UNIVERSITY OF SOUTH CAROLINA

CSCE 574 ROBOTICS

Locomotion

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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)

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

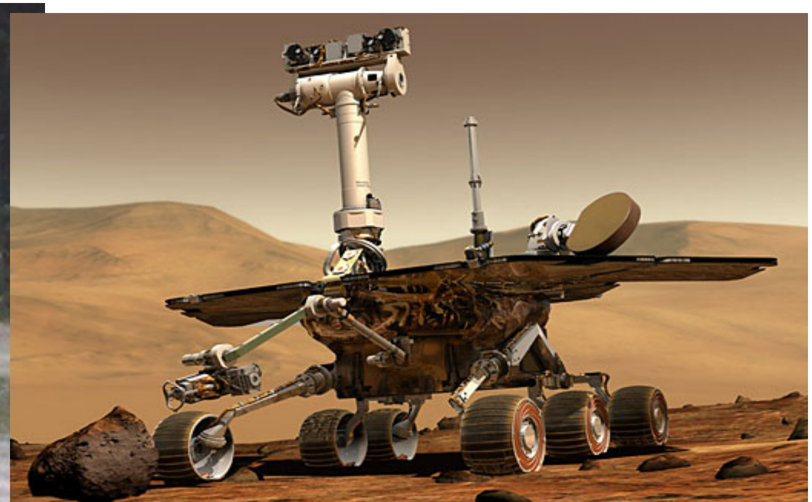
Design Tradeoffs with Mobility Configurations

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.

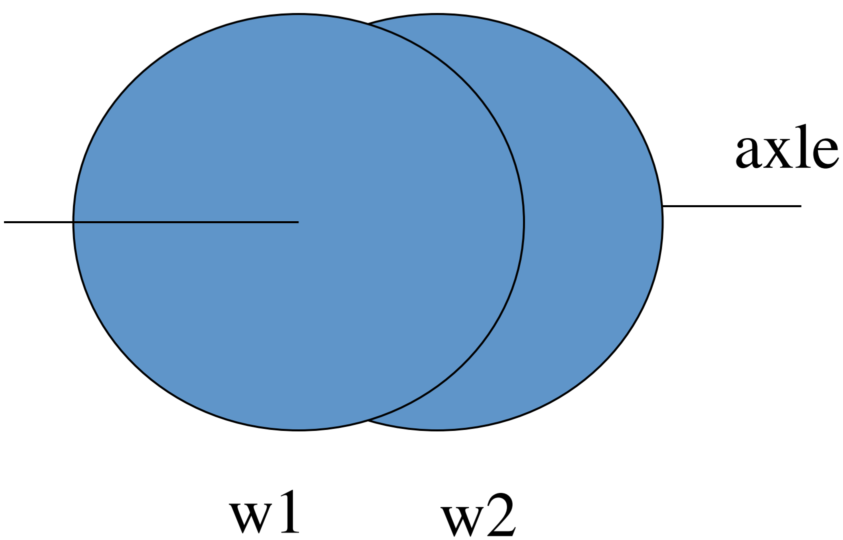
Differential drive

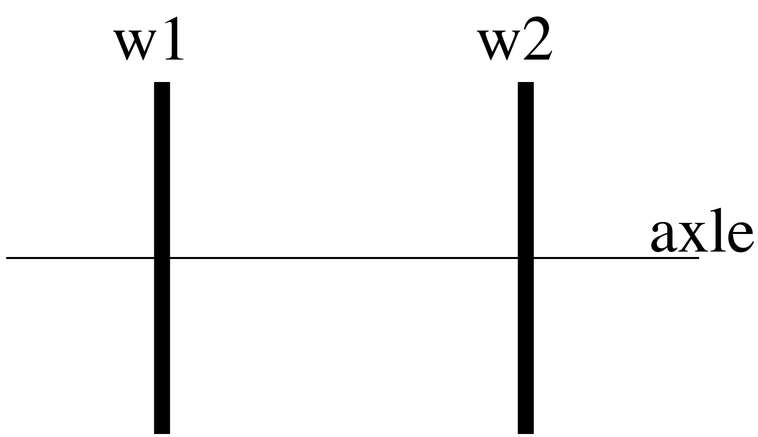
Basic design:

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

Idealized differential drive

side view





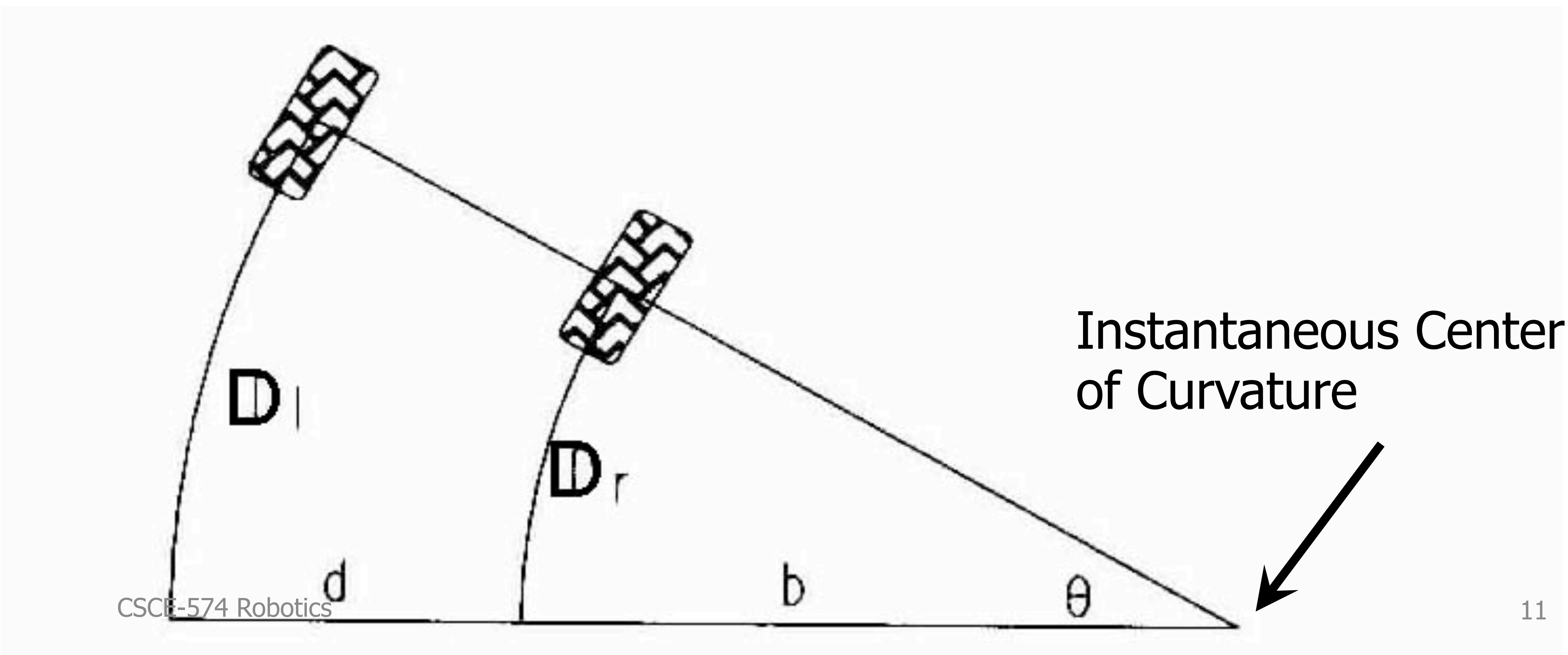
top view

Differential Drive Intuition

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

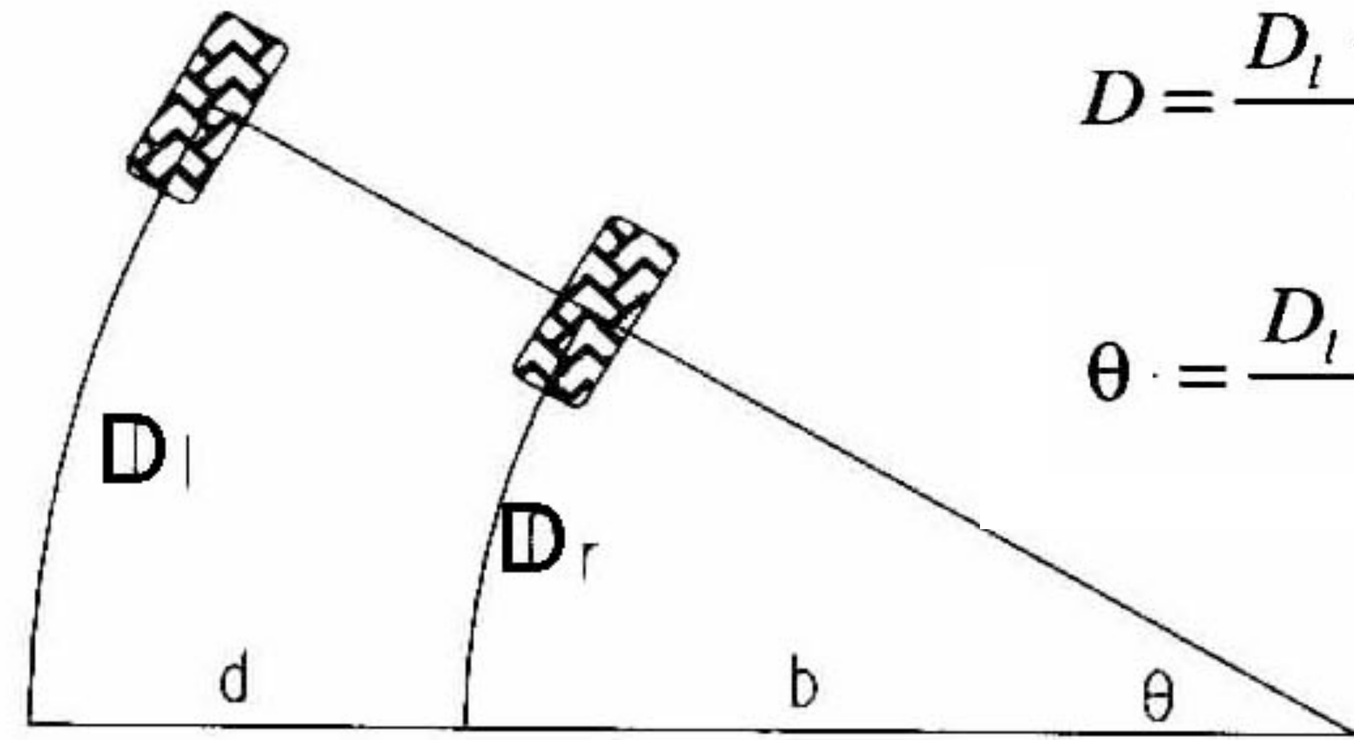
Differential Drive Observation

- 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

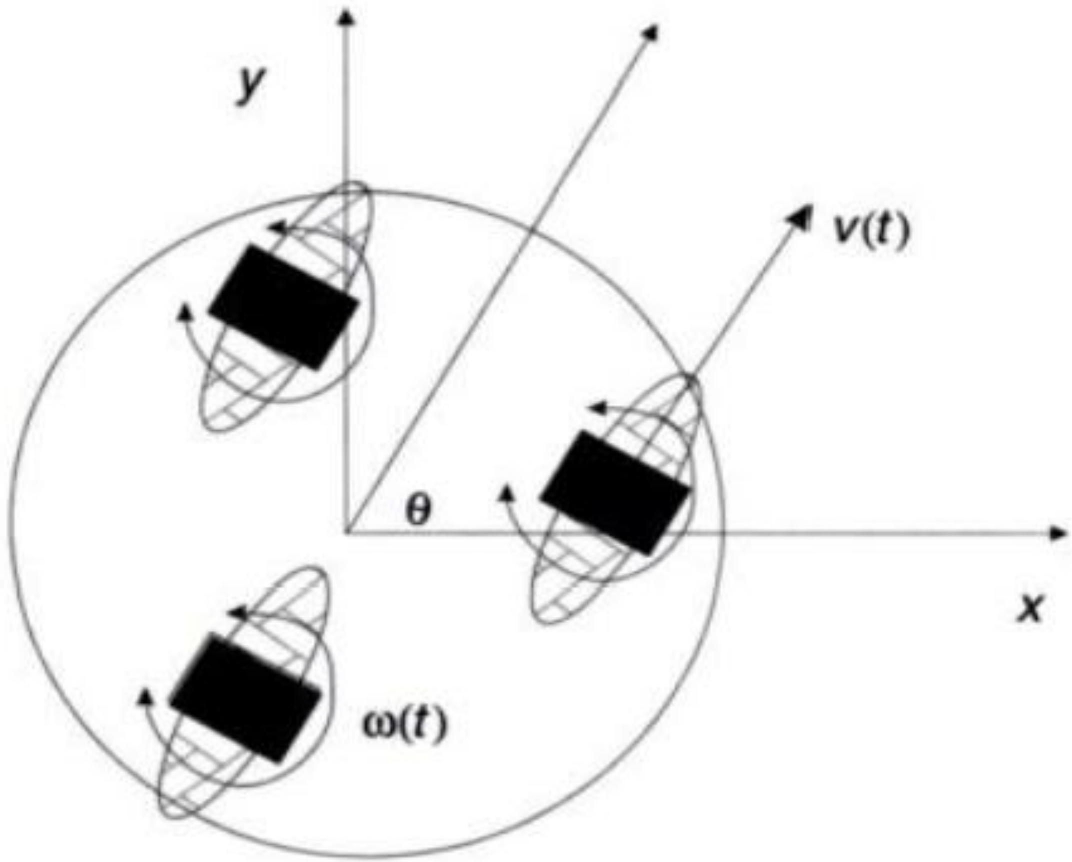
- Cannot change robot pose arbitrarily
- In D.D: Robot cannot move sideways
- Complicates planning:
  - Parallel parking…

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:

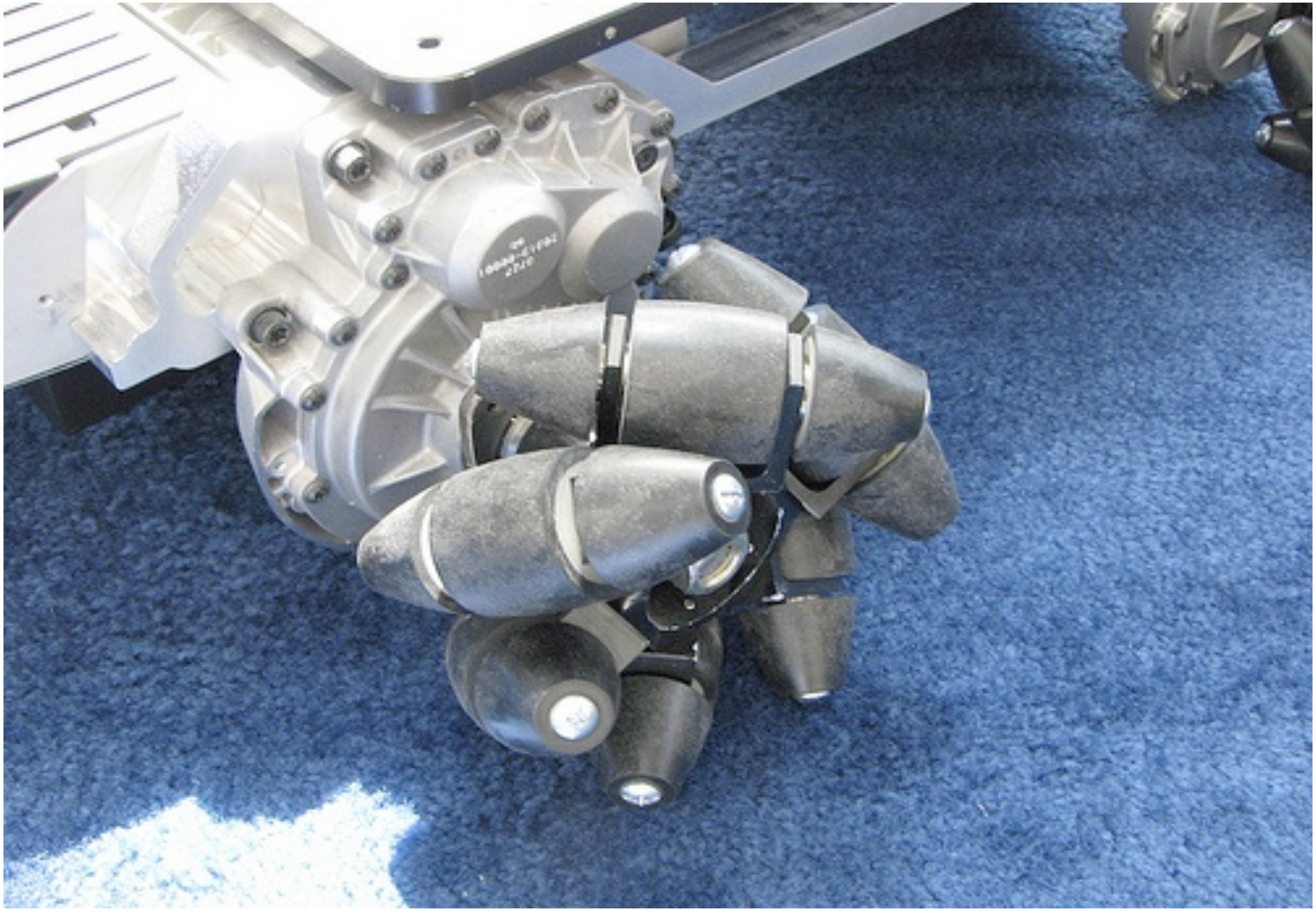
$$x(t) = \frac{1}{2}\int_0^t v(t)\cos[\theta(t)]dt$$

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

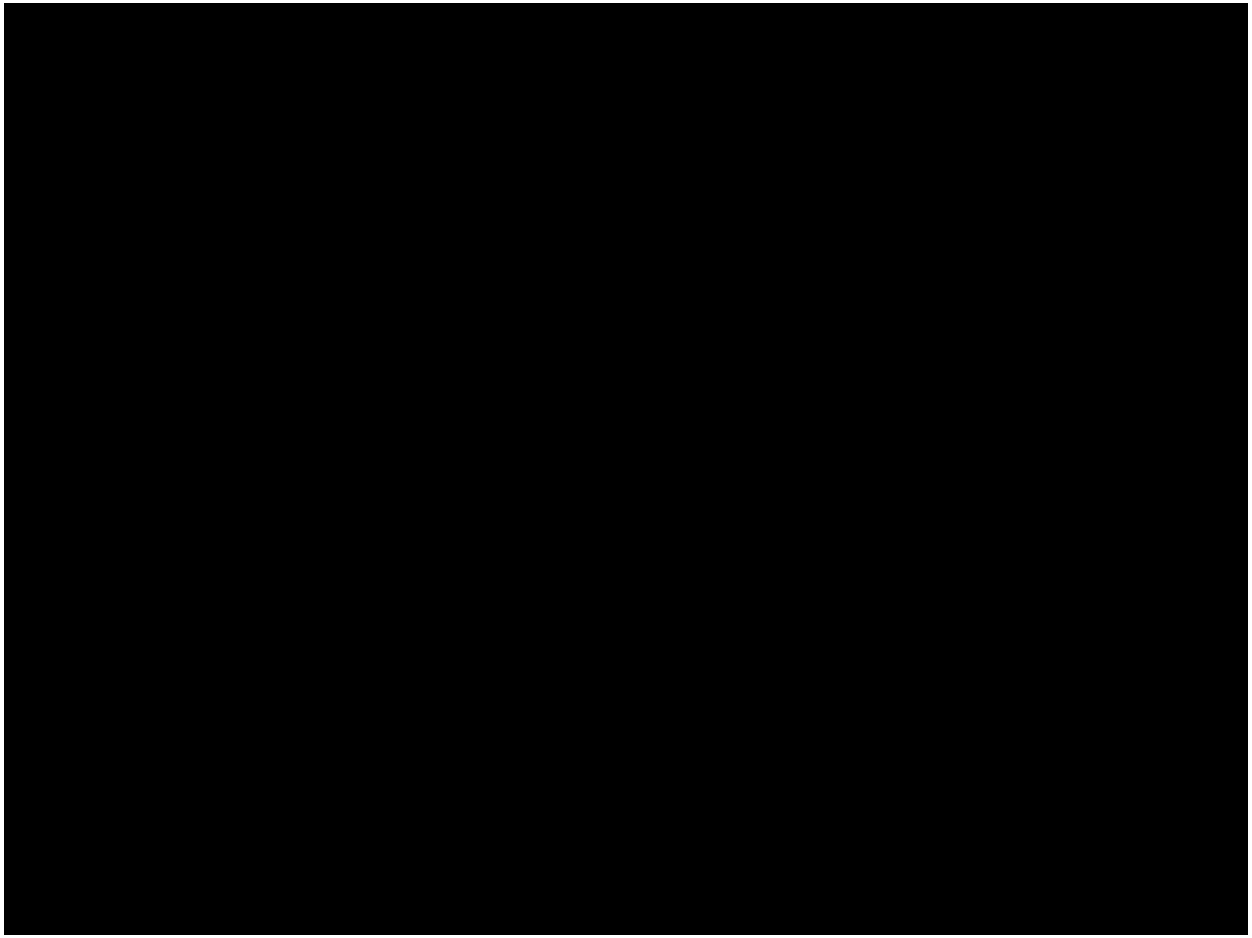
$$\theta(t) = \int_0^t \omega(t)dt$$

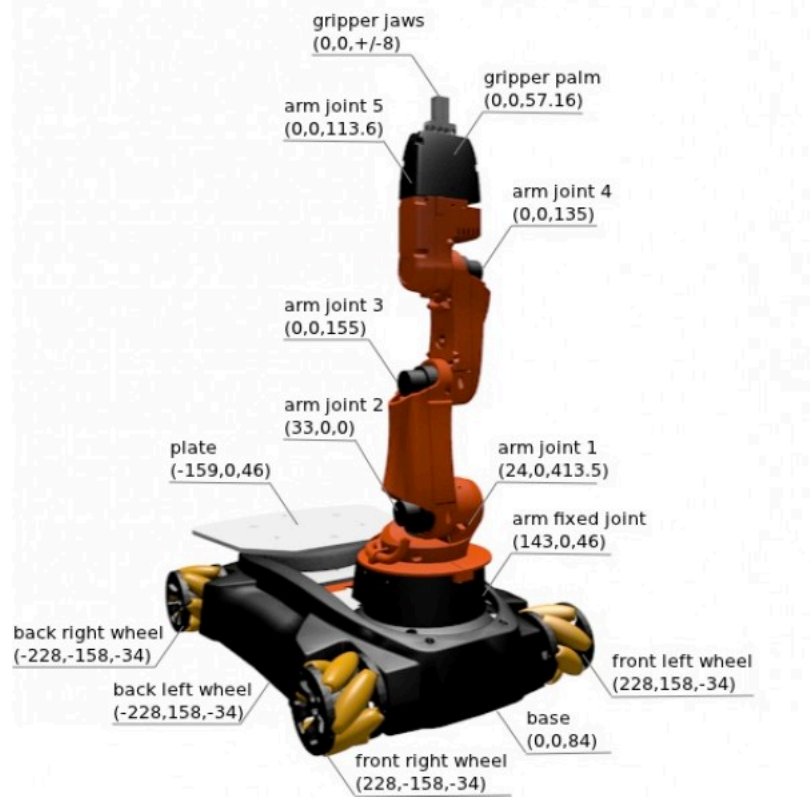
- Will not suffer from mechanical mismatch compared to Diff. Drive

Mecanum Wheels

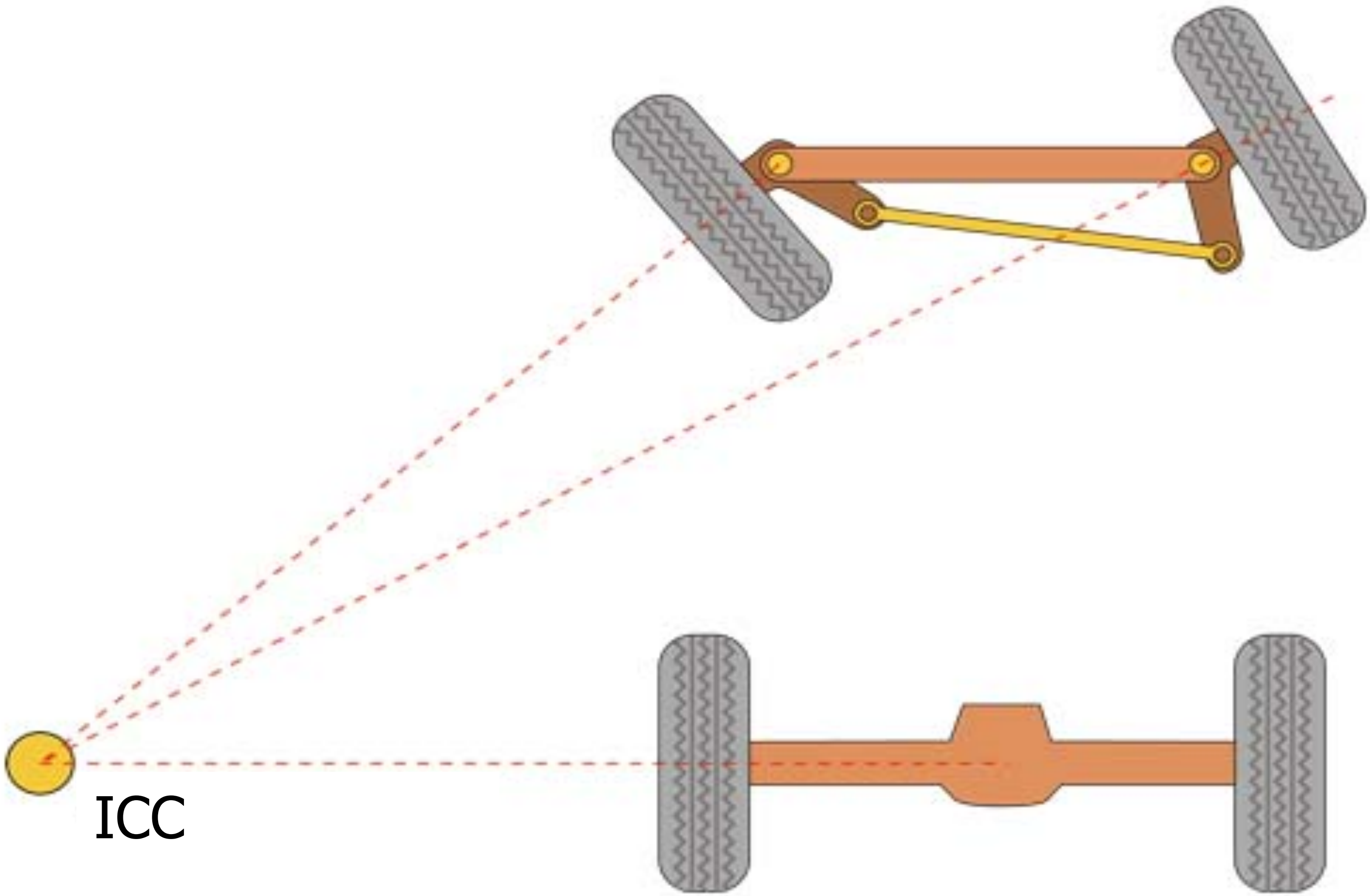


Mecanum Wheels





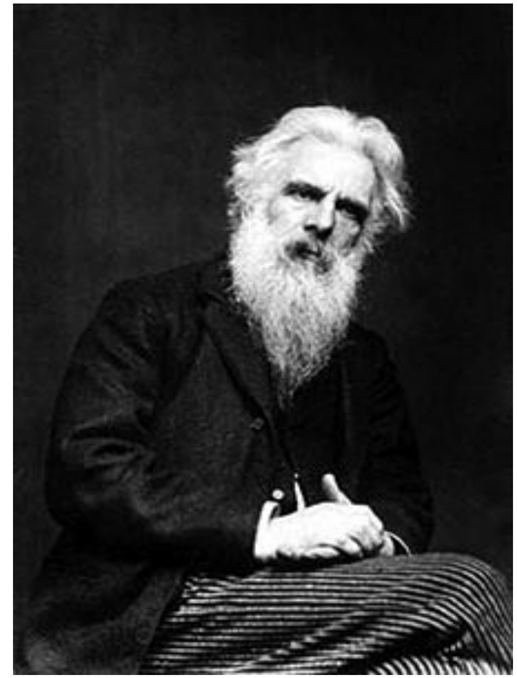
Ackerman (Used in Cars)



Legged Locomotion

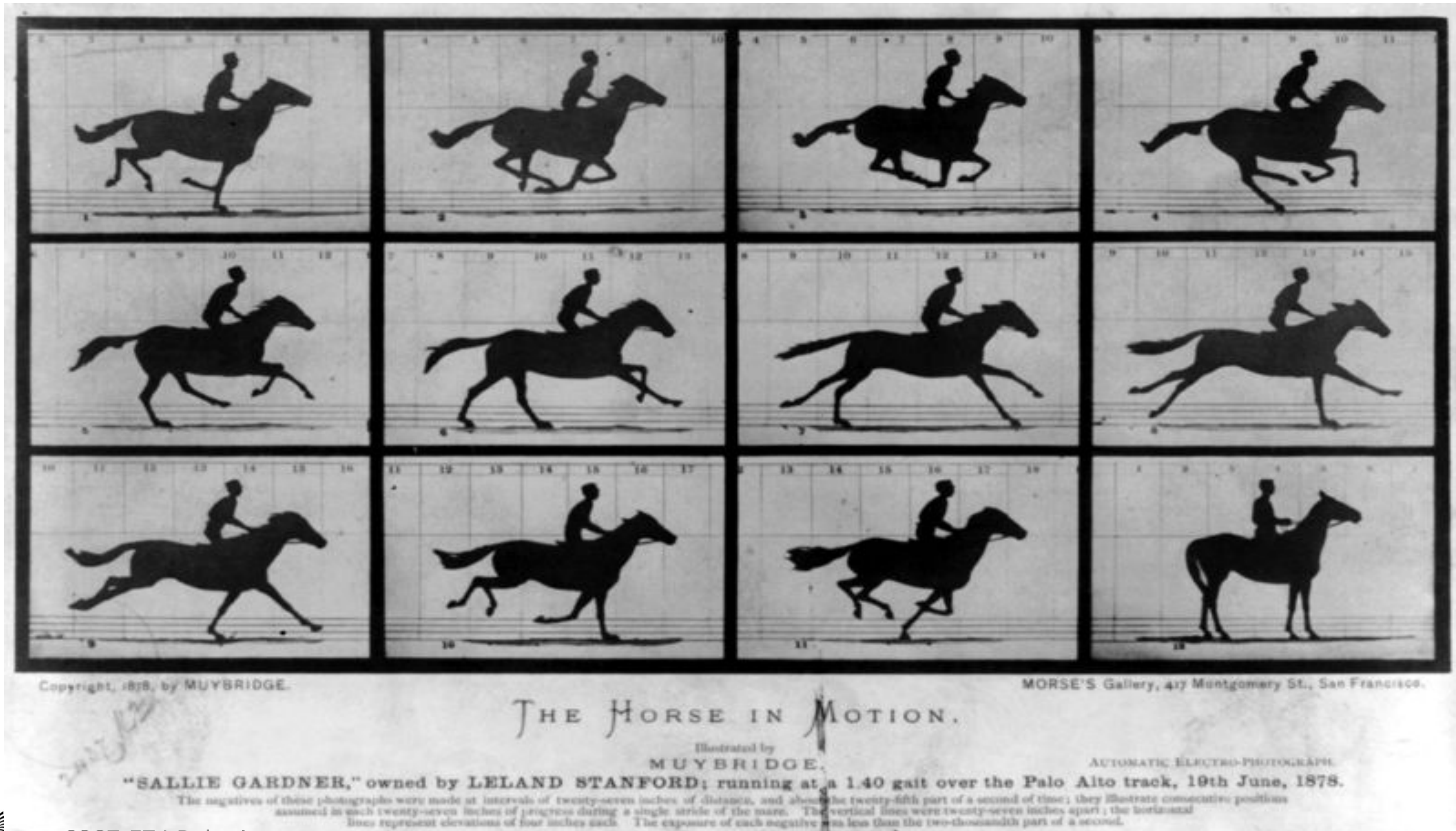
- Started to resolve a bet between Governor of California *Leland Stanford* and a friend, in 1872.

- Muybridge took the challenge

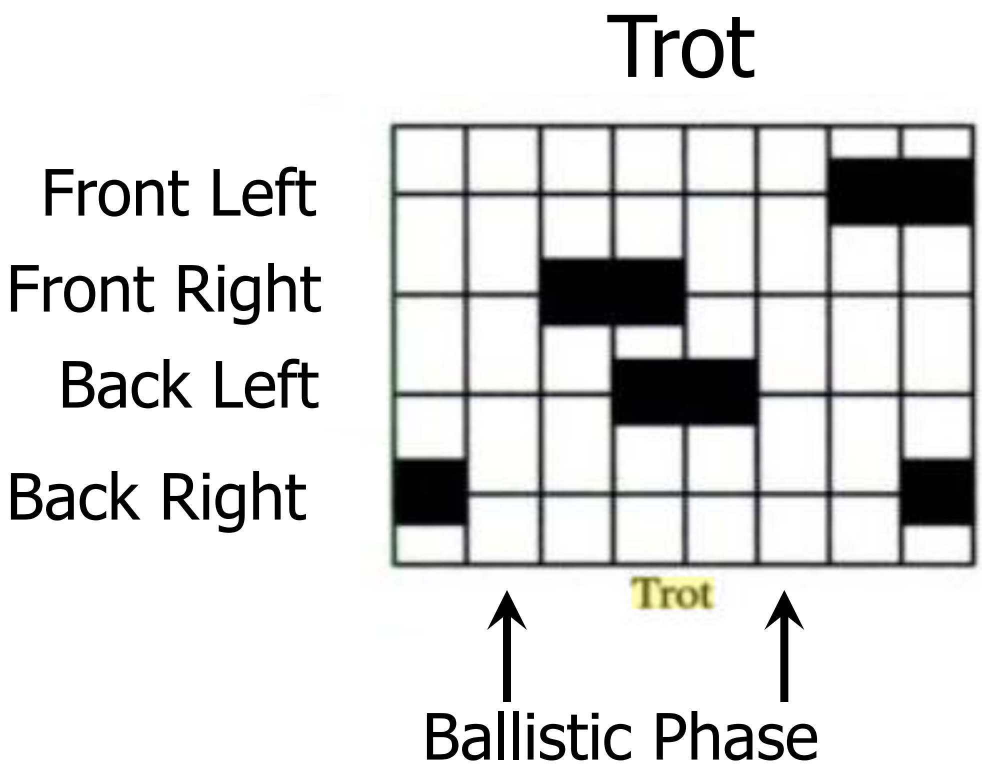


Eadweard Muybridge
(April 9, 1830 – May 8, 1904)

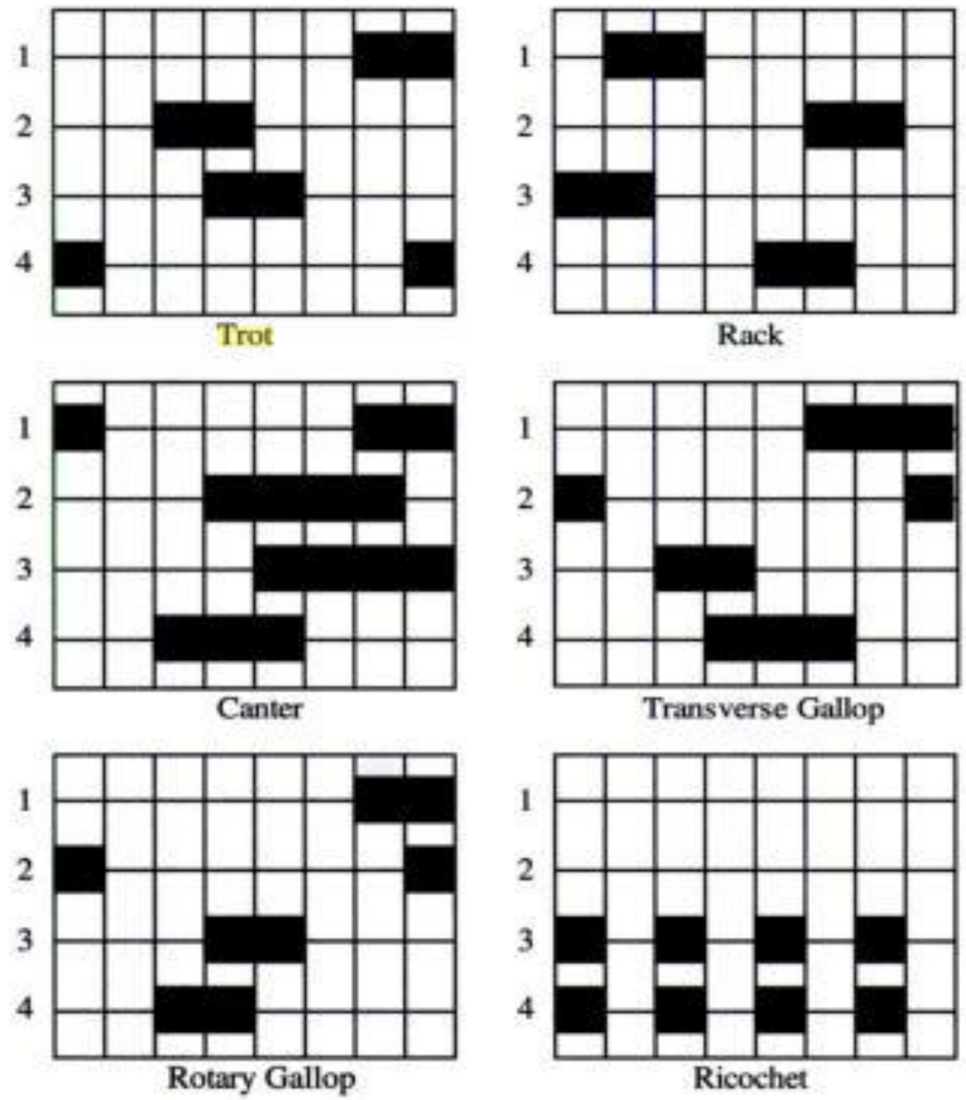
Legged Locomotion



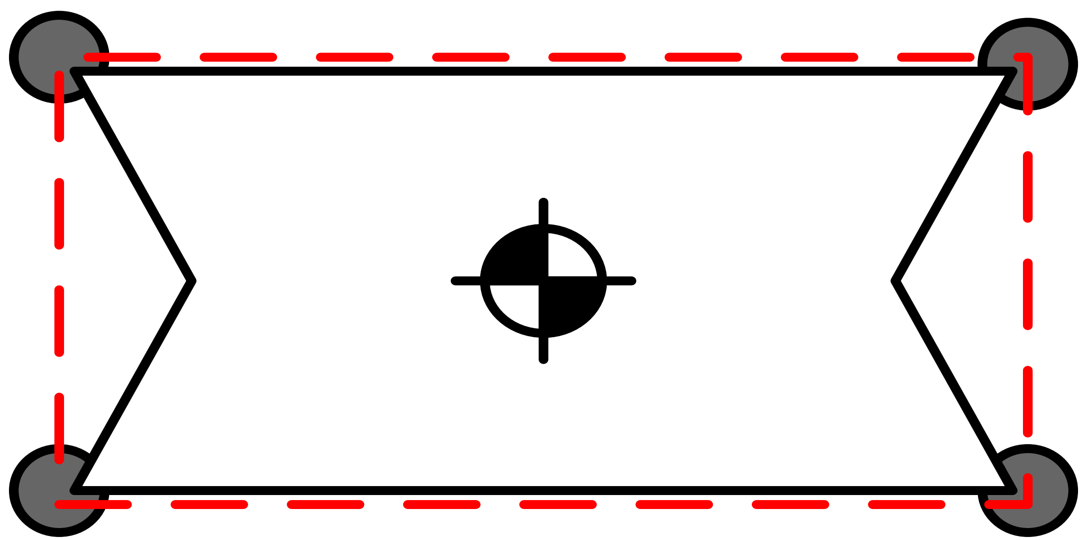
Hildebrand Gait Diagrams



Hildebrand Gait Diagrams



Support Polygon



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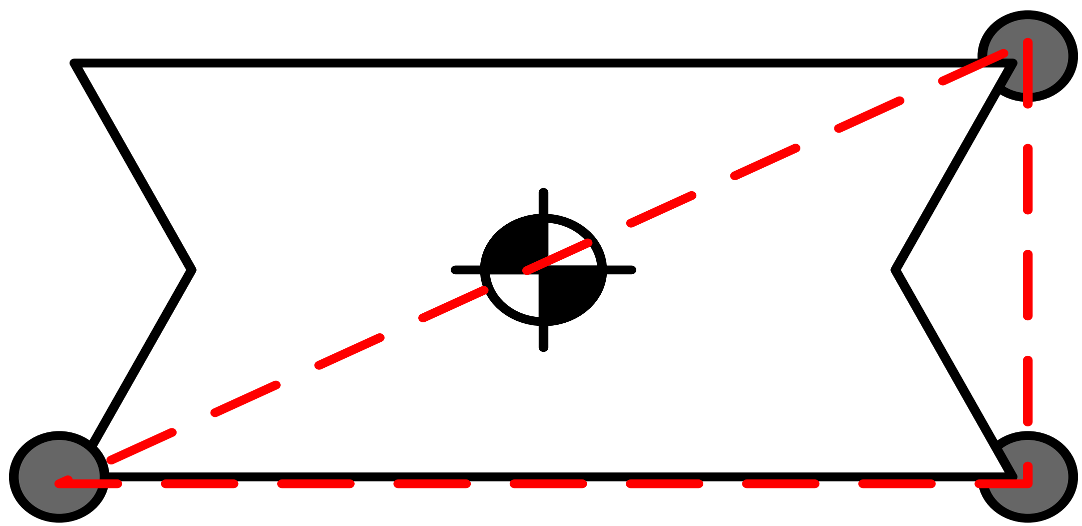

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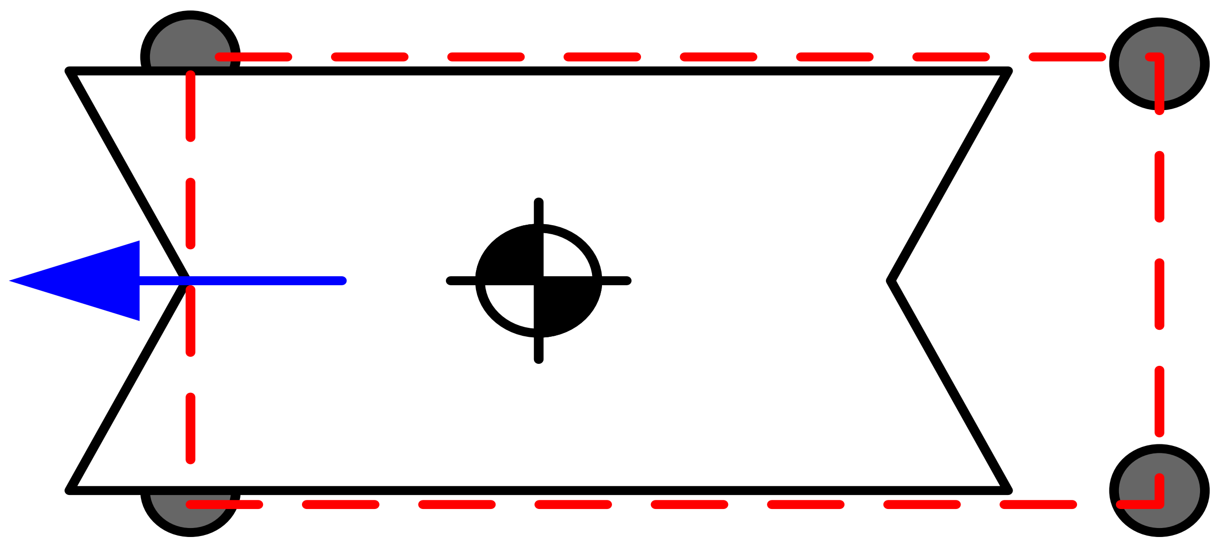

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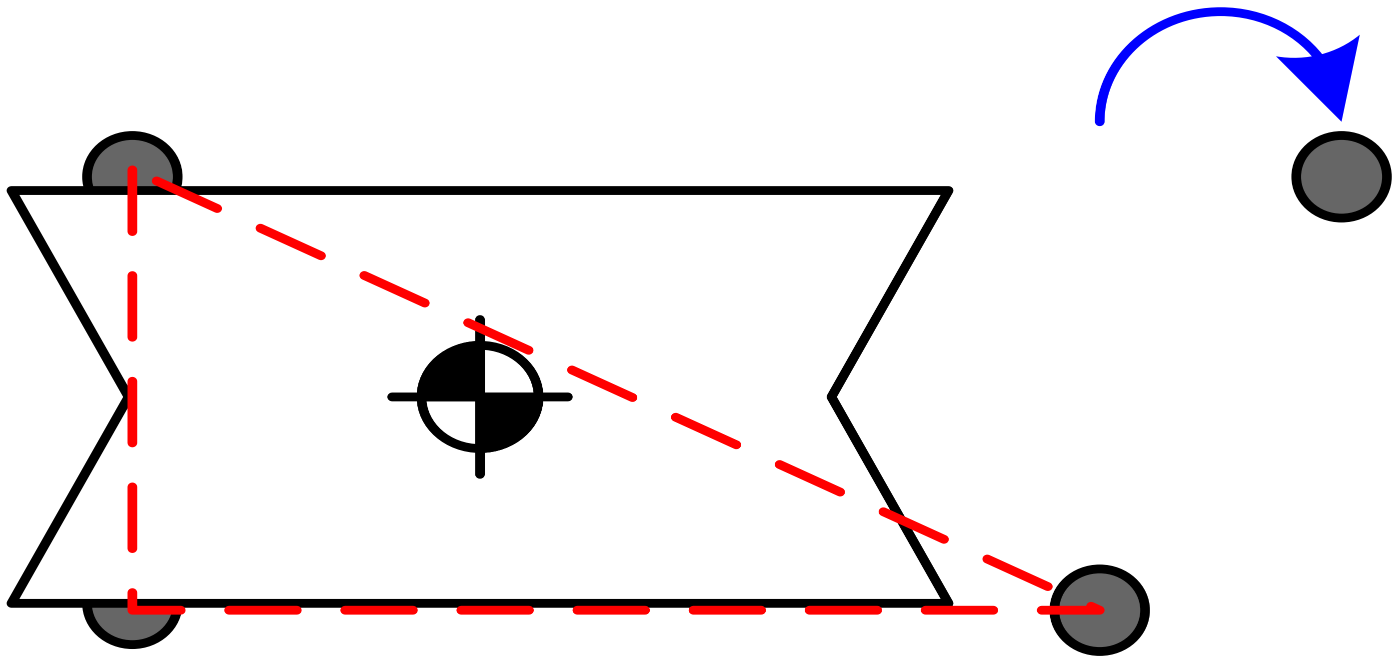

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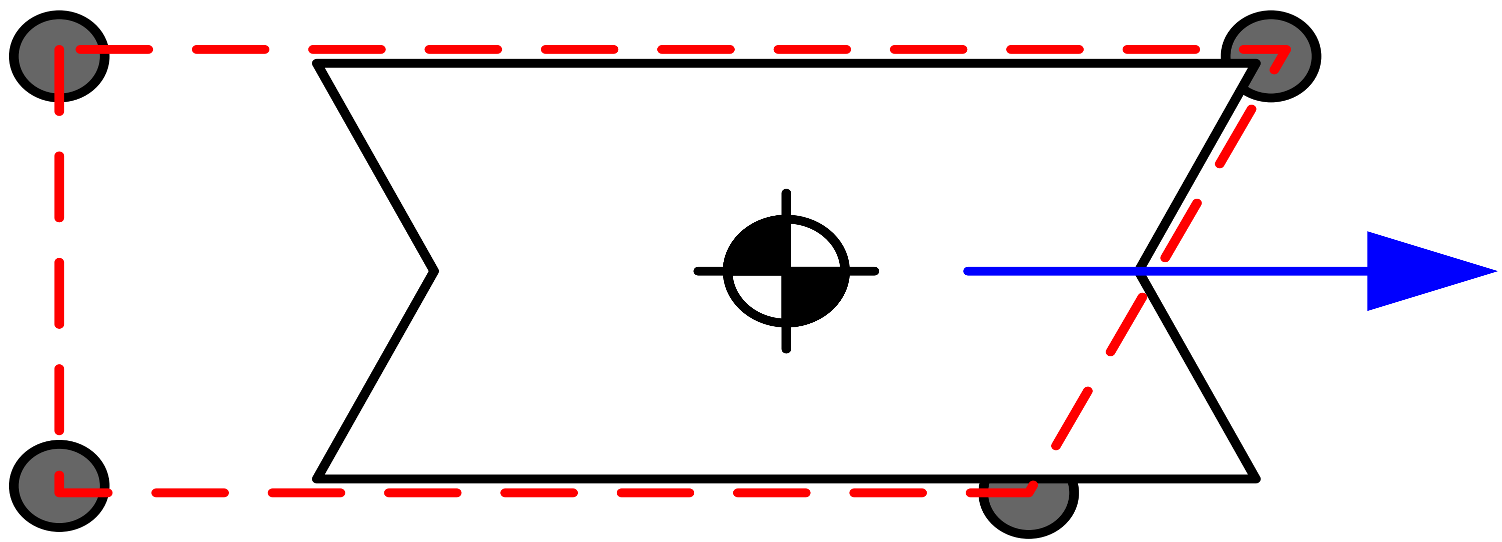

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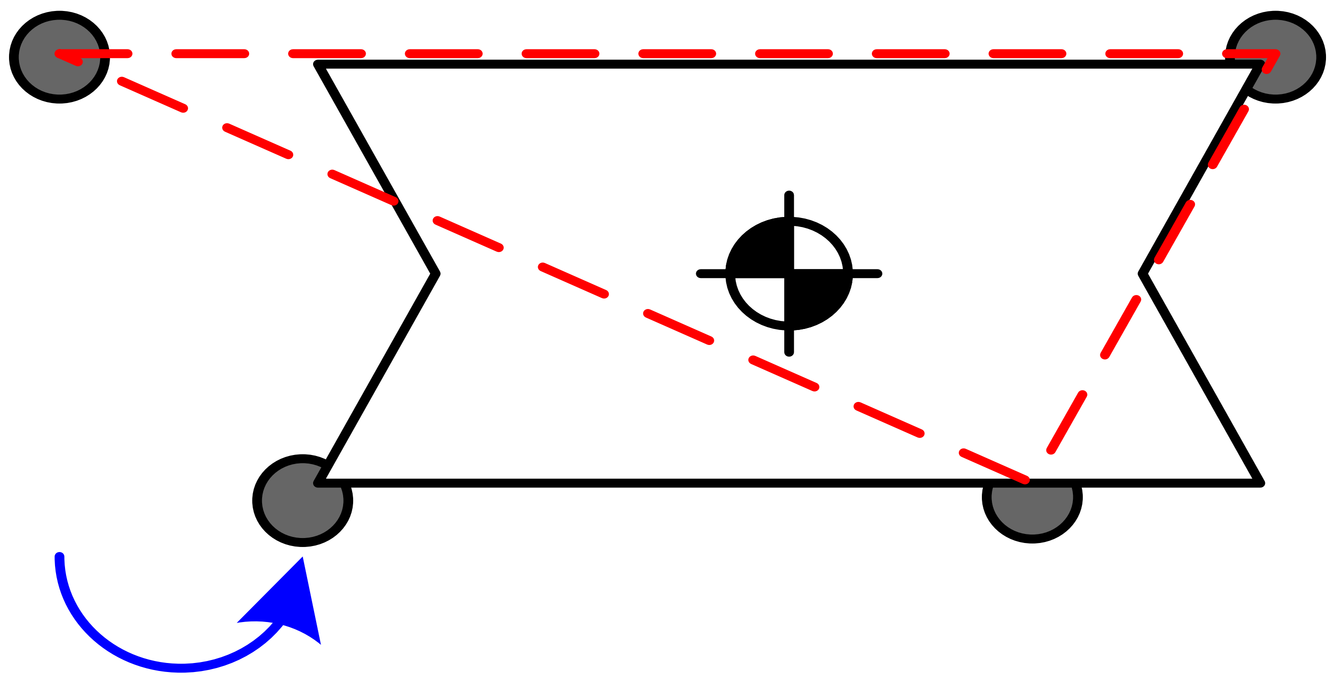

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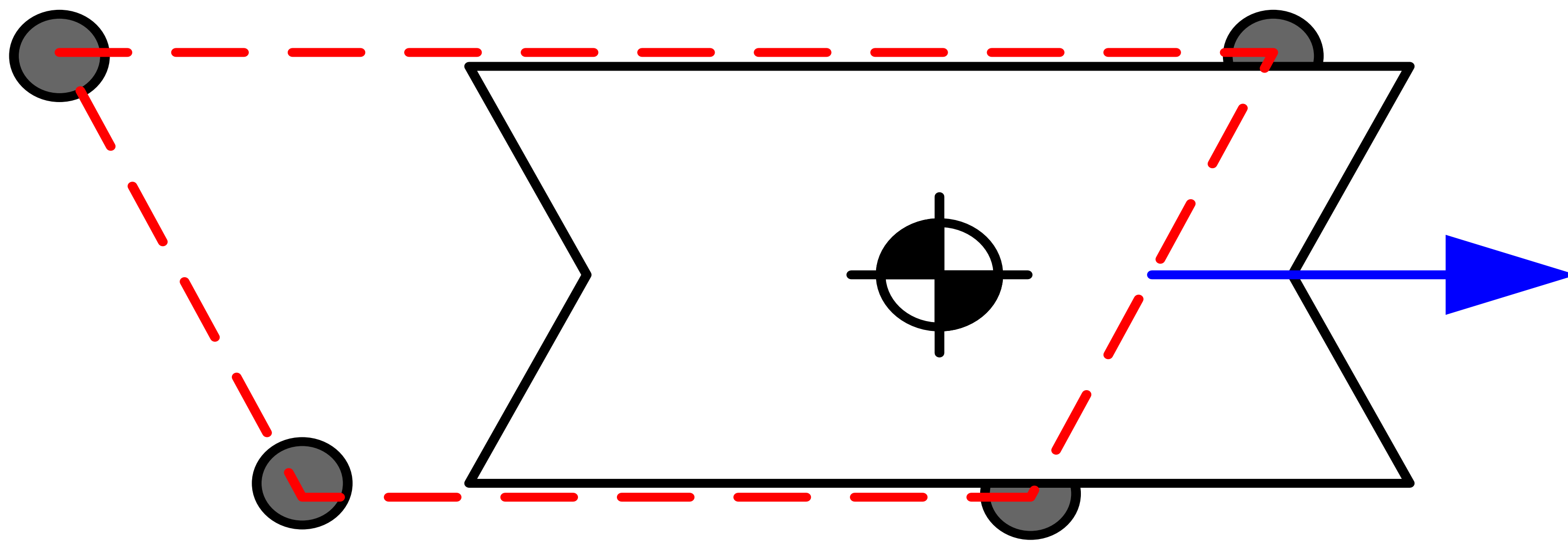

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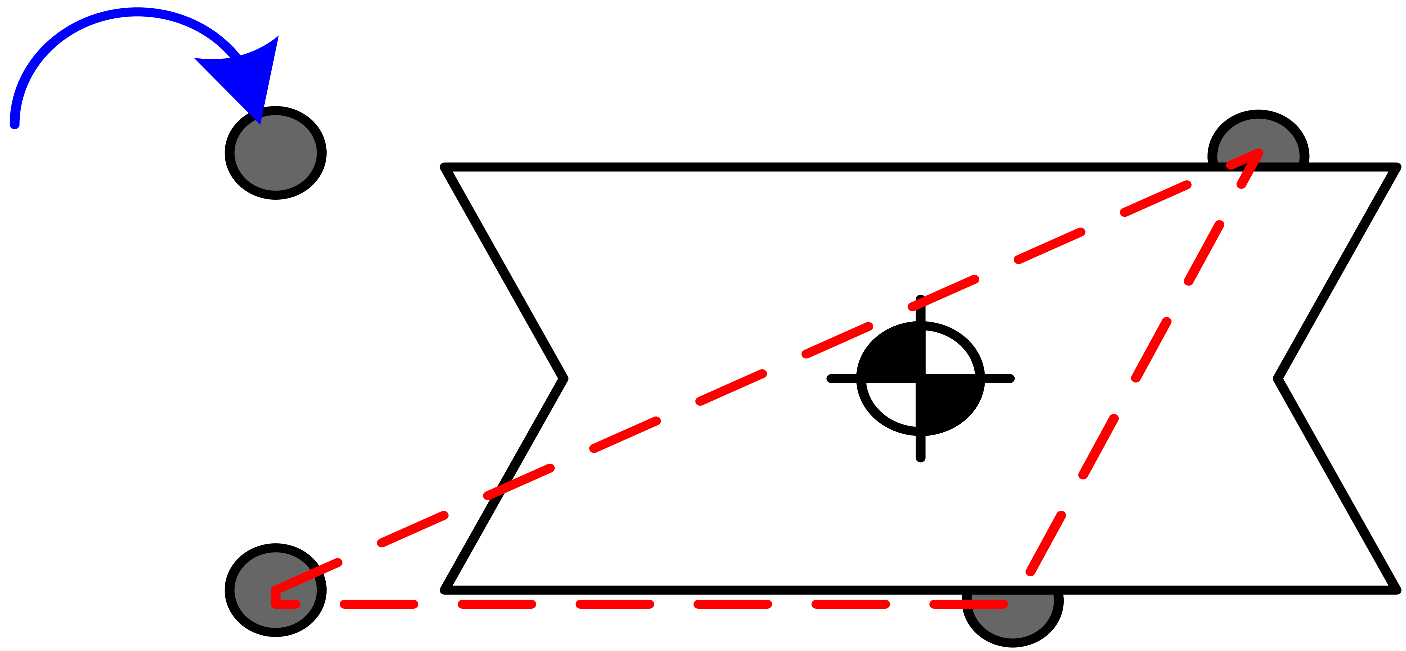
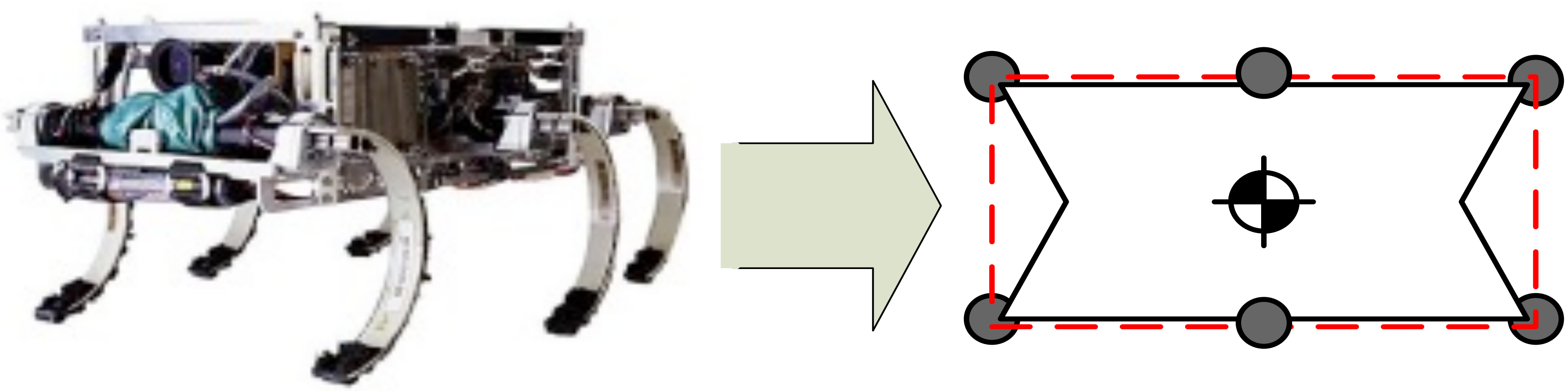
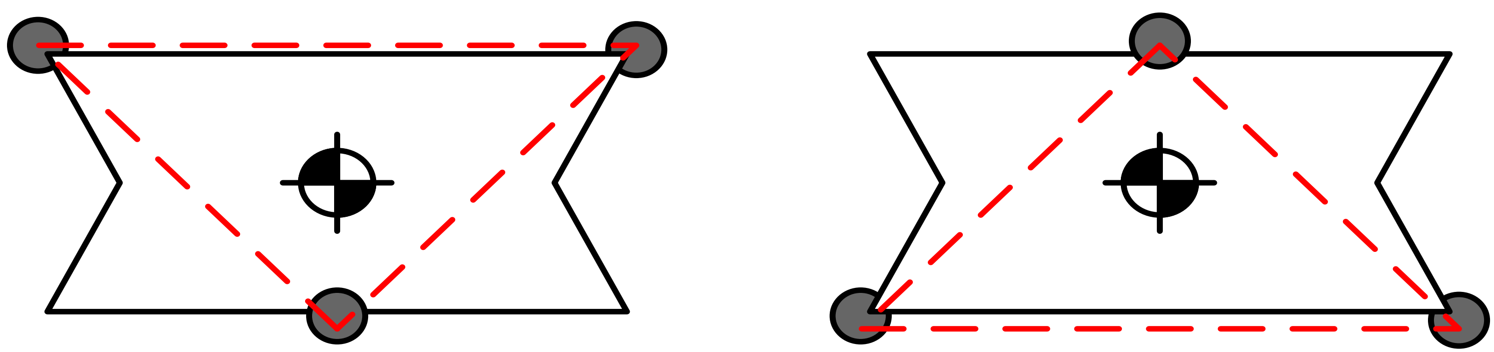


And so on...

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)