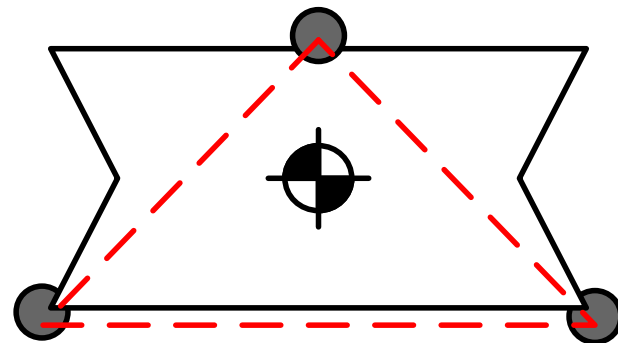
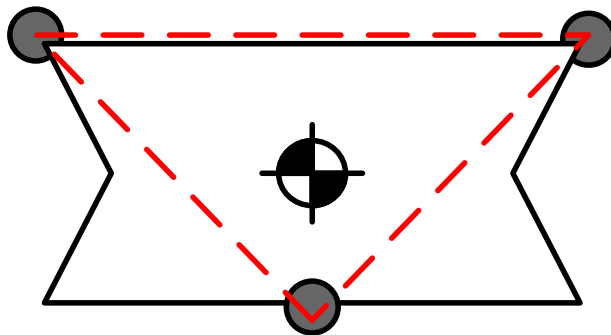
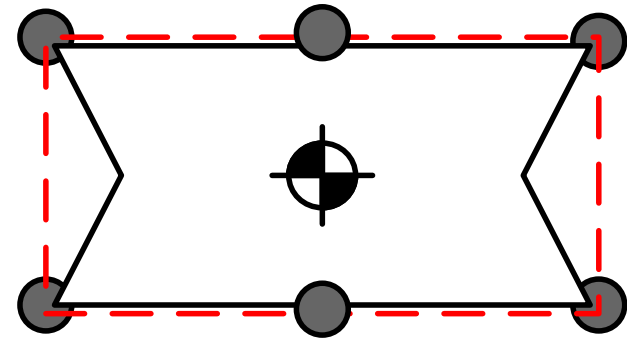
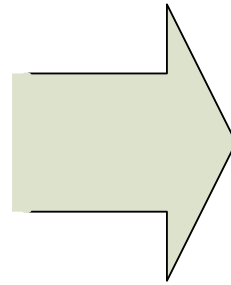
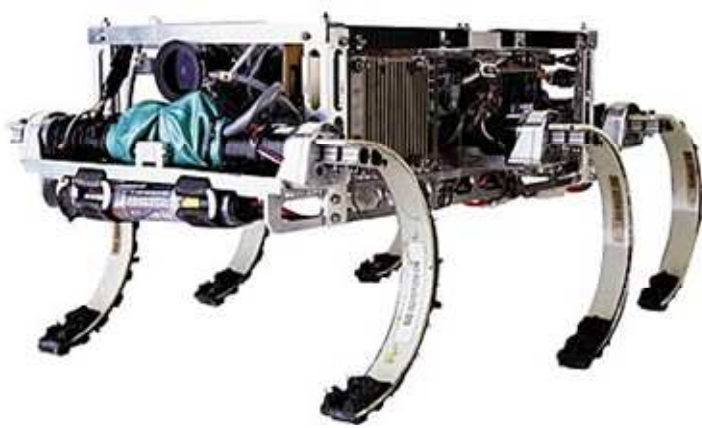
# Support Polygon



And so on...



# Hexapod RHex



# RHex: Tripod Gait

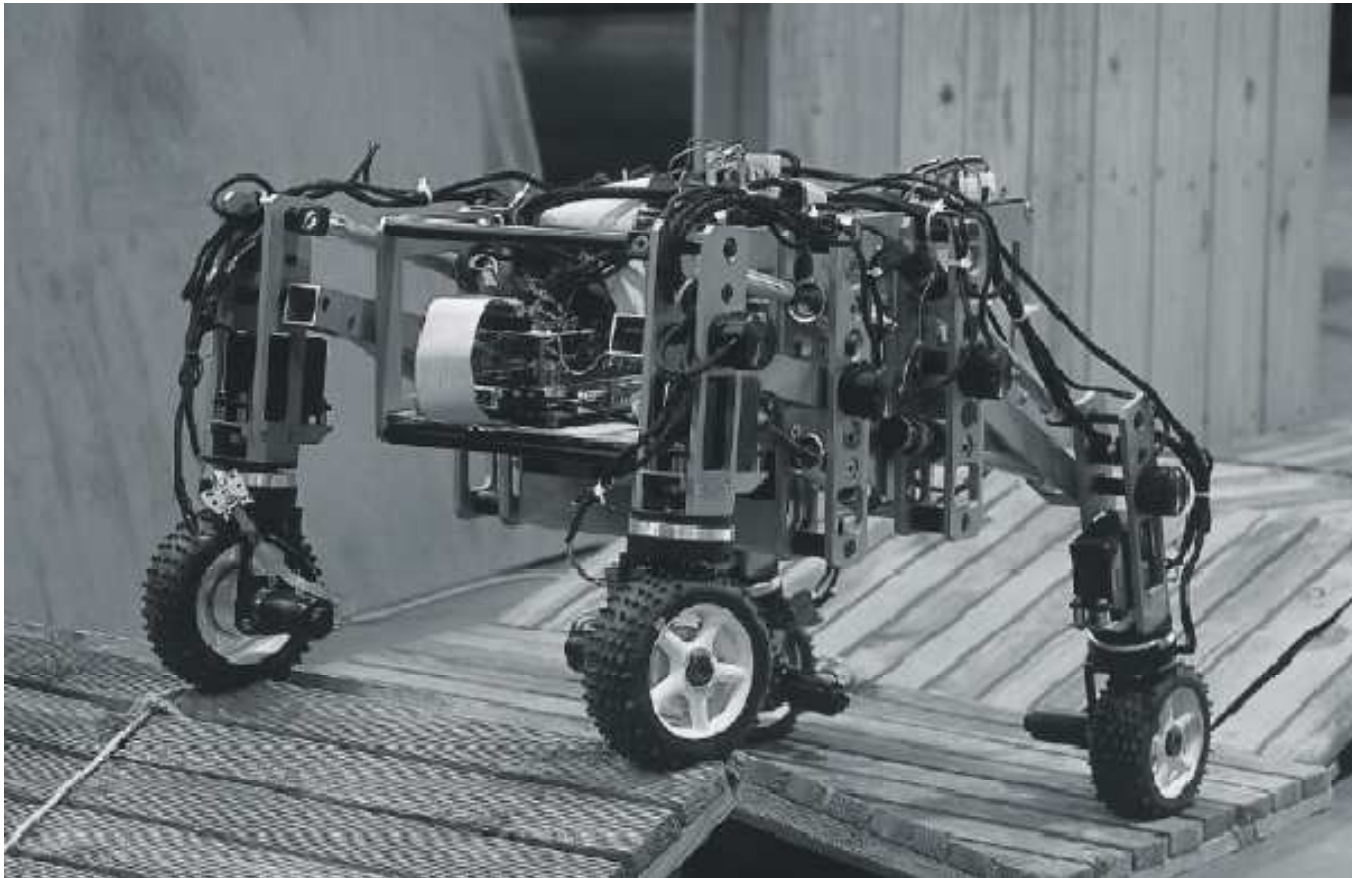


*RHex*

# Bi-Pedal: Zero Moment Point



# Crossovers: HyLoS



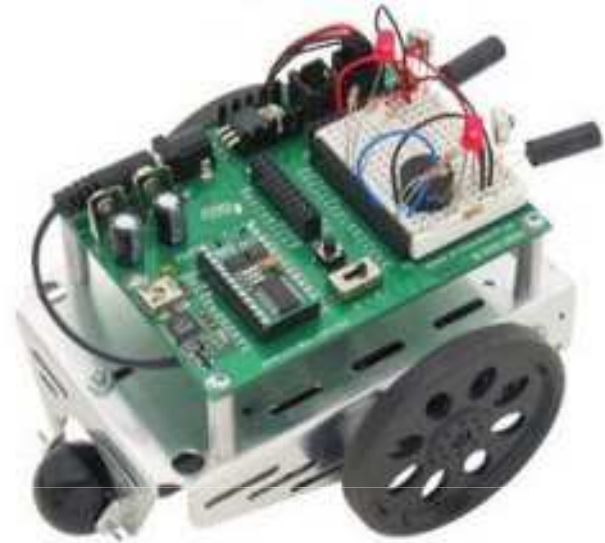
F. BenAmar, V. Budanov, P. Bidaud, F. Plumet, and G. Andrade. A high mobility redundantly actuated mini-rover for self adaptation to terrain characteristics. In 3rd Int. Conference on Climbing and Walking Robots (CLAWAR'00), pages 105–112, 2000.

# Dynamically Stable Gaits

- Robot is not always statically stable
- Must consider energy in limbs and body
- Much more complex to analyze
- E.G. Running:
  - Energy exchange:
    - Potential (ballistic)
    - Mechanical (compliance of springs/muscle)
    - Kinetic (impact)

# Differential Drive

- 2 wheels
- 2 points of contact
- 2 degrees of freedom



- Translation and rotation are *coupled*
  - “You can't have one without the other”.  
-F. Sinatra
  - Control is a "little bit" complicated.