UNIVERSITY OF SOUTH CAROLINA

CSCE 774 ROBOTIC SYSTEMS

Locomotion

Ioannis Rekleitis

Vehicle Locomotion

- Objective: convert desire to move A→B into an actual motion:
  - How to arrange actuators (mechanical design)
  - actuator output ←→ Incremental motion: *Forward kinematics* and *inverse kinematics*

Vehicle Locomotion

- *Forward Kinematics:*
  - (actuators actions) → pose

- *Inverse Kinematics (inverse-K):*
  - pose → (actuators actions)

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

Design Tradeoffs with Mobility Configurations

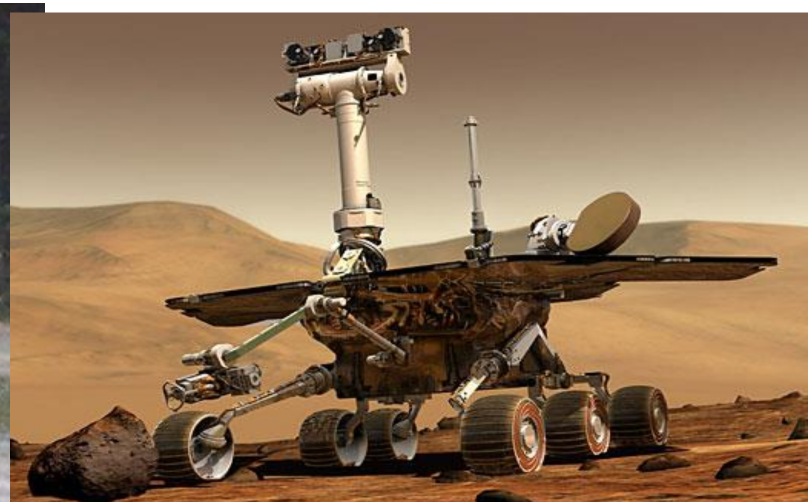
1. Maneuverability
2. Controllability
3. Traction
4. Climbing ability
5. Stability
6. Efficiency
7. Maintenance
8. Navigational considerations

Navigational considerations

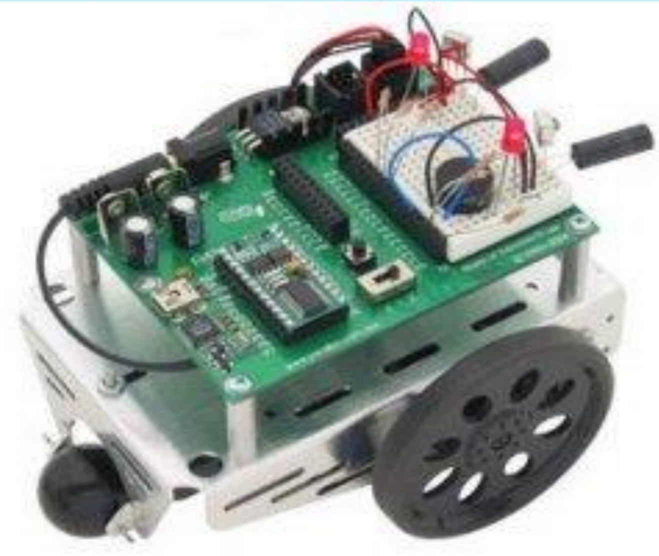
- Some mechanisms are more accurate and reliable.

- Some are mathematically more easily predicted and controlled.

Wheeled Vehicles



Differential Drive

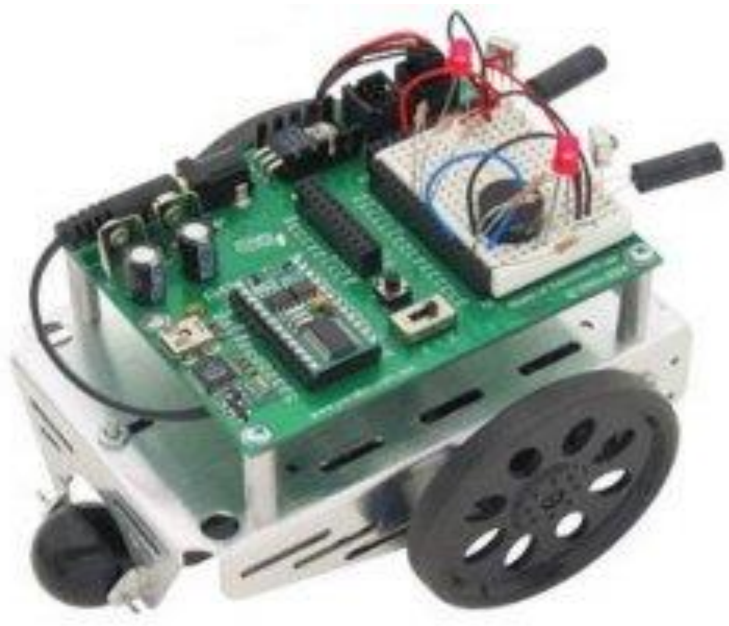


- 2 wheels
- 2 points of contact
- 2 degrees of freedom

- Translation and rotation are *coupled*
  - “You can't have one without the other”.

    -F. Sinatra
  - Control is a "little bit" complicated.

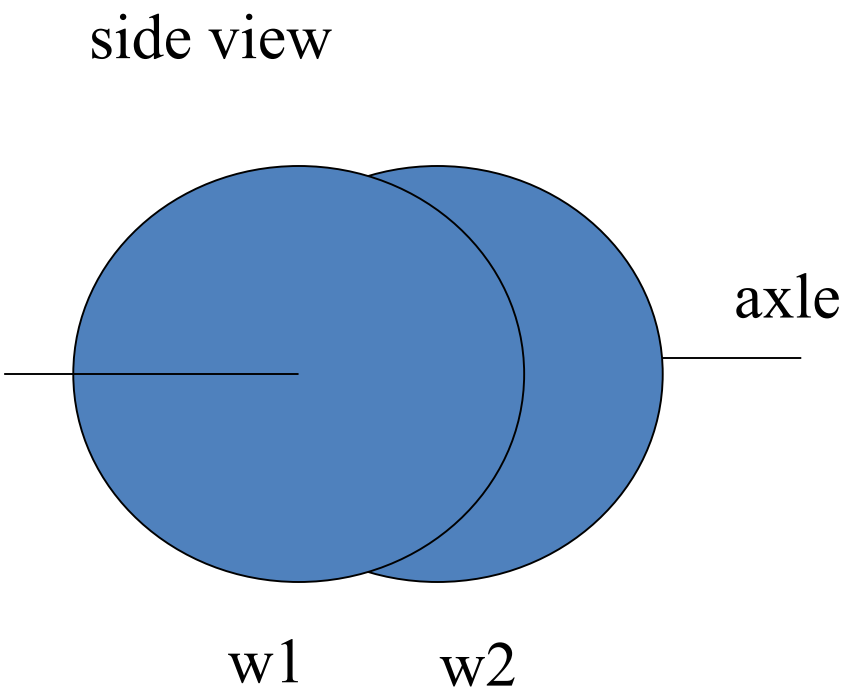
Differential drive

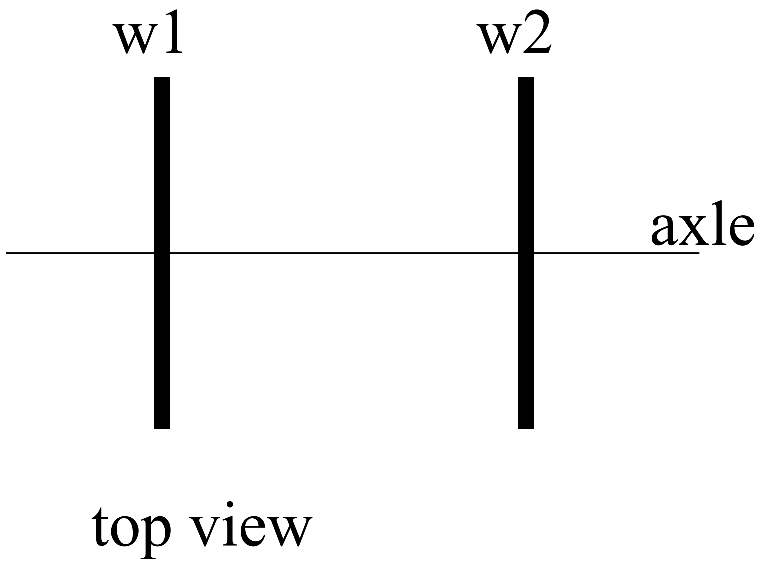


Basic design:

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

Idealized differential drive



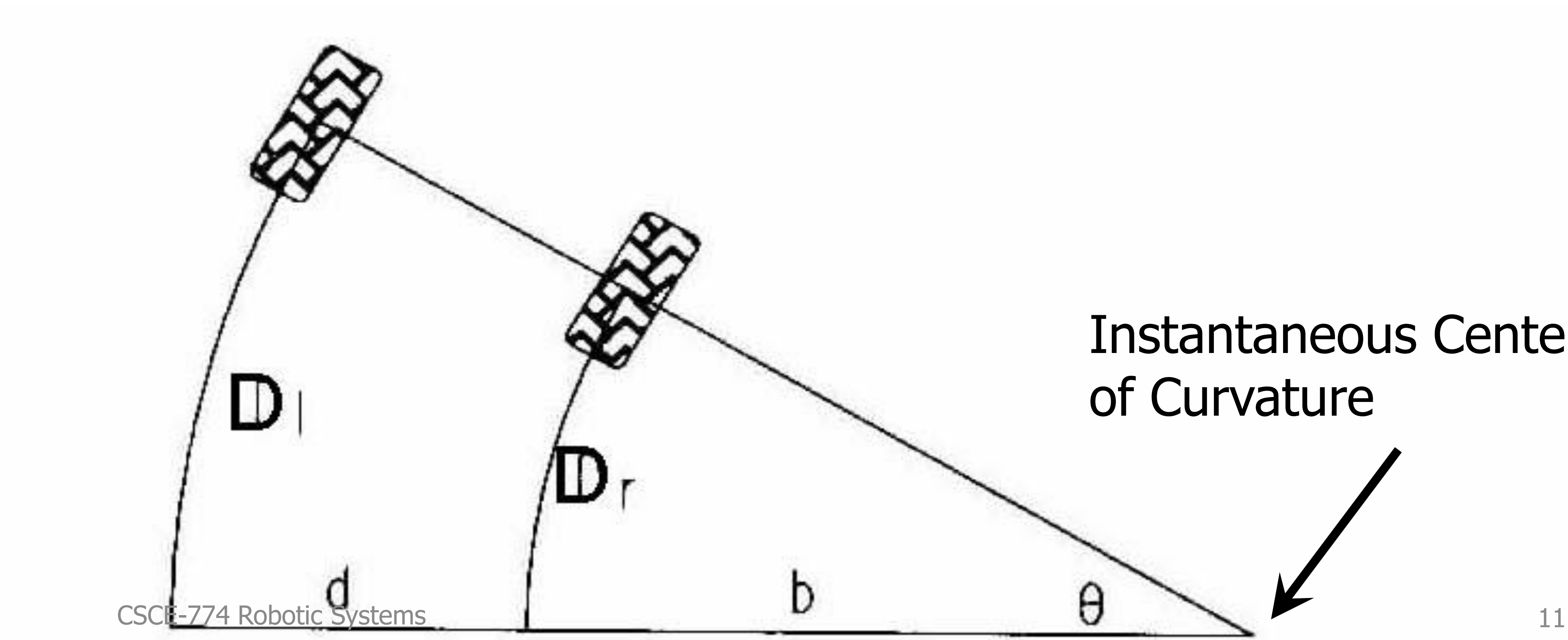


Differential Drive Intuition

- Drive straight ahead?
- Turn in place?
- (these are questions of *kinematics*)

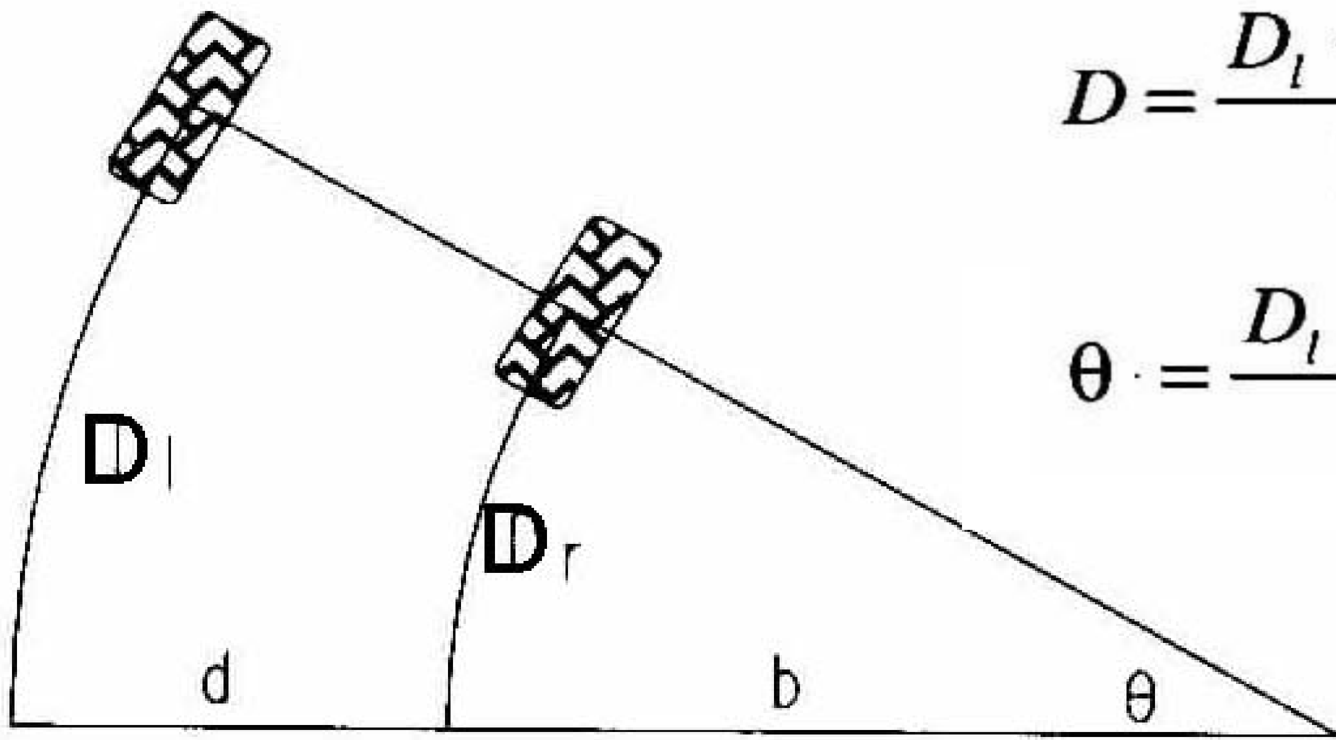
Differential Drive Observation

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



Forward Kinematics of Differential Drive

- Wheel rotation by angle ϕ_1, ϕ_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

- D, θ determine *differential* motion:
  - the tangent and velocity of the vehicle motion.
- To get the path followed, you have to integrate over *time*.

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

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

$$\theta(t) = \frac{1}{d}\int_0^t [v_r(t) - v_l(t)]dt$$

Non-Holonomic Constraints

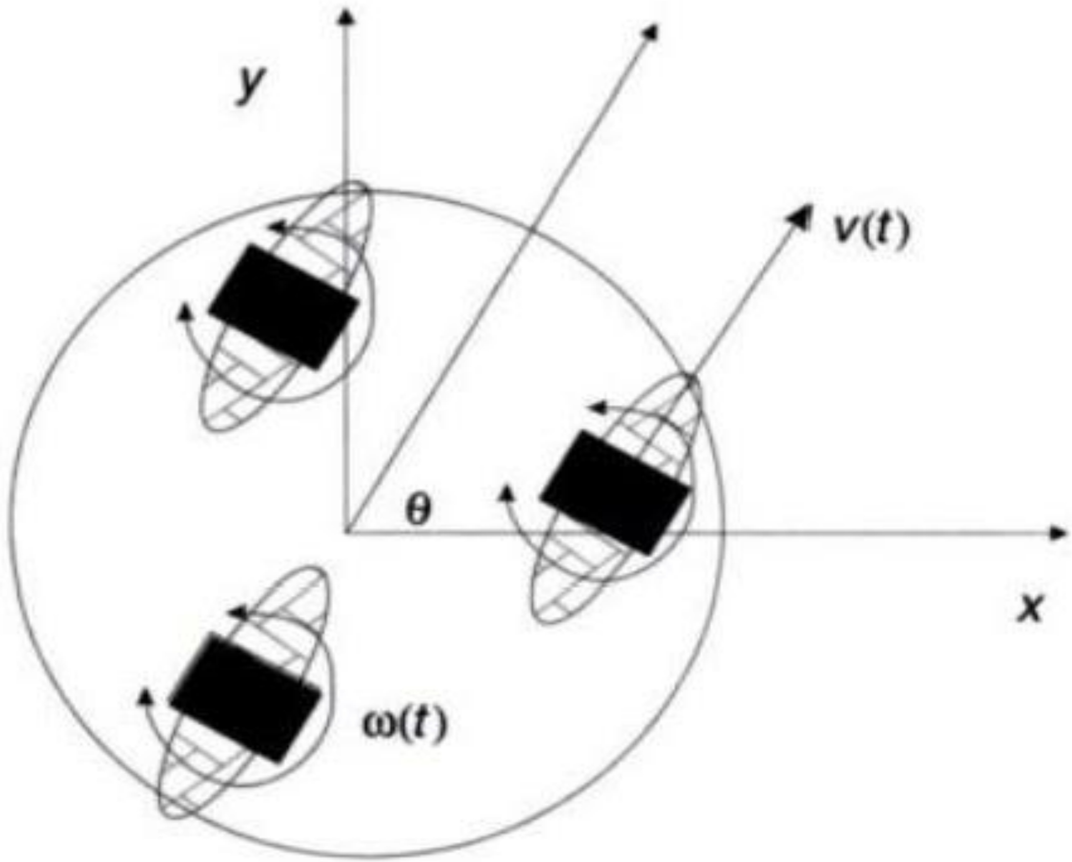
- Cannot change robot pose arbitrarily
- In D.D: Robot cannot move sideways
- Complicates planning:
  - Parallel parking…

Differential Drive Issues

- Matching of drive mechanisms
  - Tire wear (r is wrong)
  - Motors (ϕ is wrong)
  - Ground traction (rotation ϕr is not motion of ϕr)
  - Net result: motion ϕr is actually wrong

- Balance
  - Castor (caster) wheel

Synchronous Drive



Forward Kinematic - Synchronous Drive

- Simpler:

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

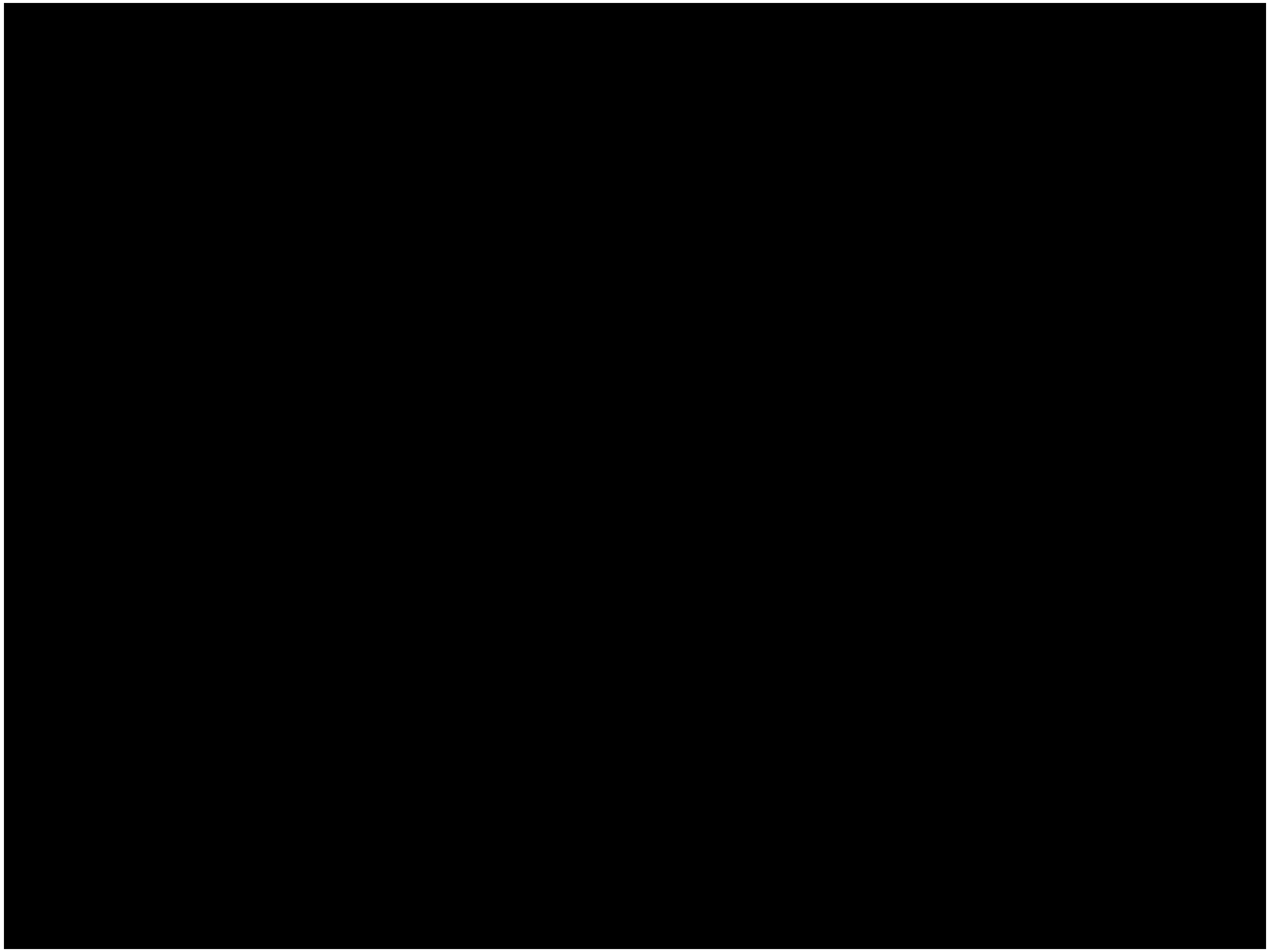
$$y(t) = \frac{1}{2}\int_0^t v(t)\sin[\theta(t)]dt$$

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

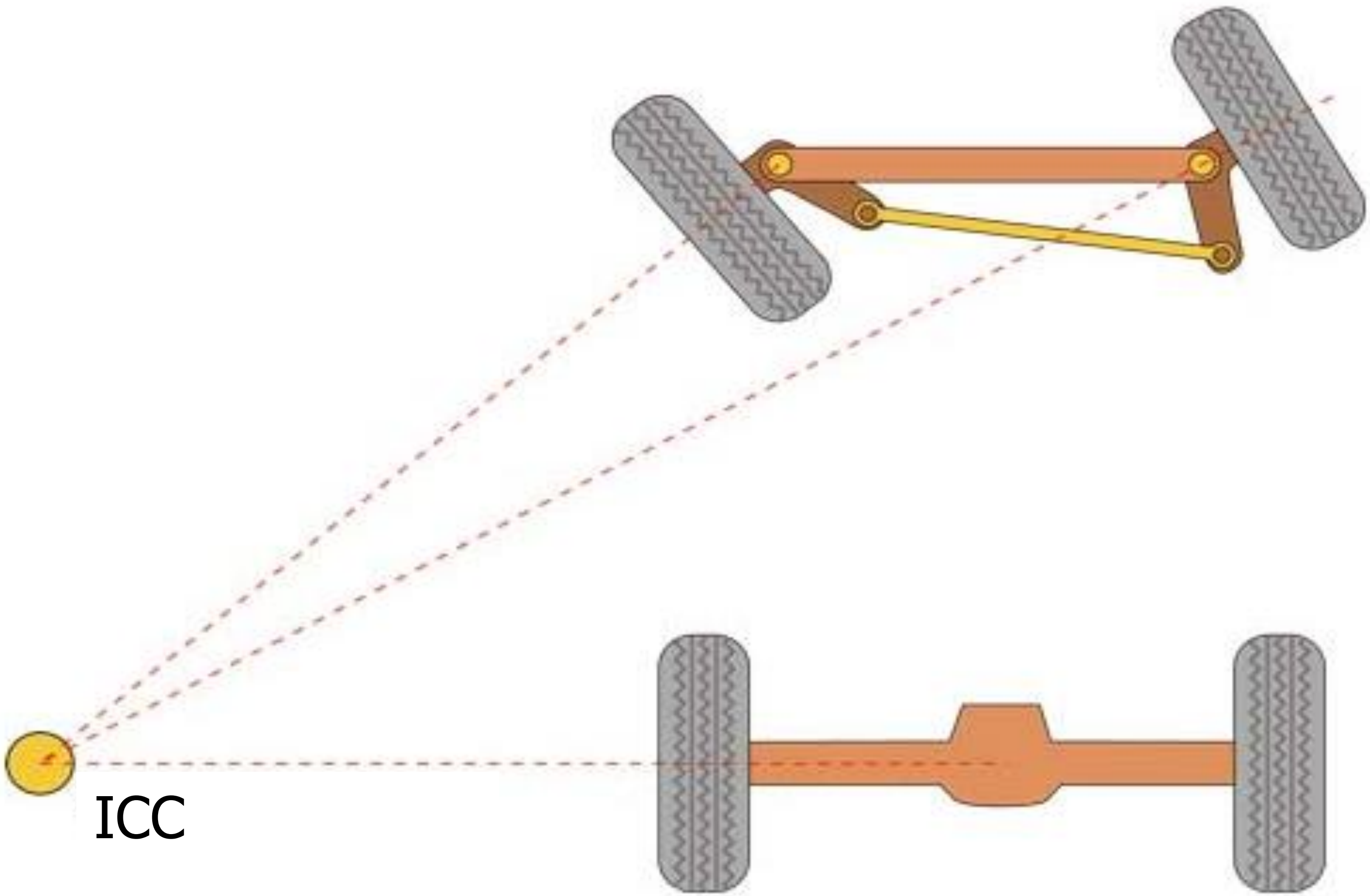
- Will not suffer from mechanical mismatch compared to Diff. Drive

Mecanum Wheels

Mecanum Wheels



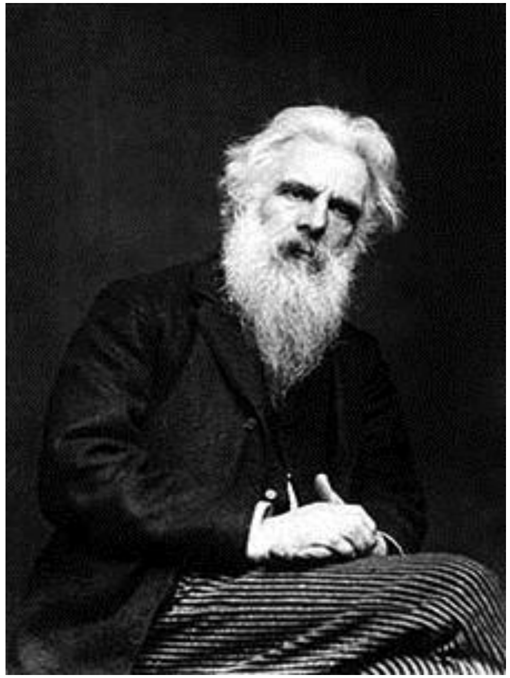
Ackerman (Used in Cars)



Legged Locomotion

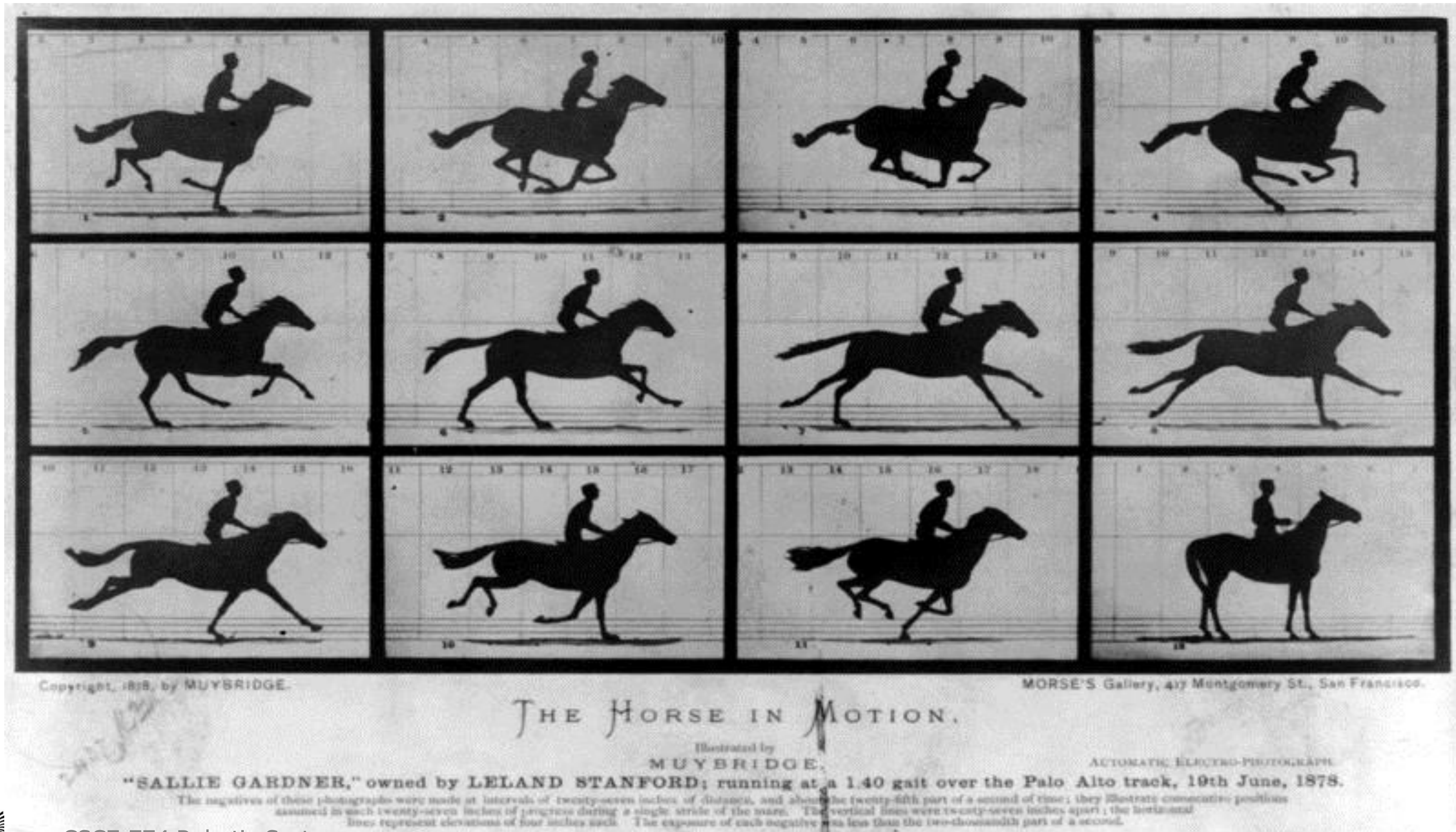
- Started to resolve a bet between Governor of California *Leland Stanford* and a friend, in 1872.

- Muybridge took the challenge



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

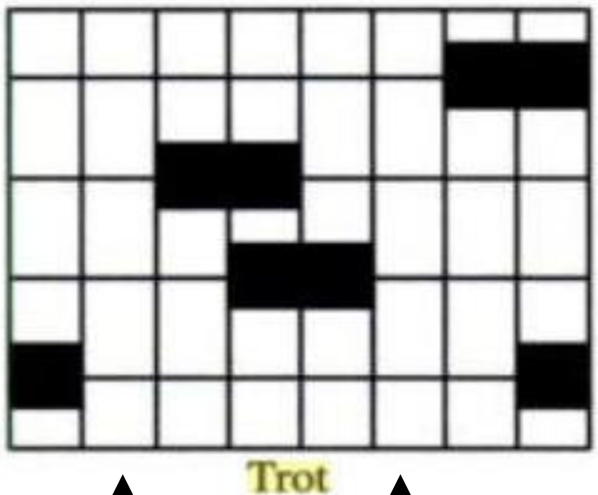
Legged Locomotion



Hildebrand Gait Diagrams

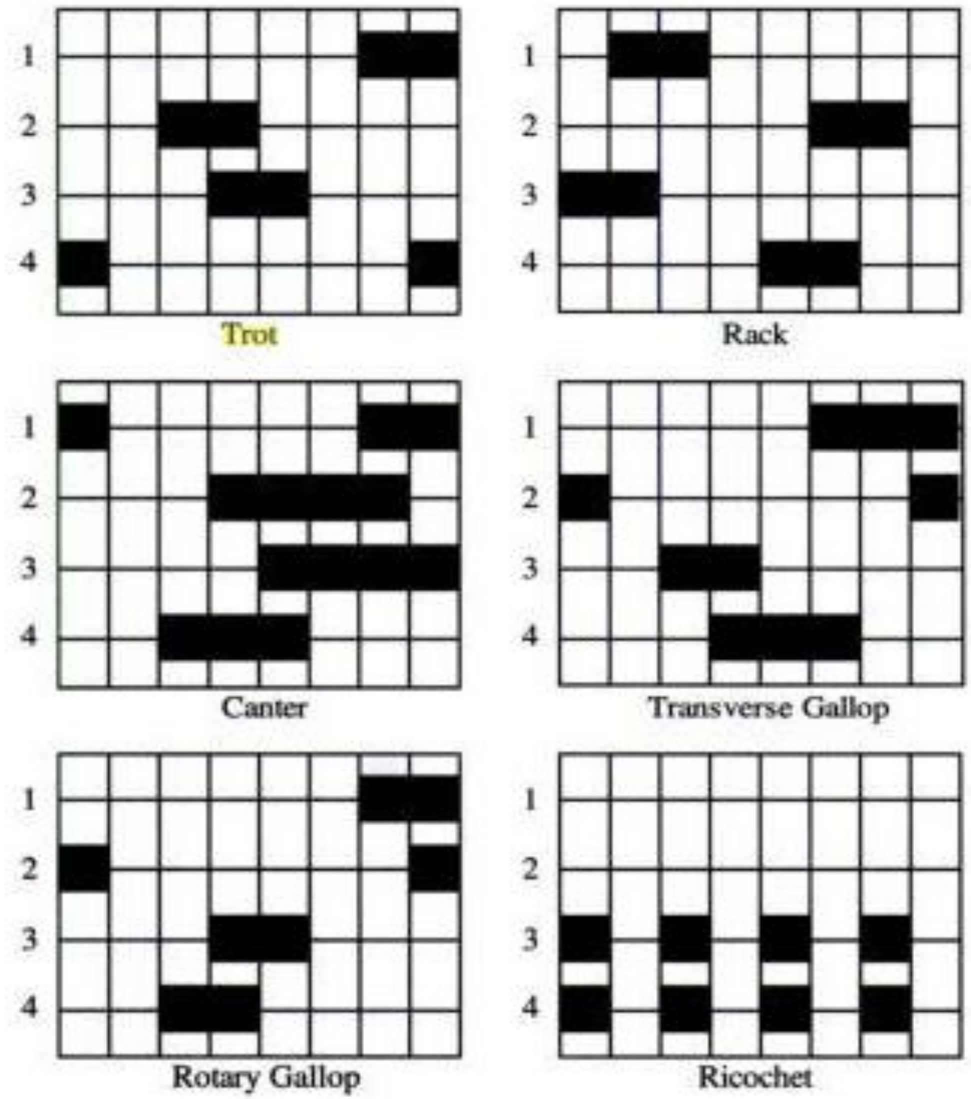
Trot

Front Left
Front Right
Back Left
Back Right

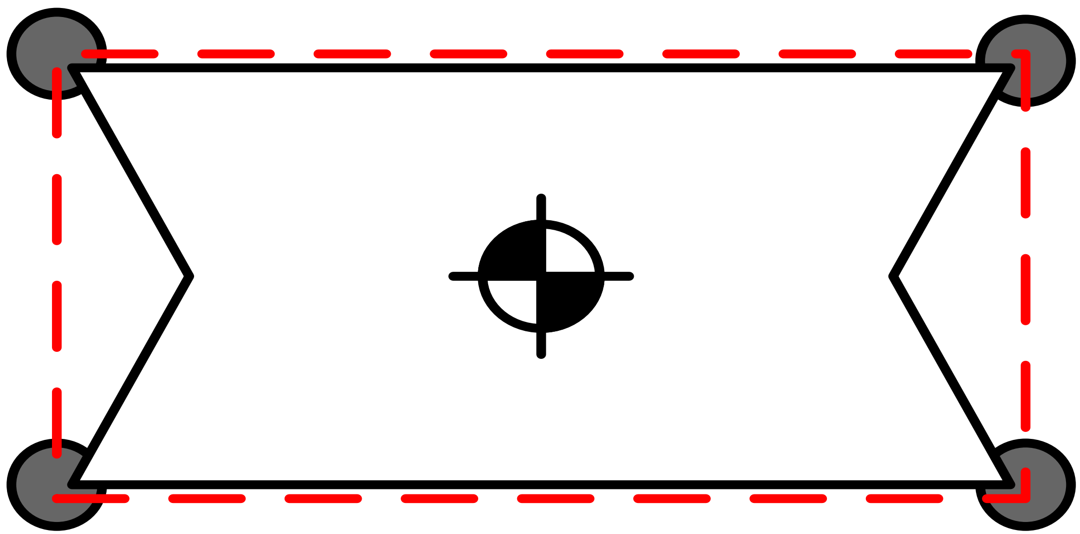


Ballistic Phase

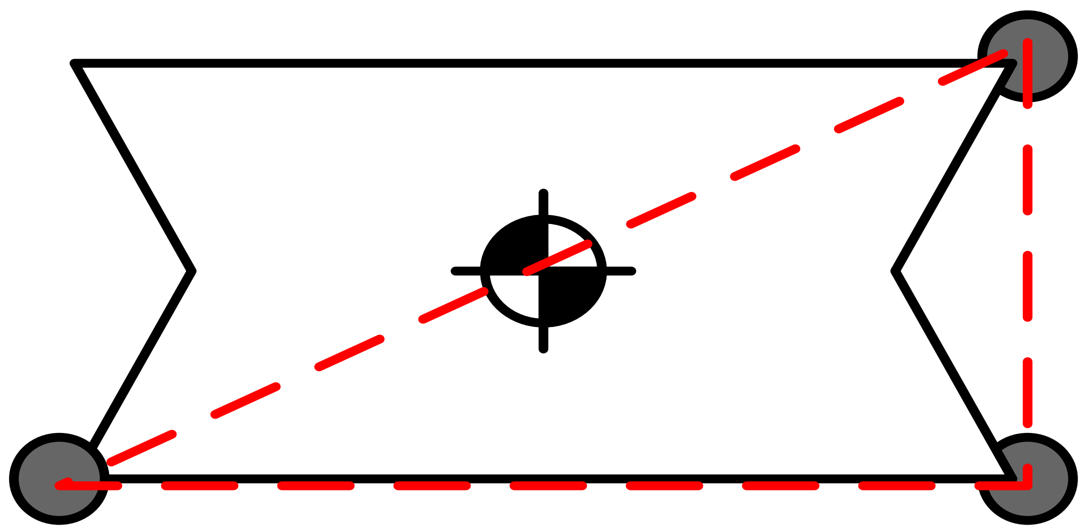
Hildebrand Gait Diagrams



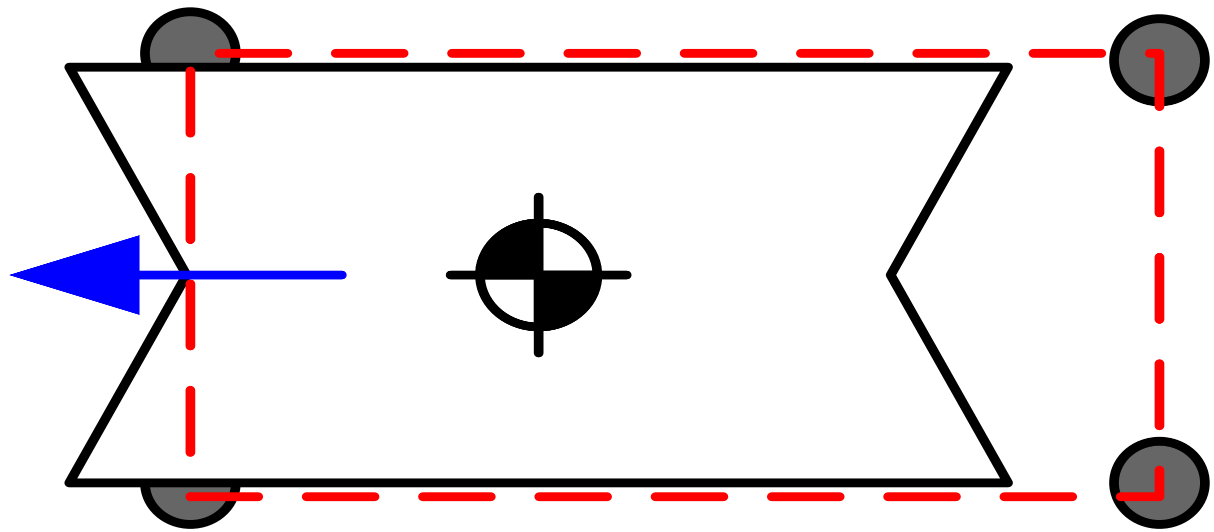
Support Polygon



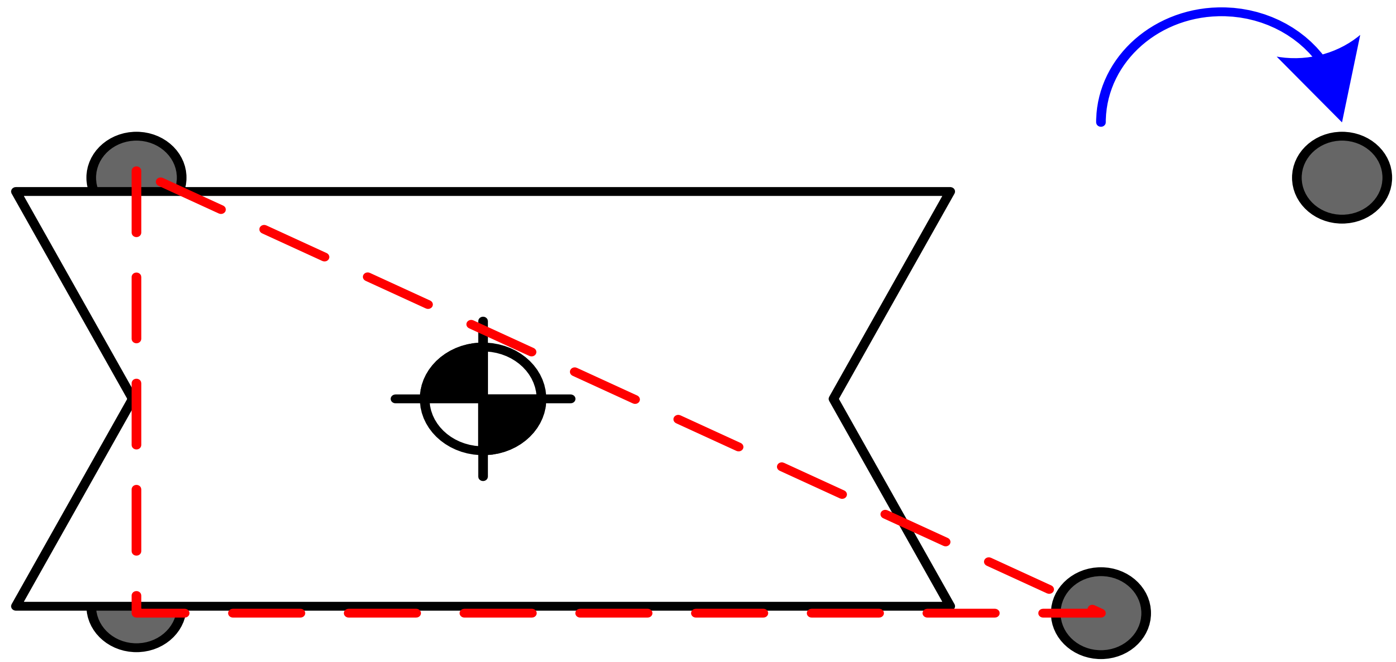
Support Polygon



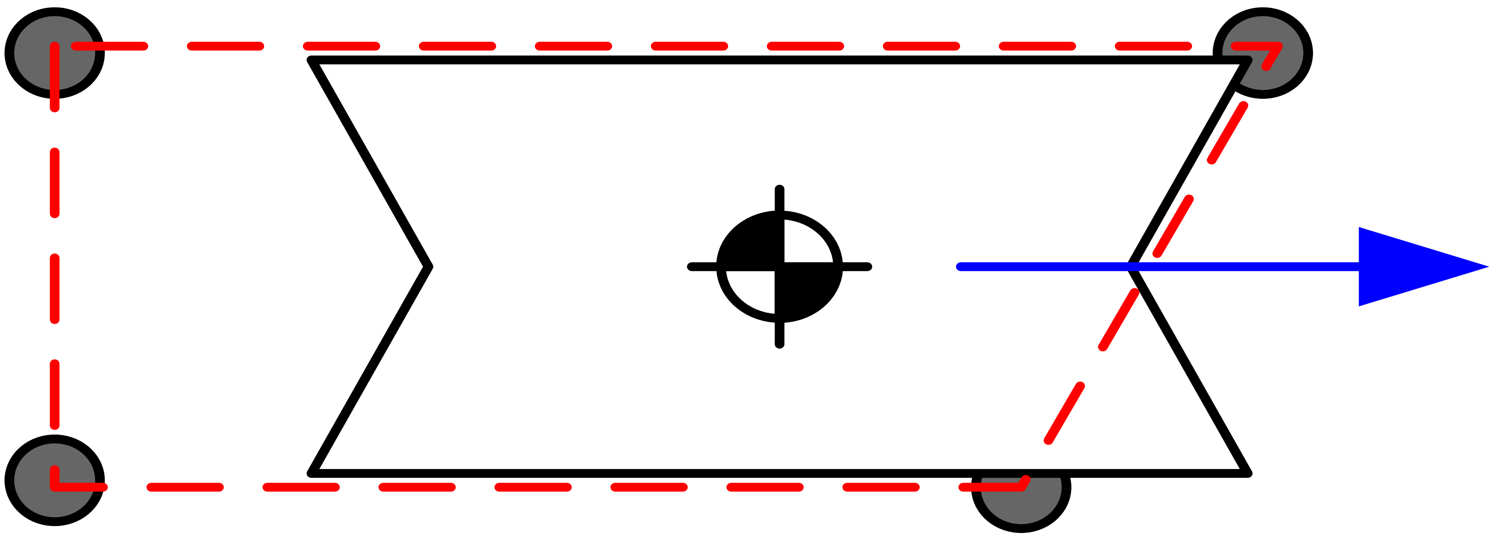
Support Polygon



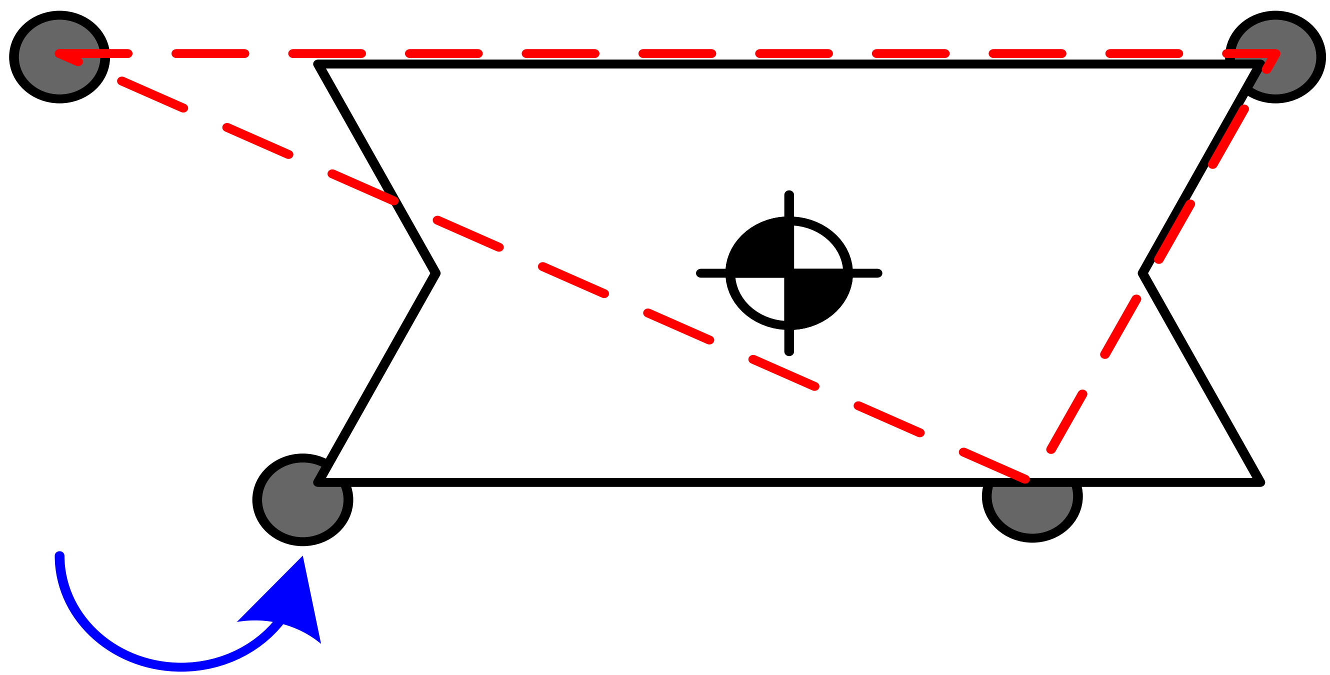
Support Polygon



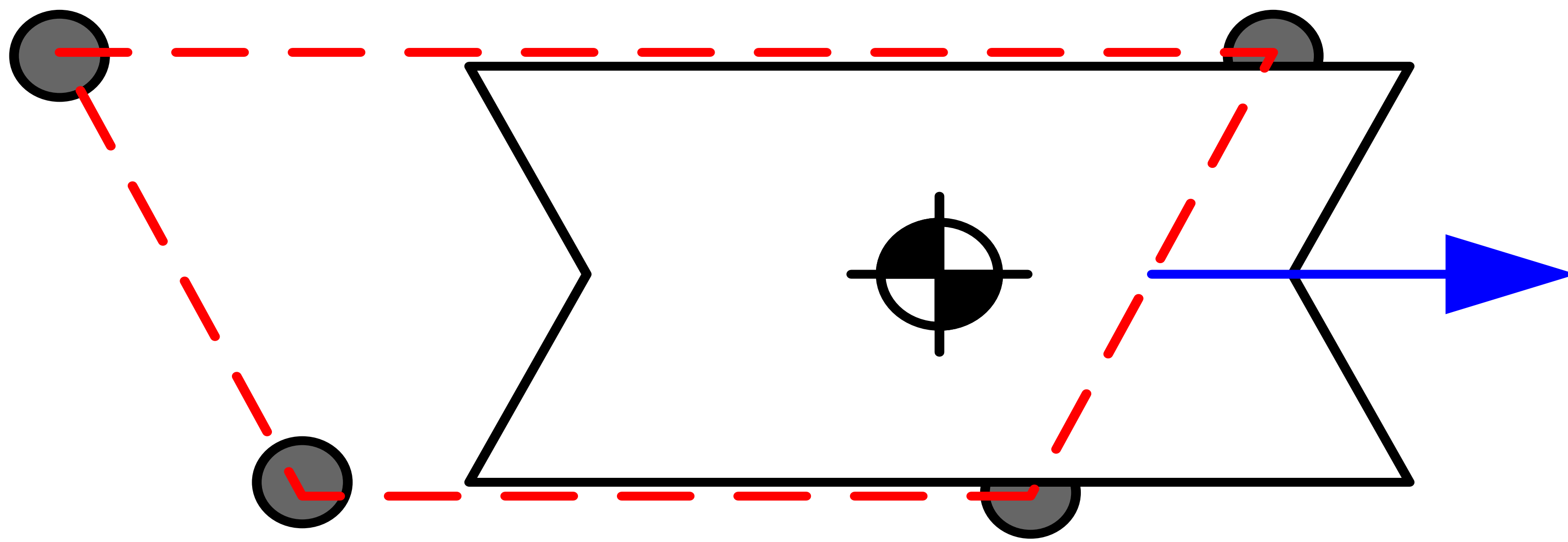
Support Polygon



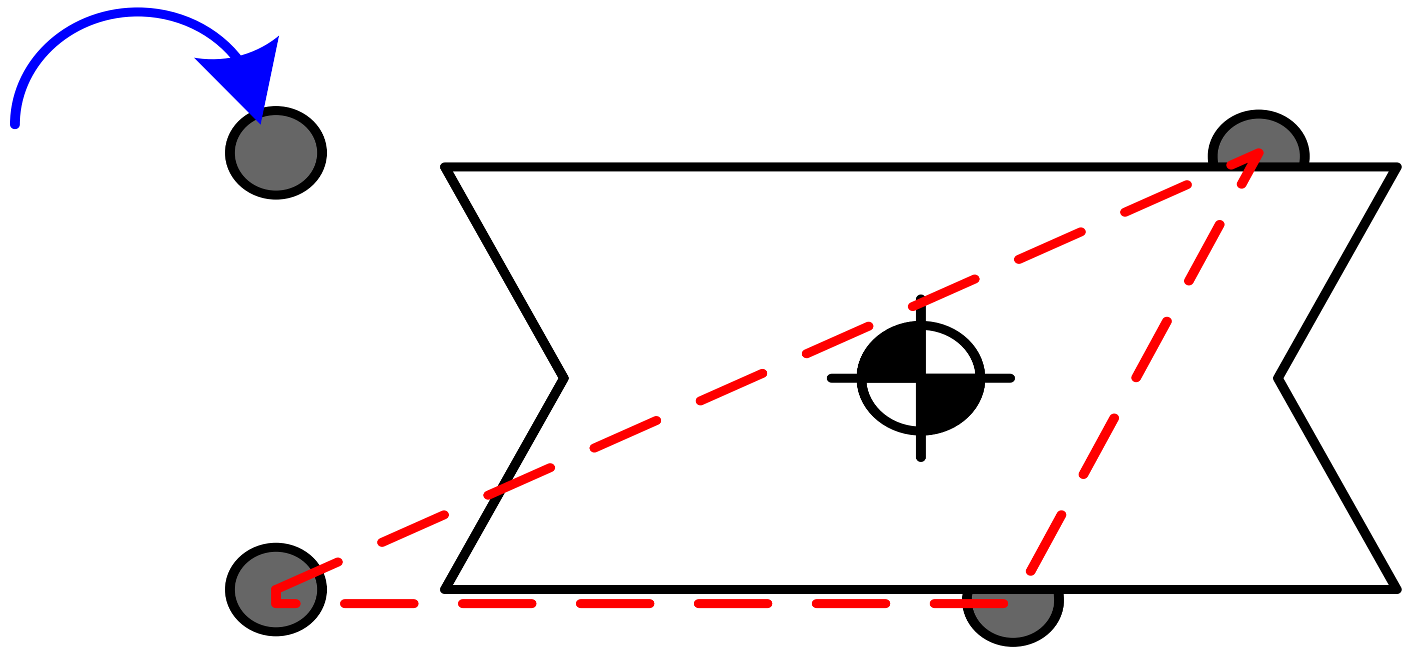
Support Polygon



Support Polygon

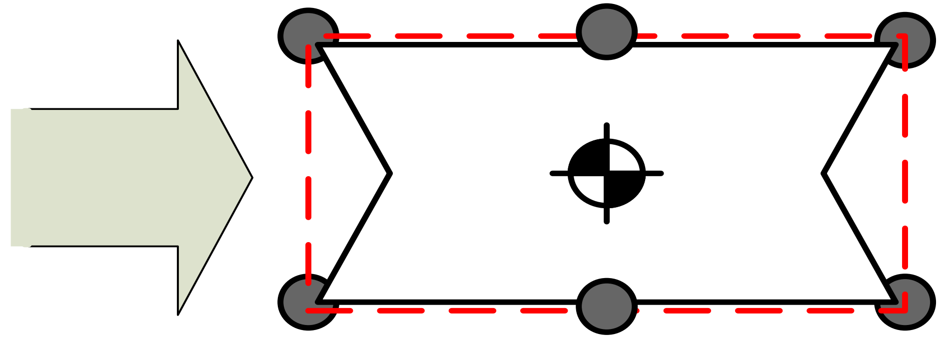


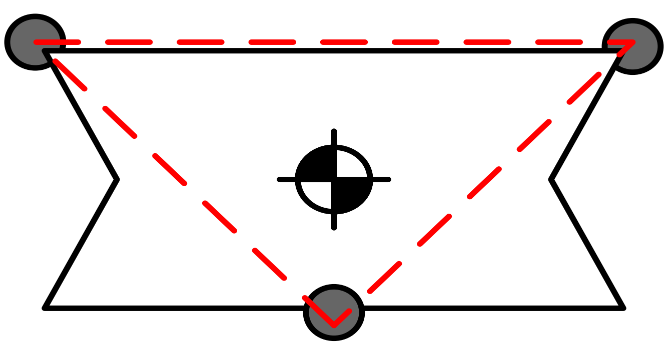
Support Polygon

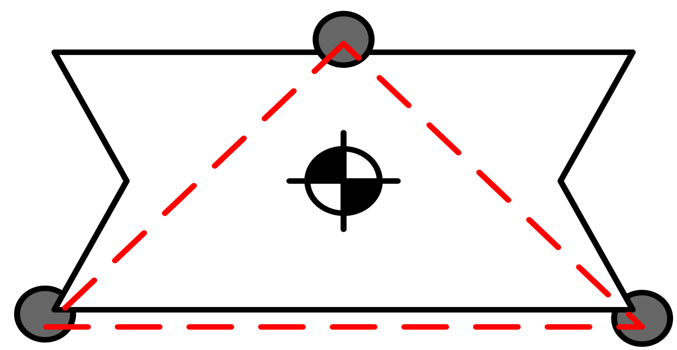


And so on...

Hexapod RHex







RHex: Tripod Gait

Bi-Pedal: Zero Moment Point

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)