



UNIVERSITY OF
SOUTH CAROLINA

CSCE 574 ROBOTICS

Locomotion

Vehicle Locomotion

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



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

- 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

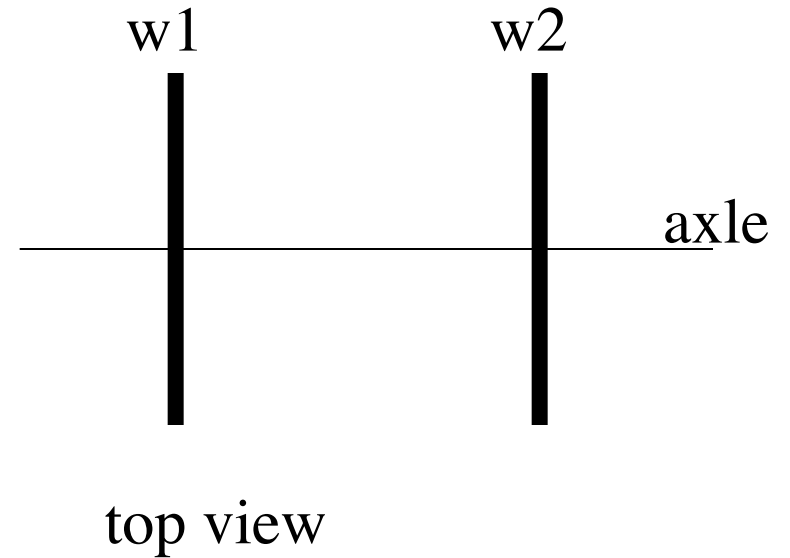
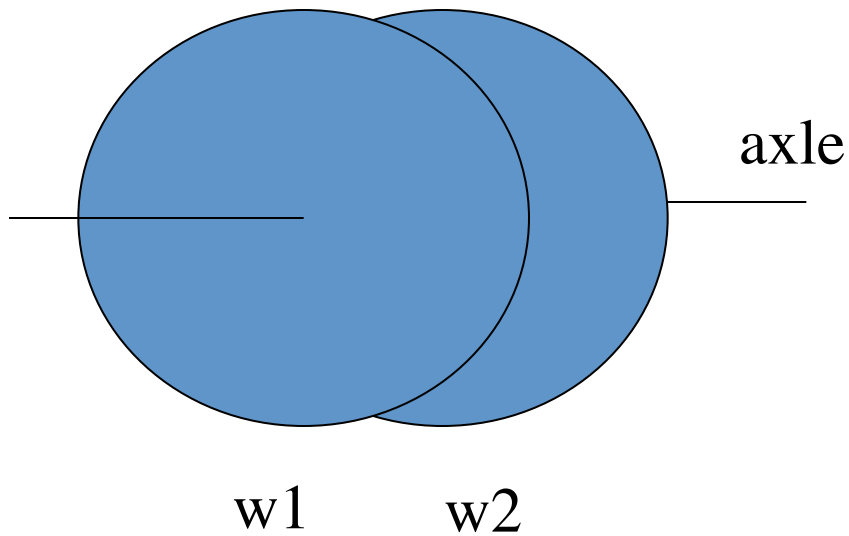
Basic design:

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



Idealized differential drive

side view



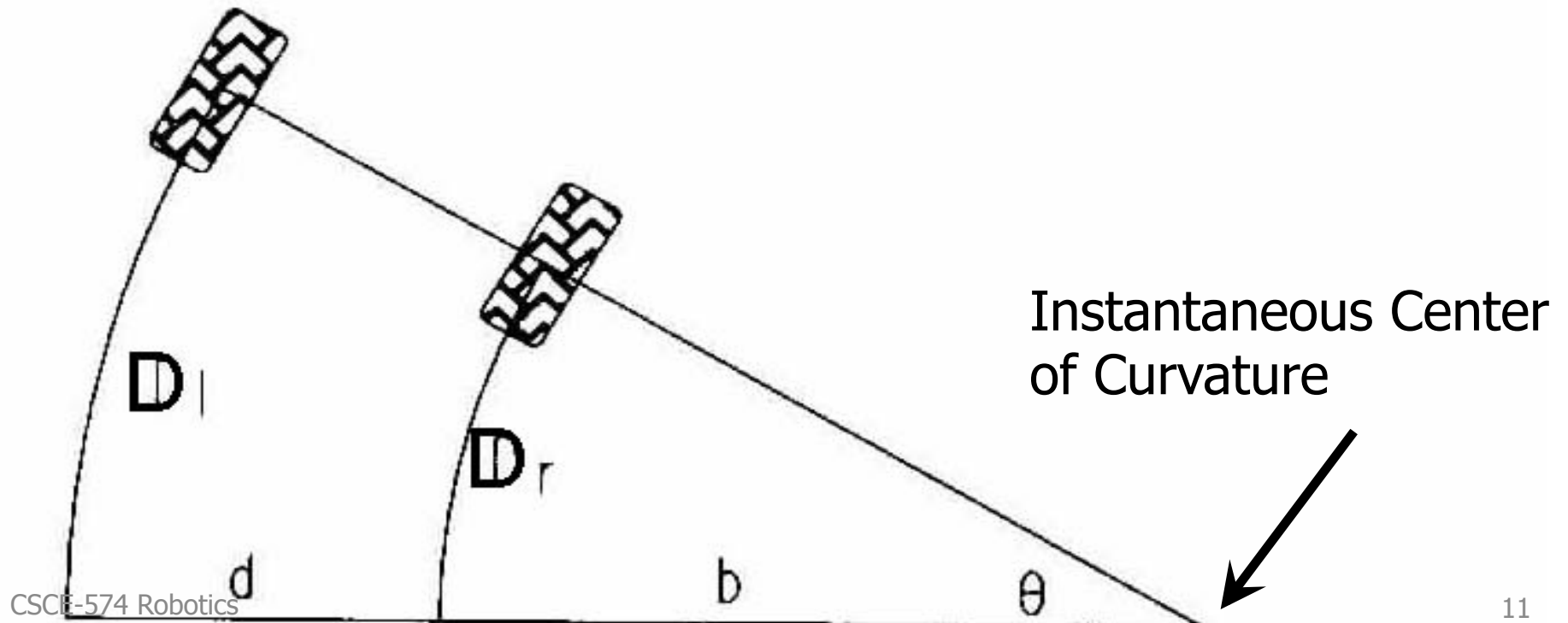
Differential Drive Intuition

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



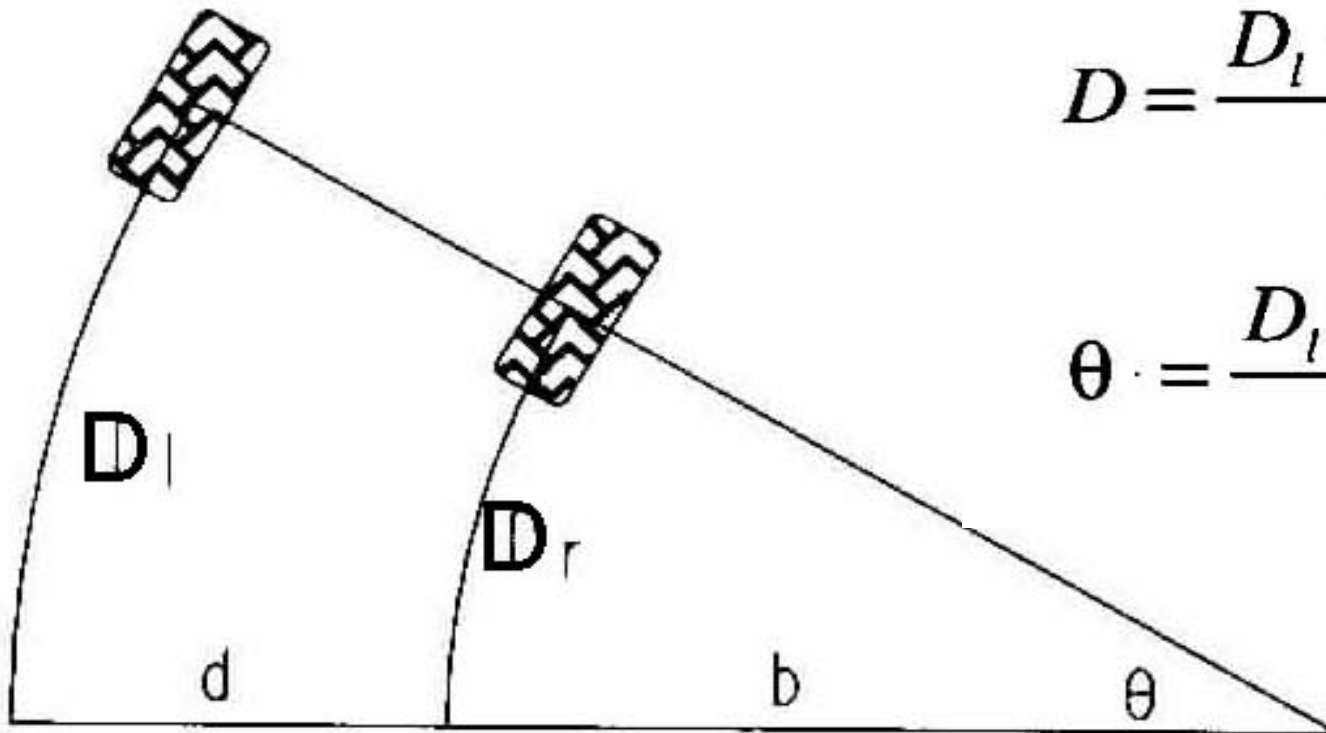
Differential Drive Observation

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

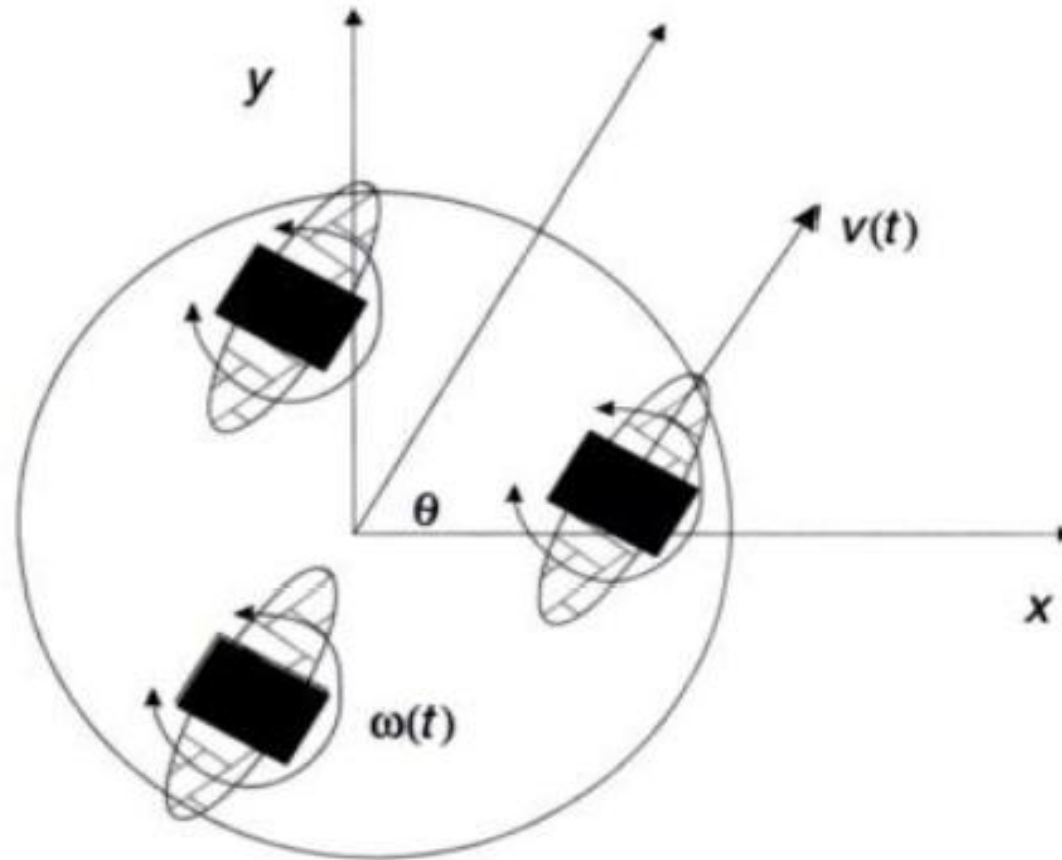


Differential Drive Issues

- 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:

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

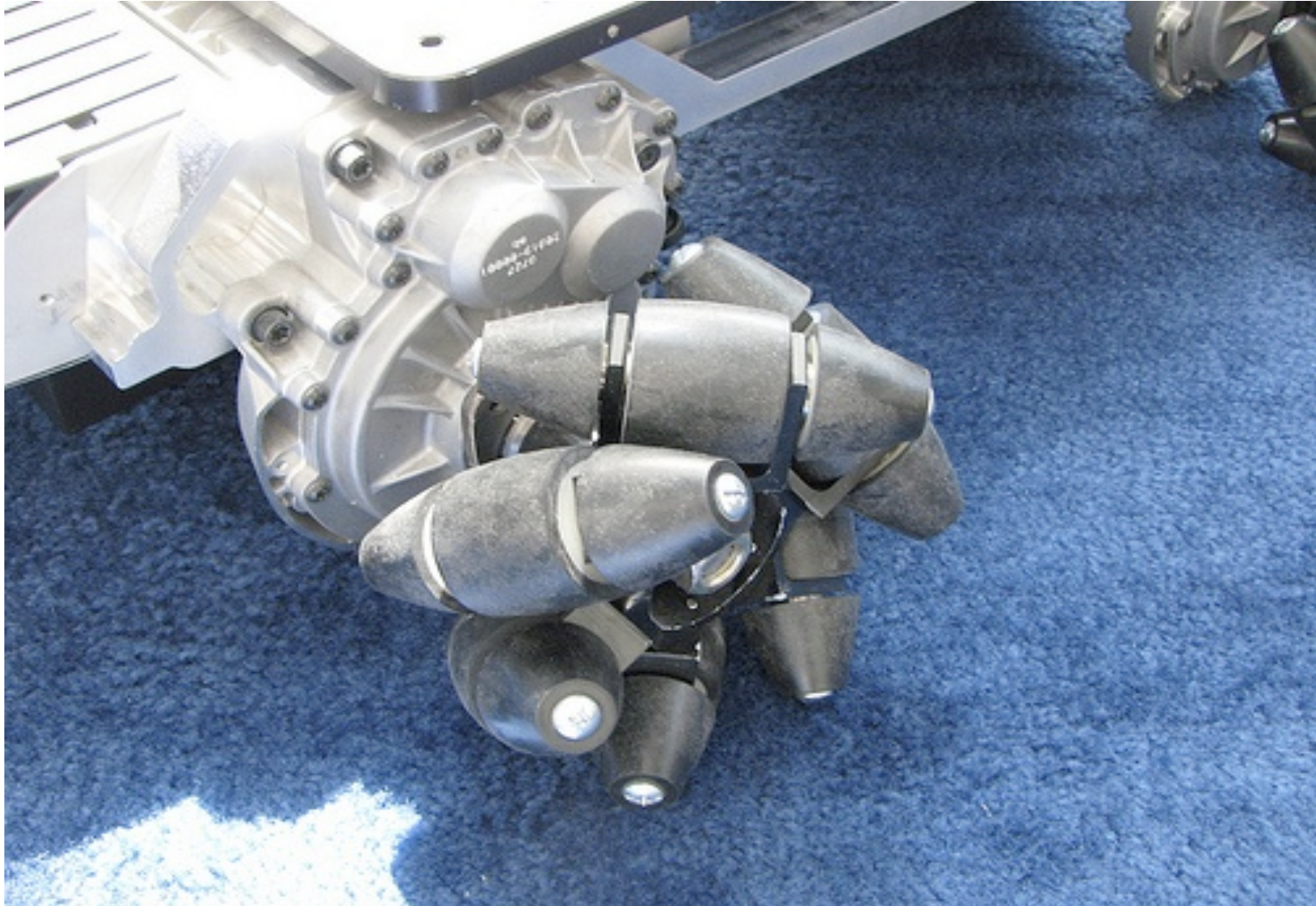
$$y(t) = \frac{1}{2} \int_0^t v(t) \sin[\theta(t)] dt$$

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

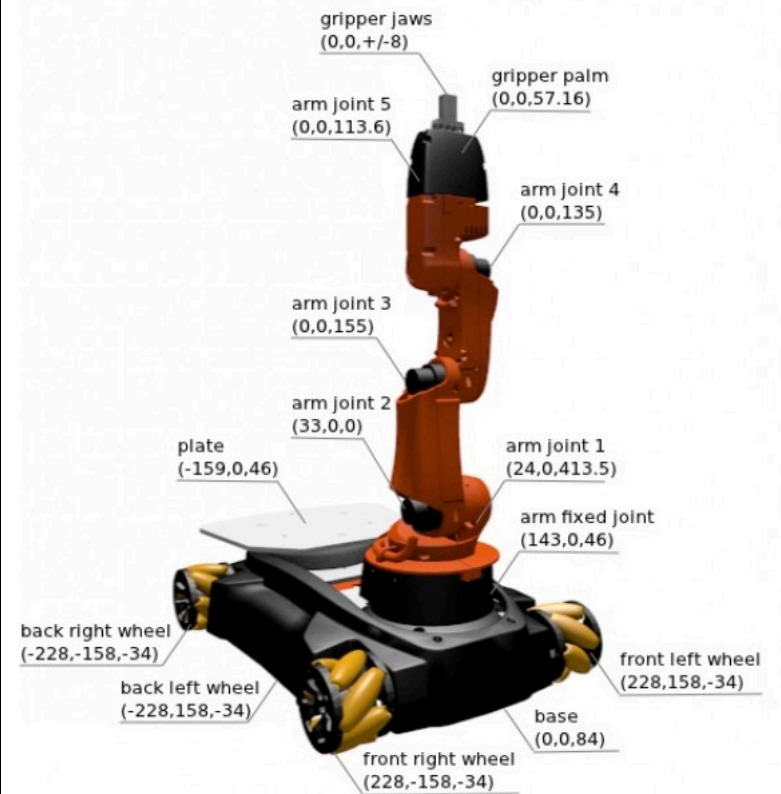
- Will not suffer from mechanical mismatch compared to Diff. Drive



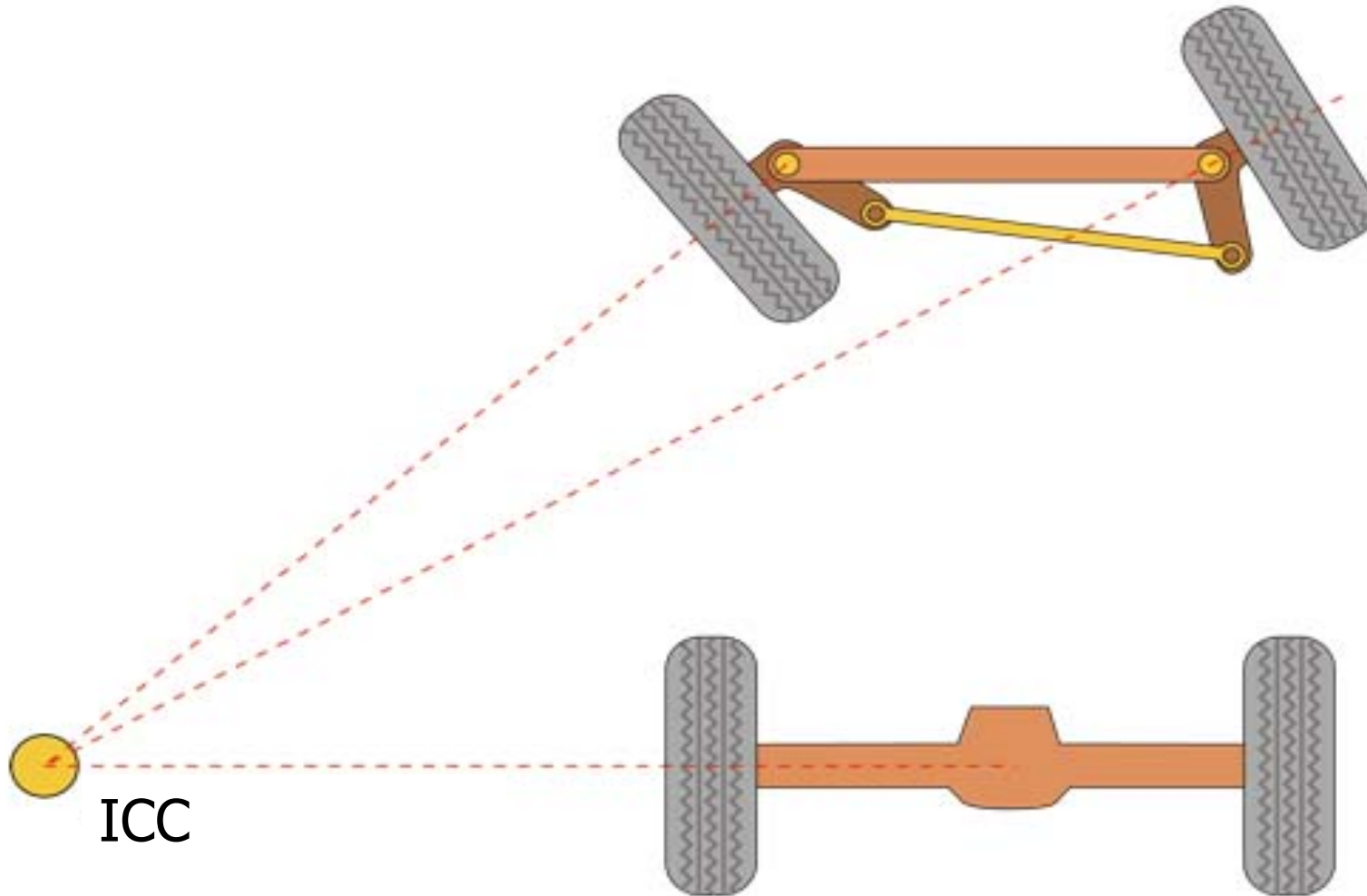
Mecanum Wheels



Mecanum Wheels

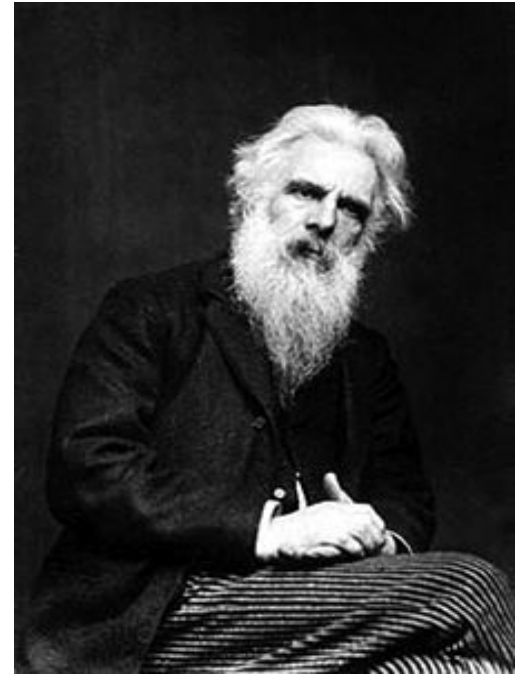


Ackerman (Used in Cars)



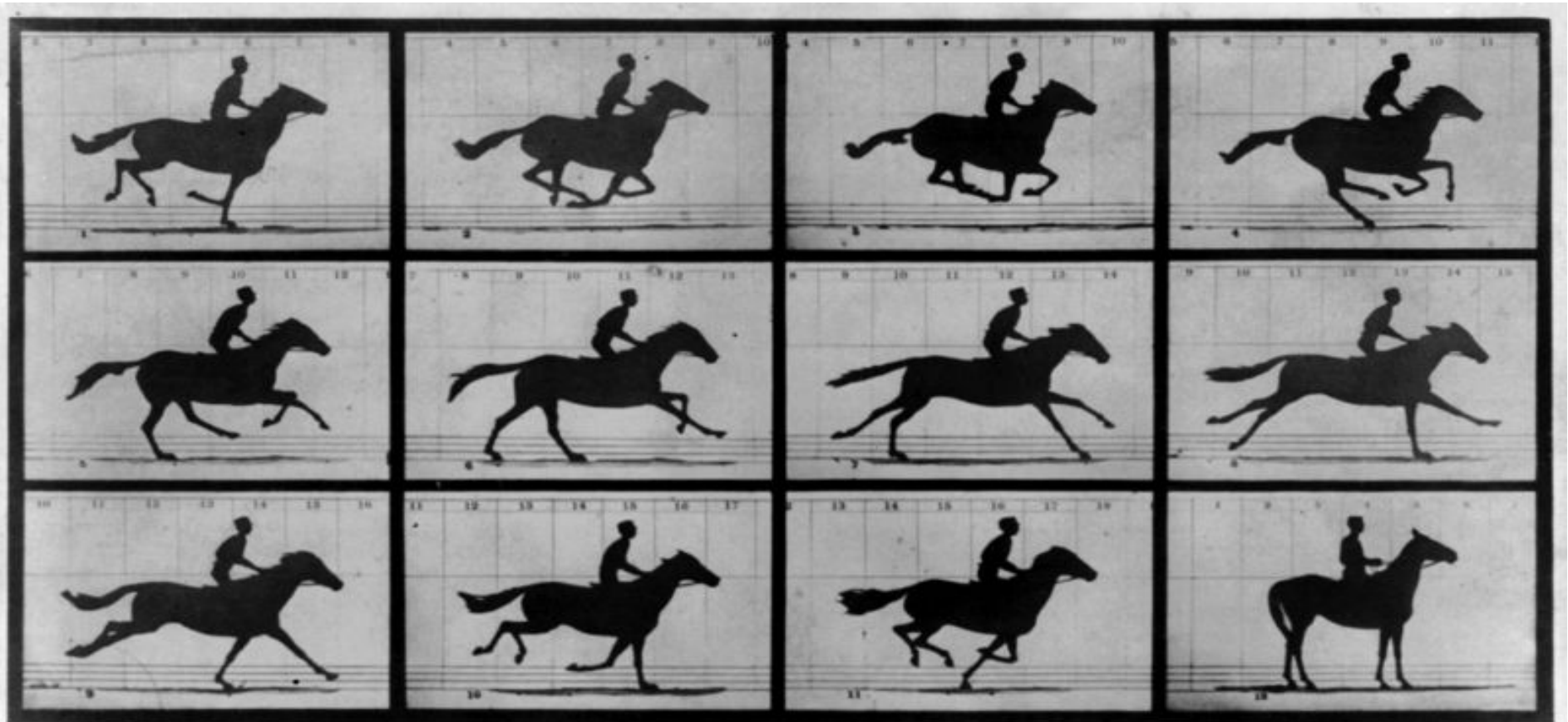
Legged Locomotion

- 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



Copyright, 1878, by MUYBRIDGE.

MORSE'S Gallery, 477 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.



Hildebrand Gait Diagrams

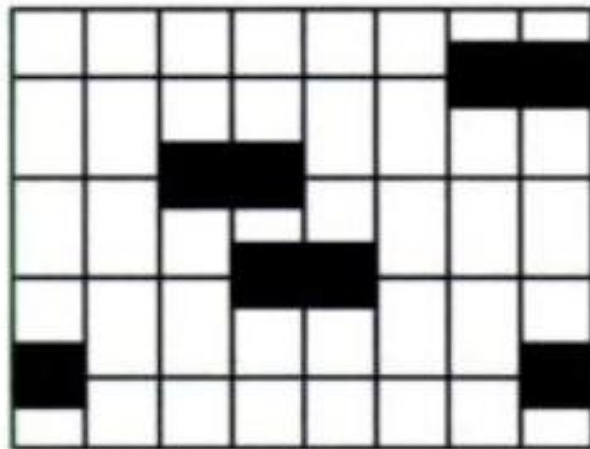
Trot

Front Left

Front Right

Back Left

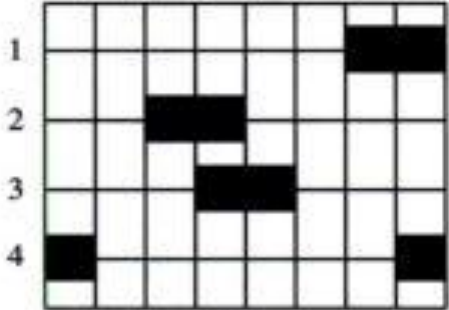
Back Right



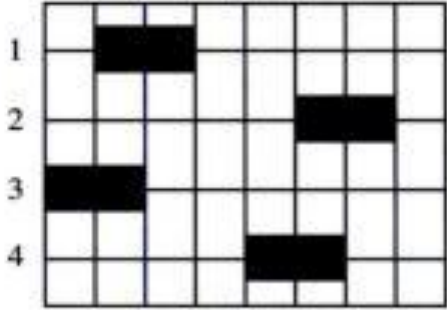
↑ Trot ↑
Ballistic Phase



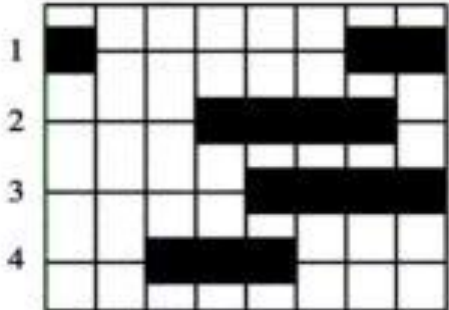
Hildebrand Gait Diagrams



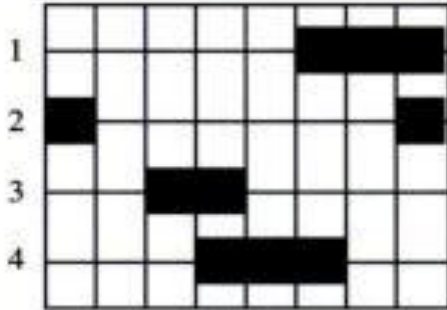
Trot



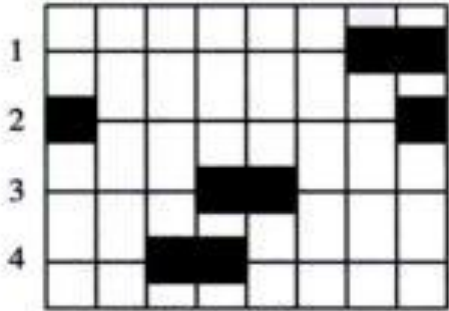
Rack



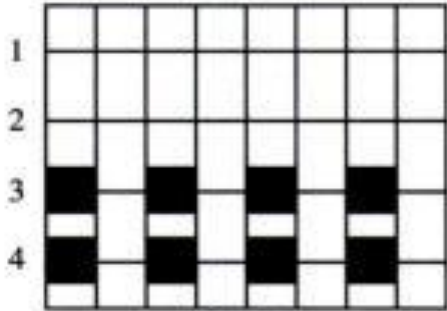
Canter



Transverse Gallop



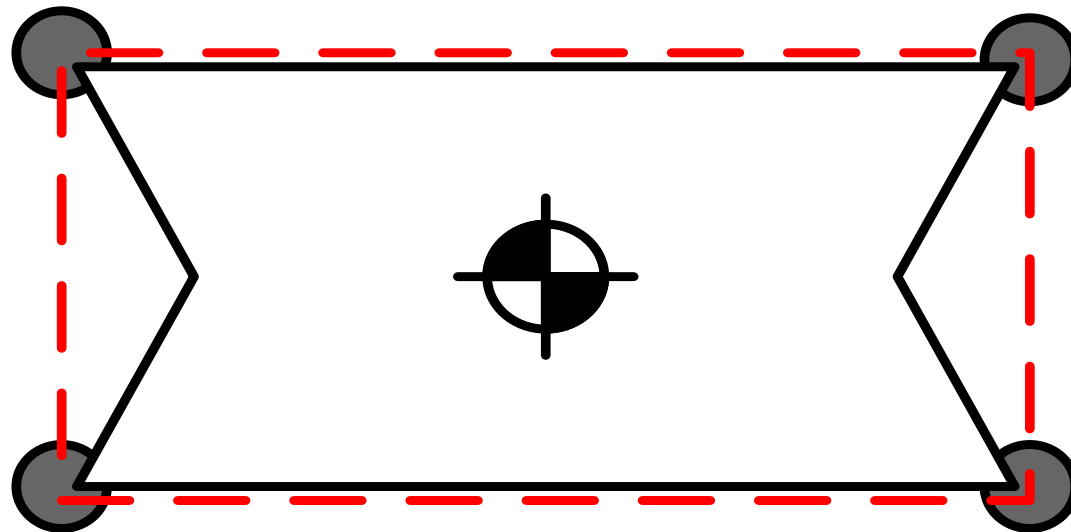
Rotary Gallop



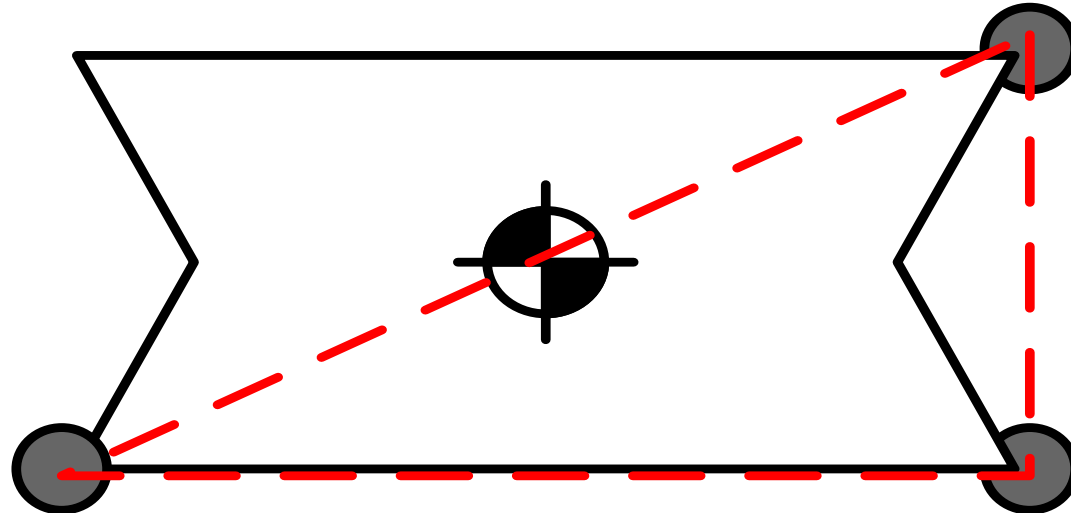
Ricochet



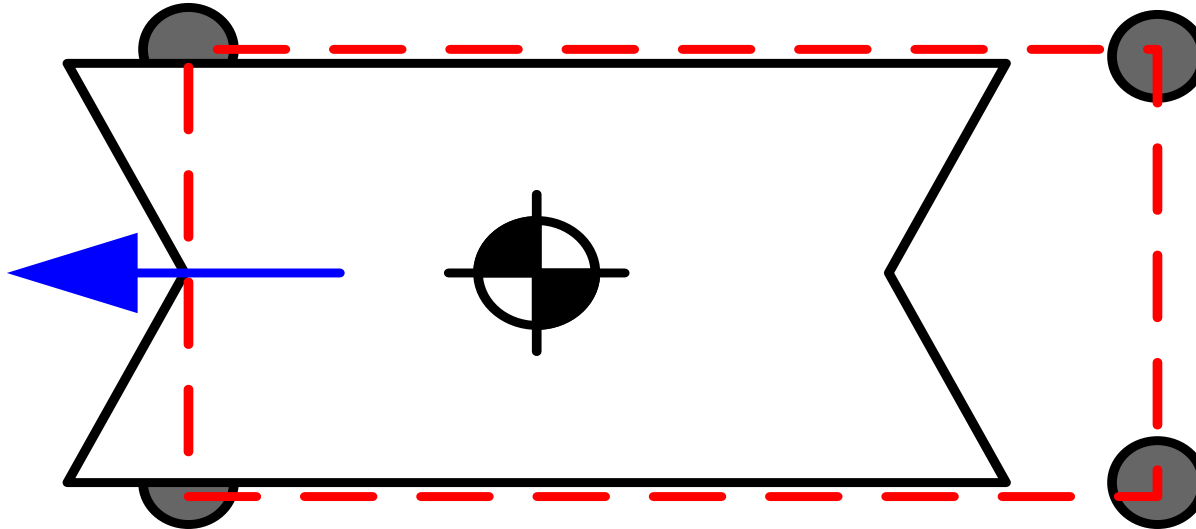
Support Polygon



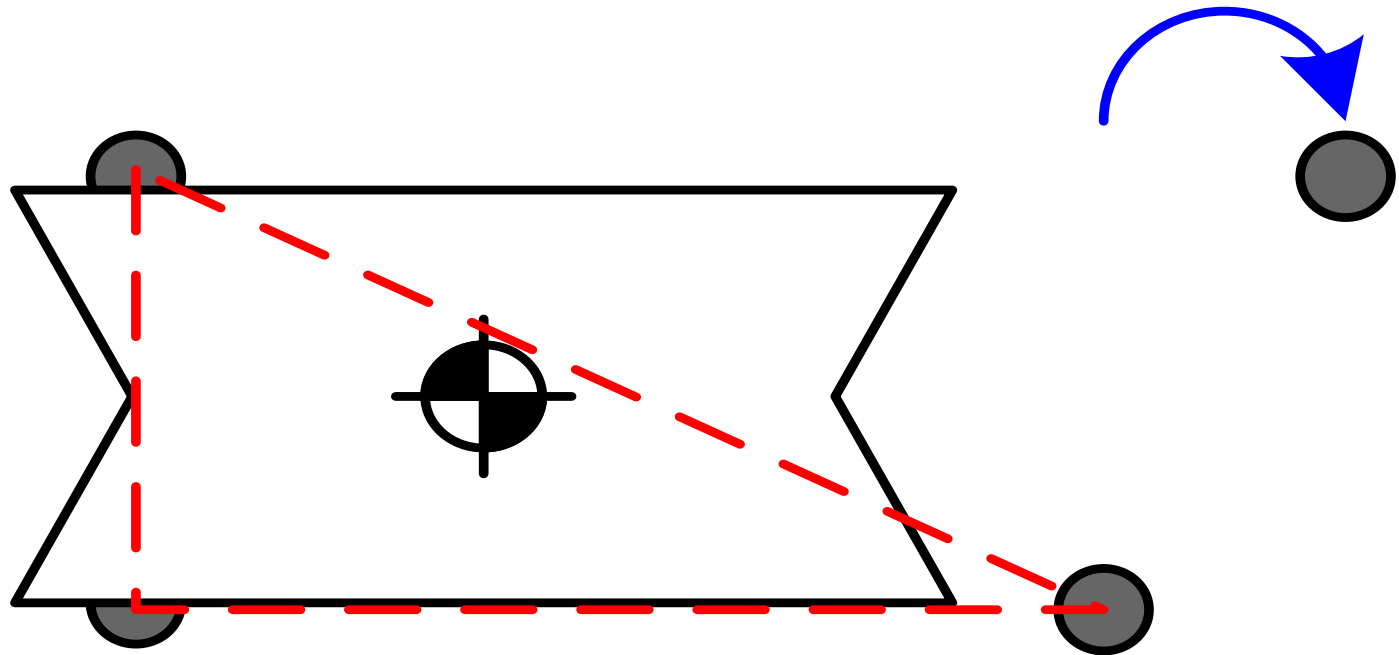
Support Polygon



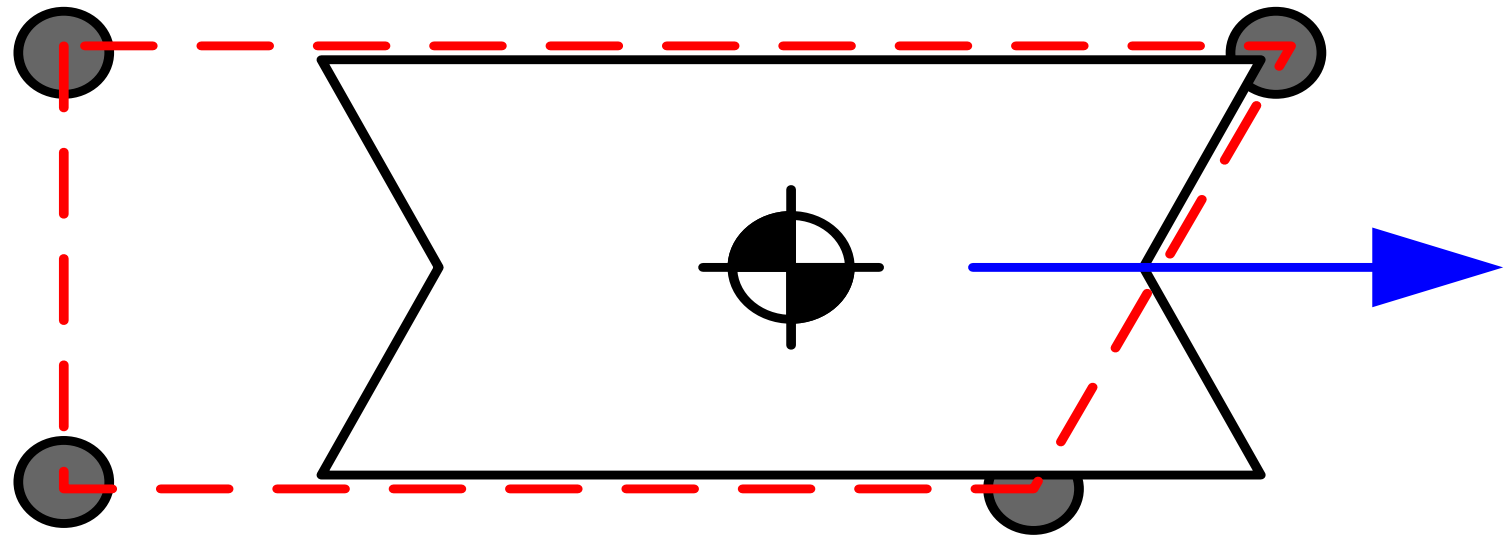
Support Polygon



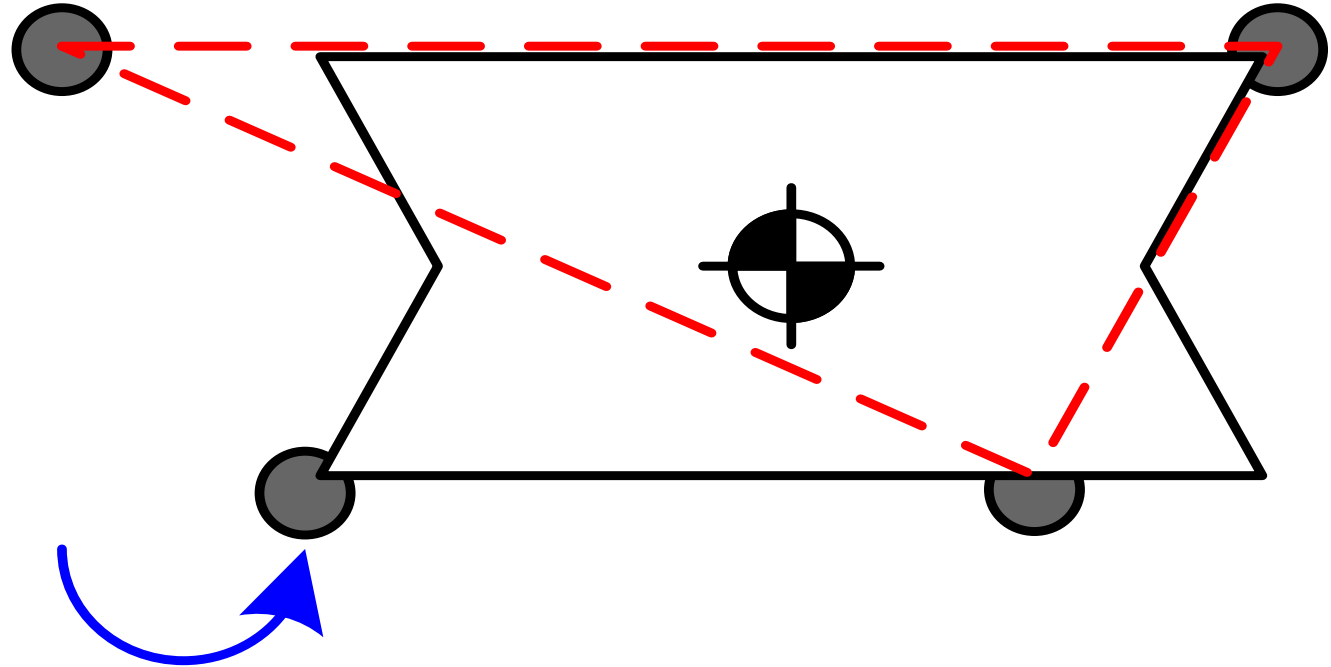
Support Polygon



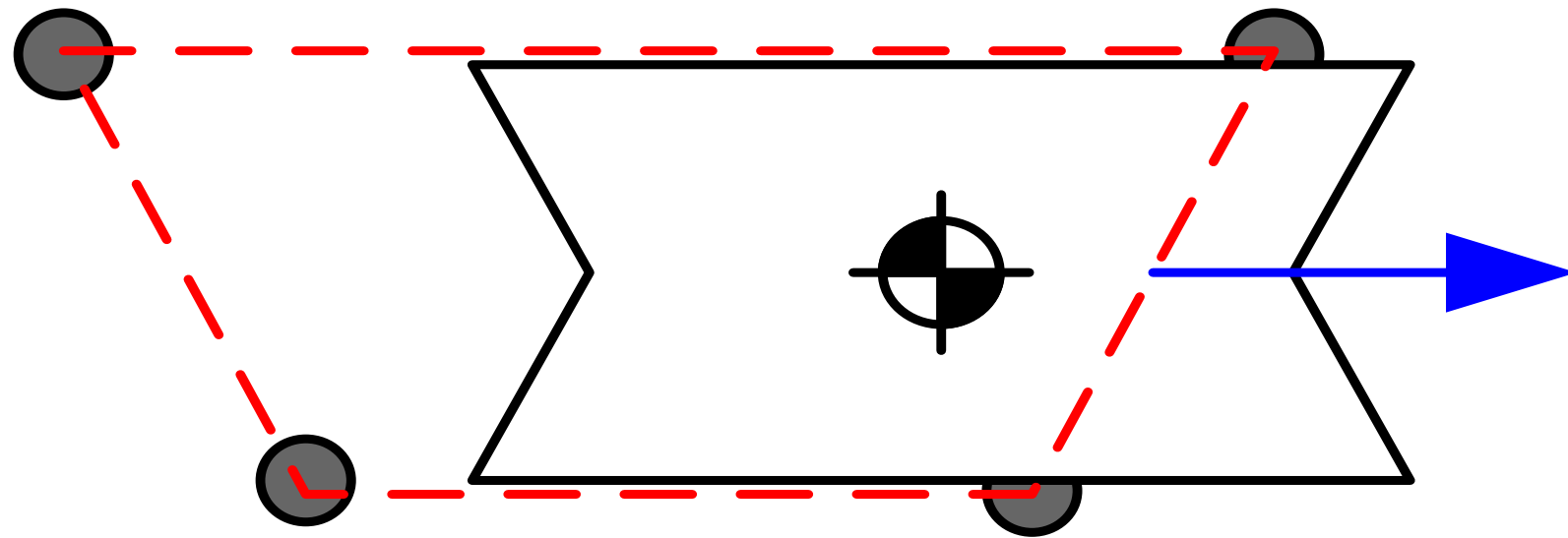
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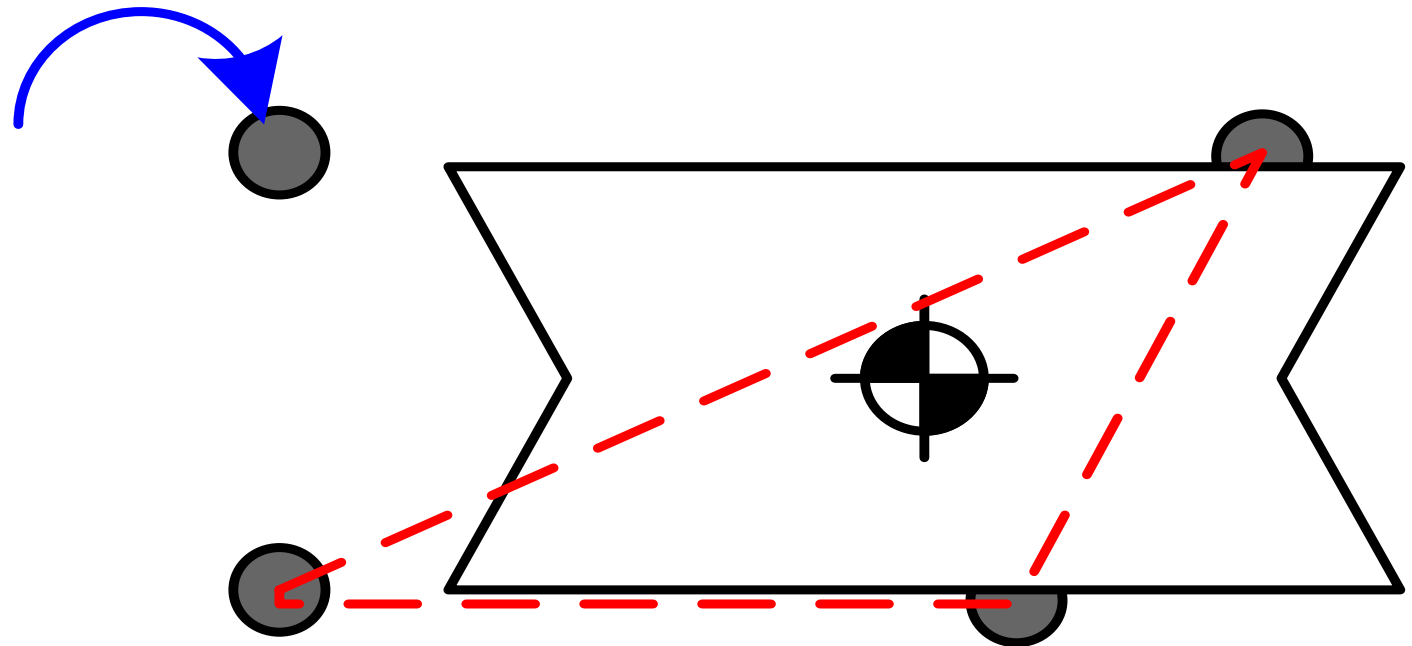
Support Polygon



Support Polygon

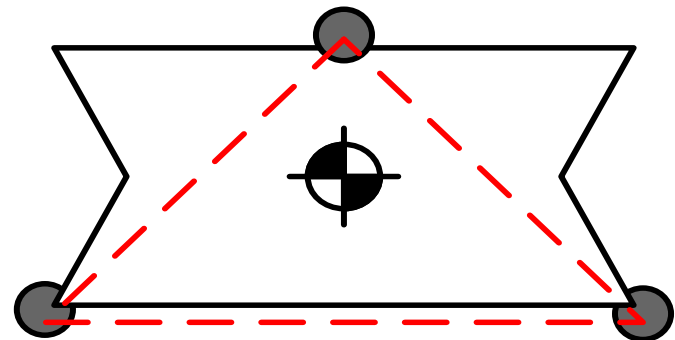
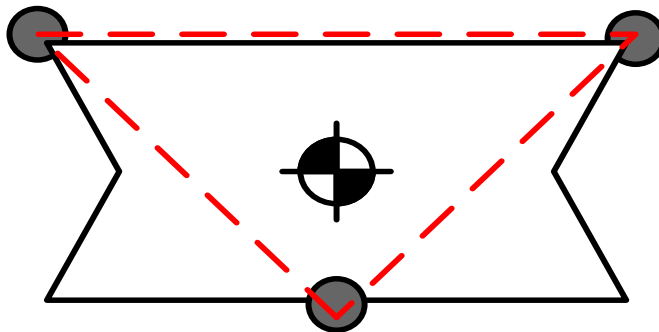
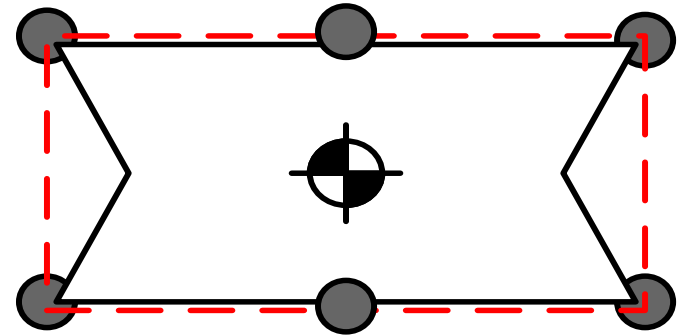
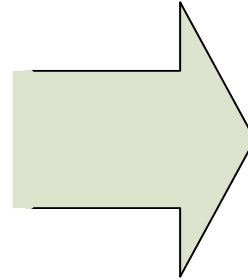


Support Polygon



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)

