



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

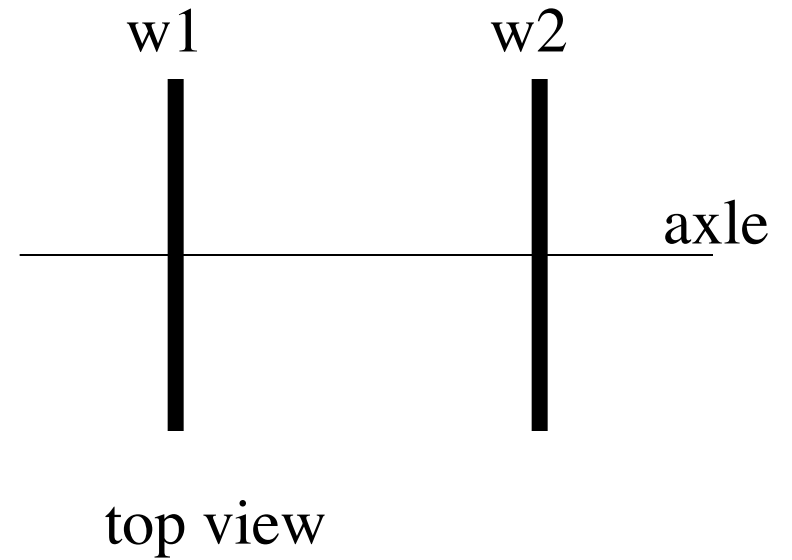
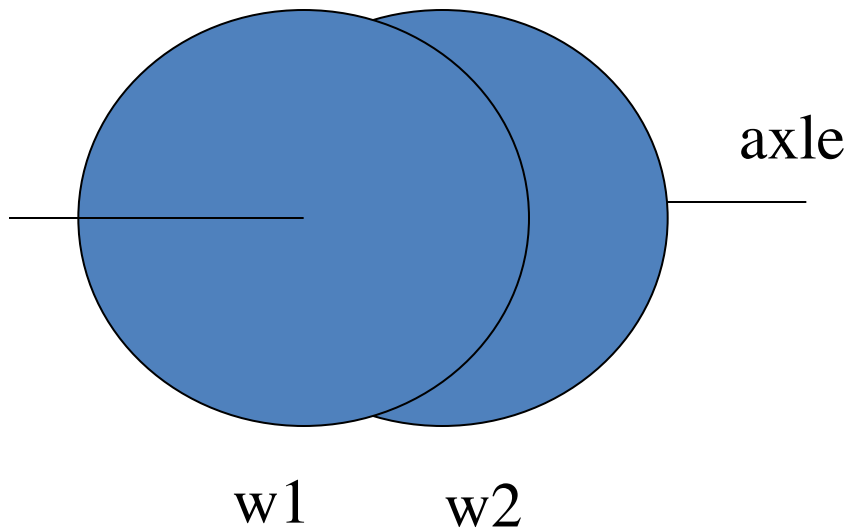
Basic design:

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



Idealized differential drive

side view



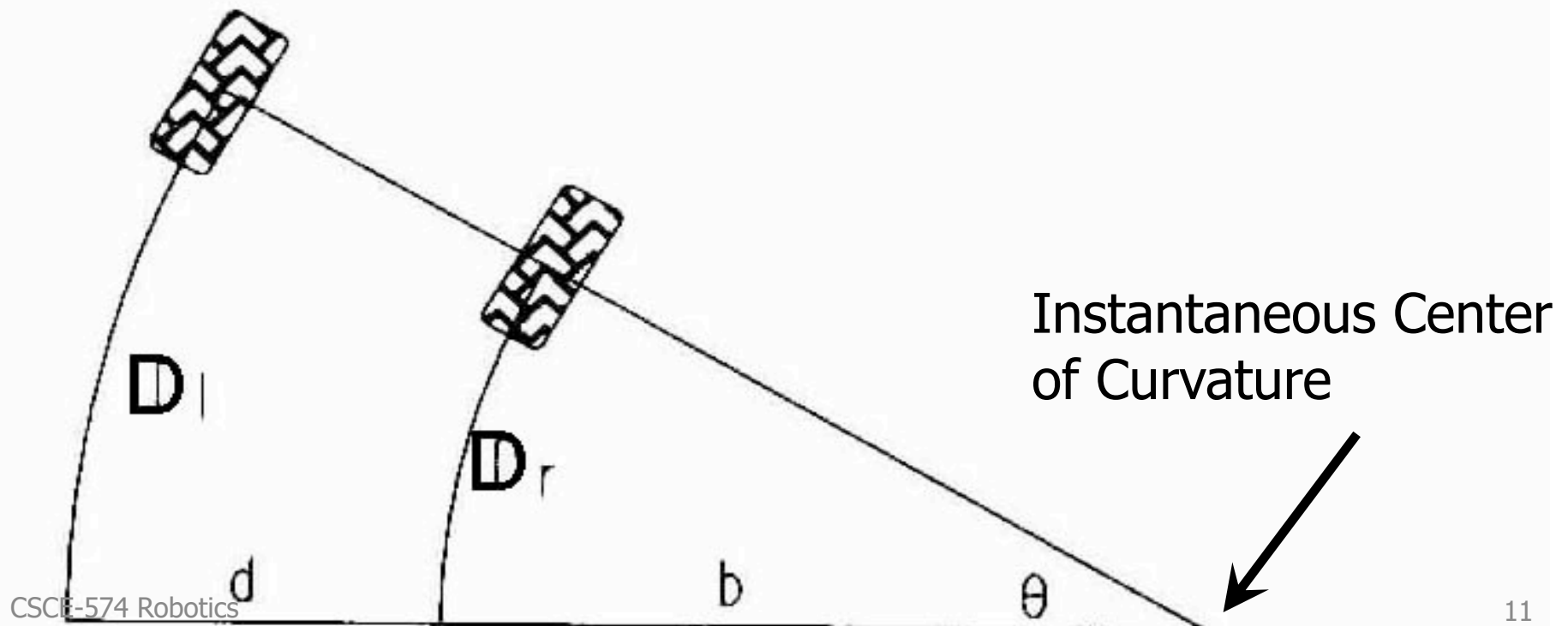
Differential Drive Intuition

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



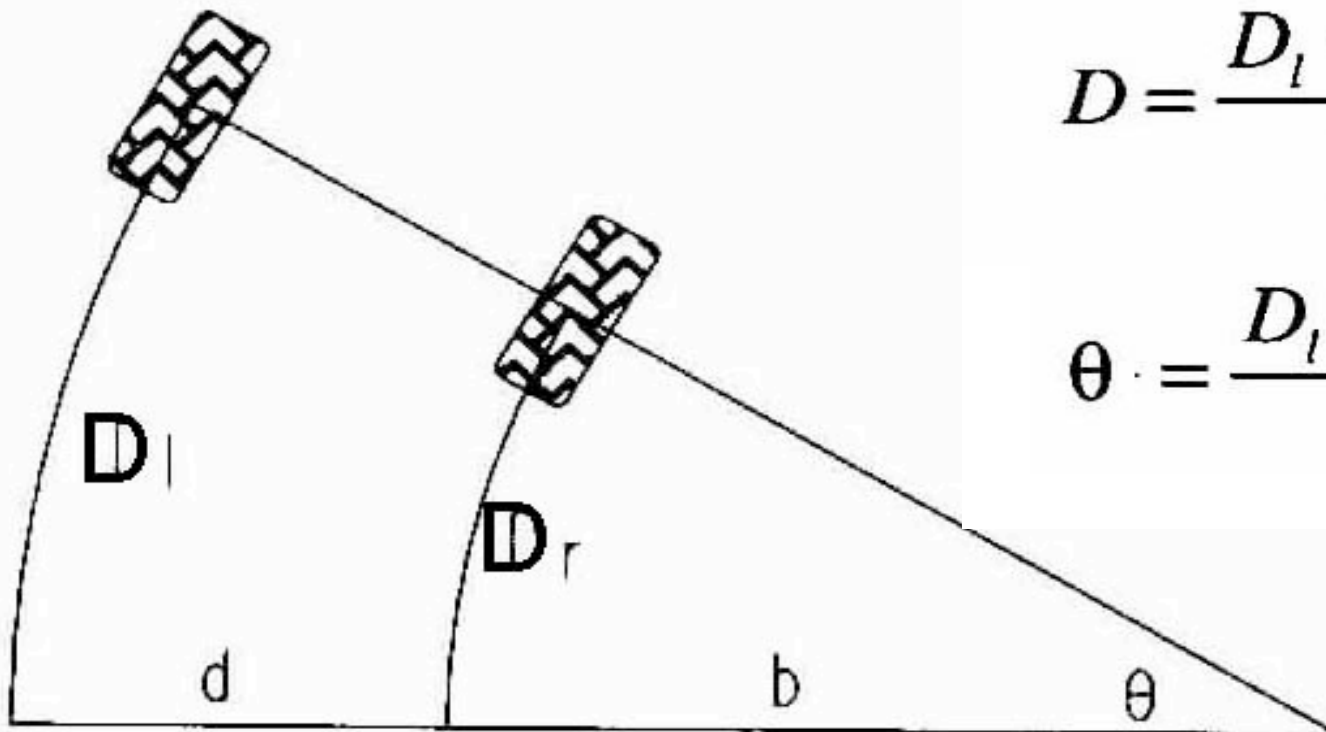
Differential Drive Observation

- 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...

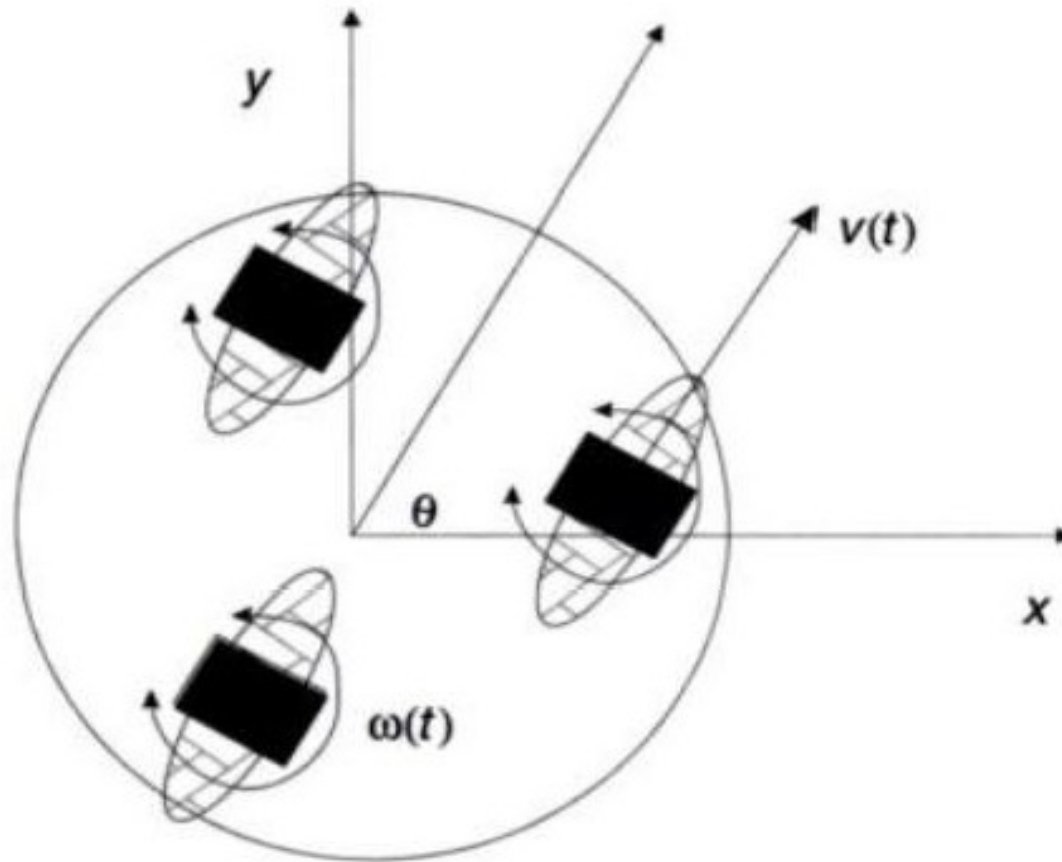


Differential Drive Issues

- 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:

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

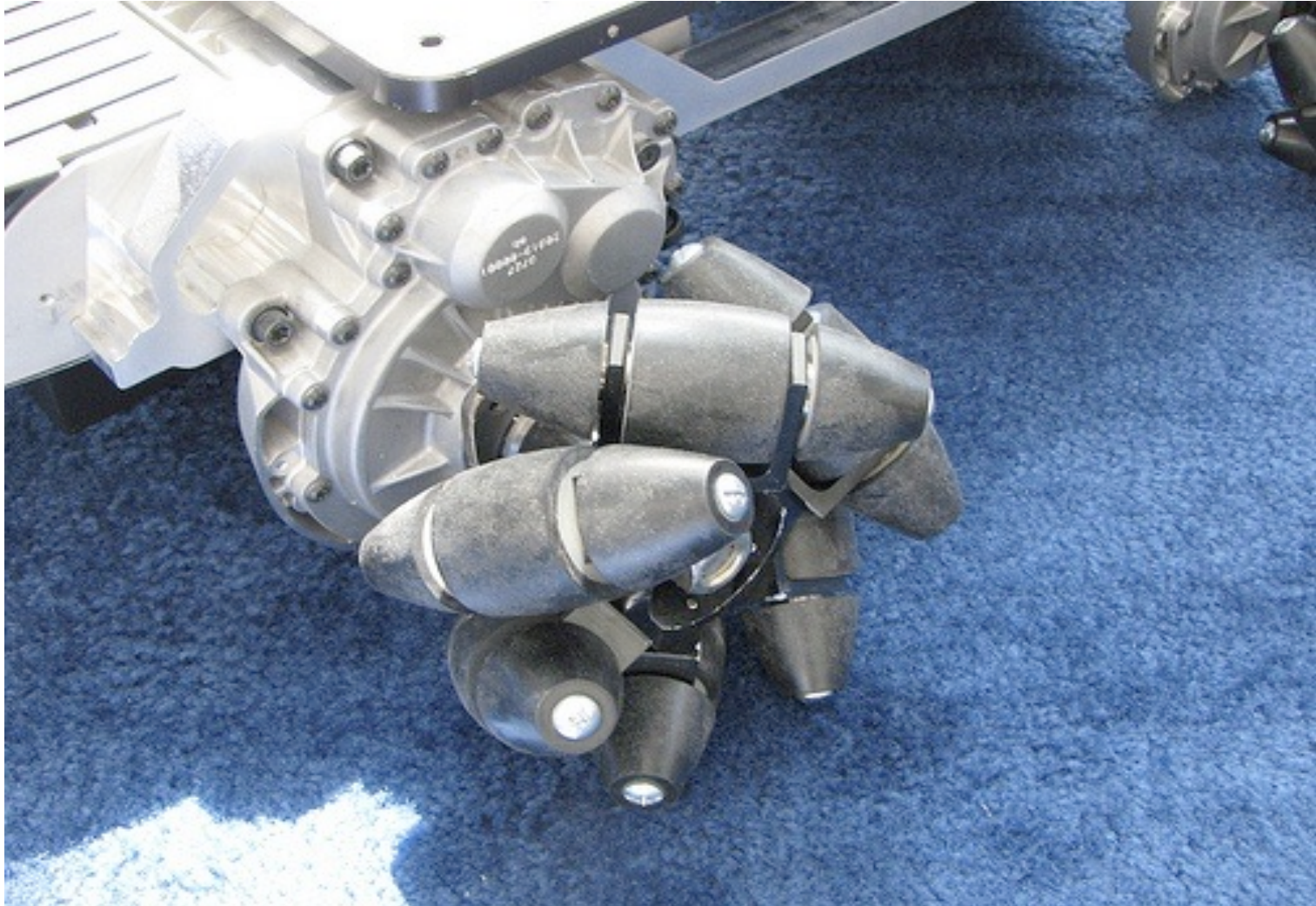
$$y(t) = \frac{1}{2} \int_0^t v(t) \sin[\theta(t)] dt$$

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

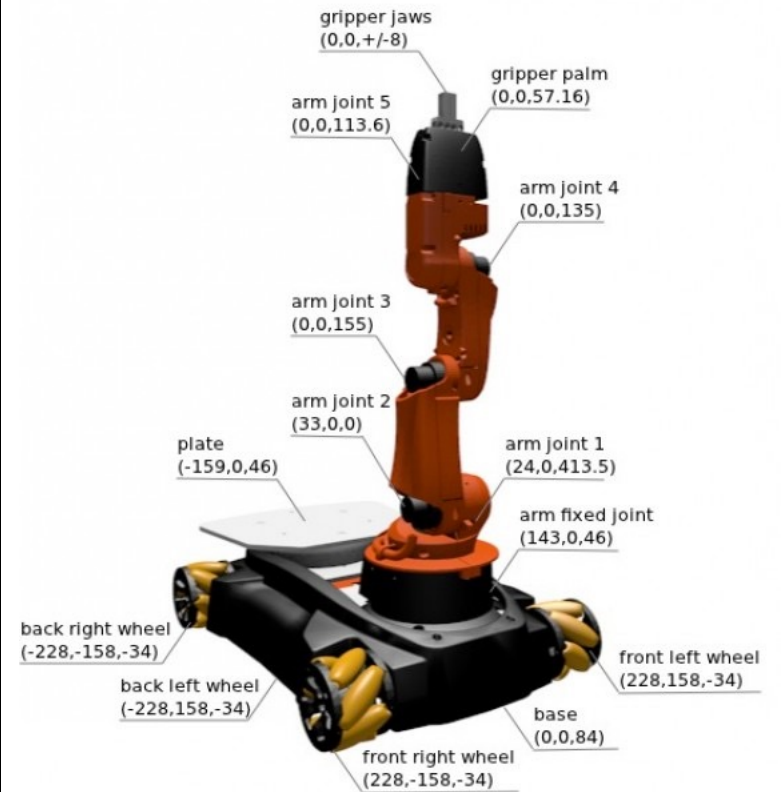
- Will not suffer from mechanical mismatch compared to Diff. Drive



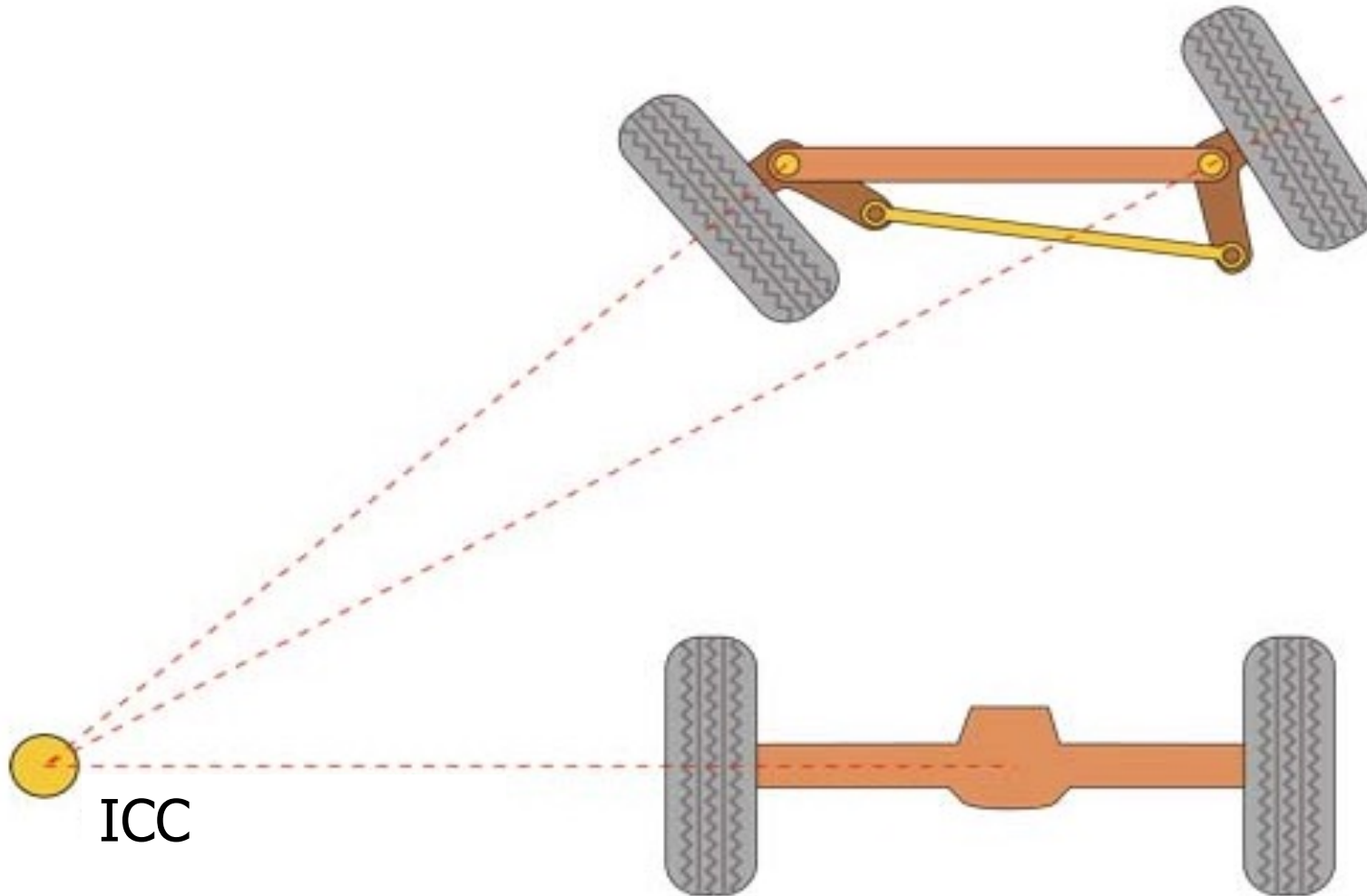
Mecanum Wheels



Mecanum Wheels

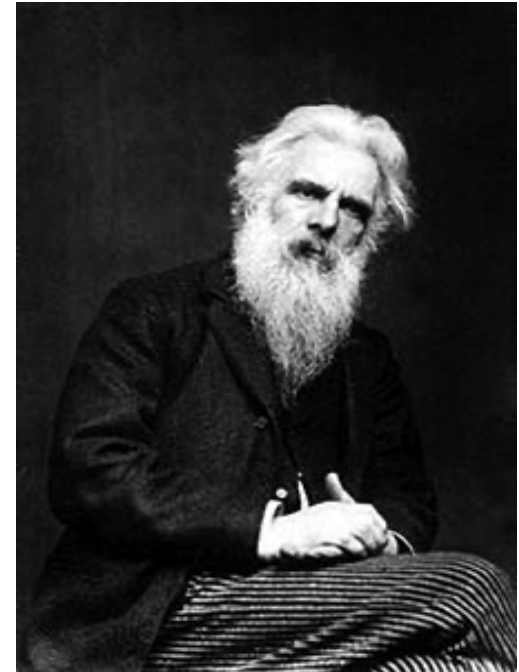


Ackerman (Used in Cars)



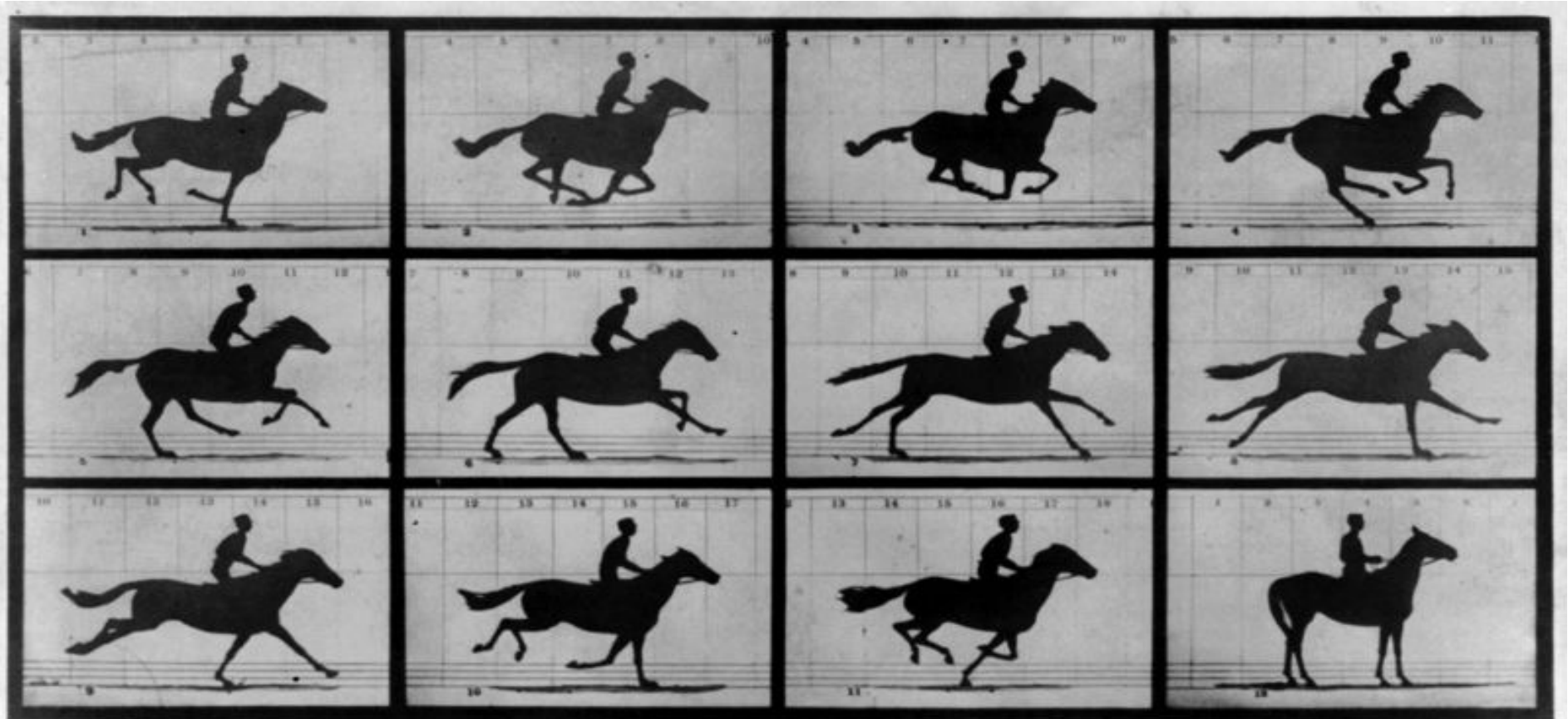
Legged Locomotion

- 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.

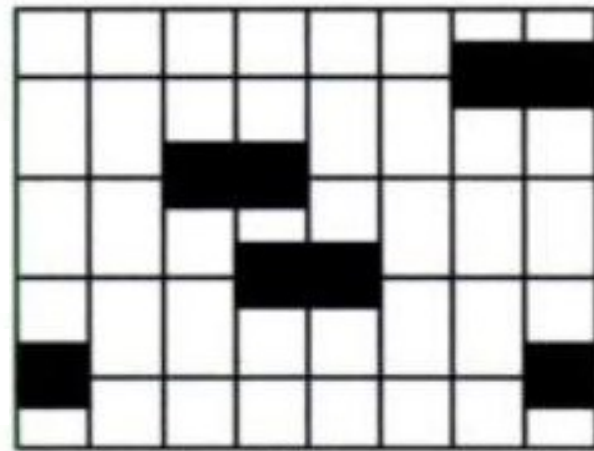
"SALLIE GARDNER," owned by LELAND STANFORD; running at a 1.40 gait over the Palo Alto track, 19th June, 1878.

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

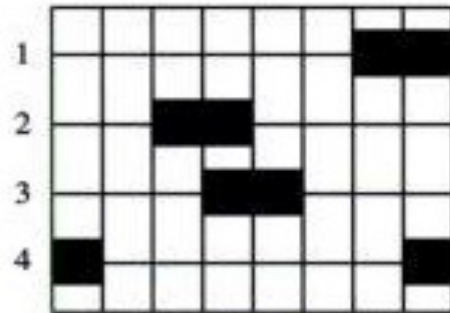
Trot



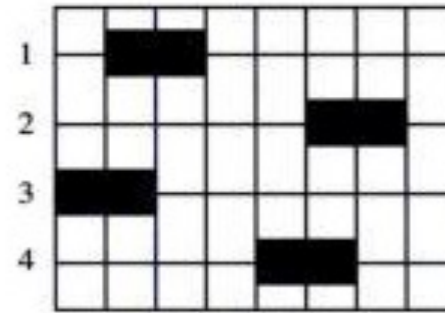
↑ Trot ↑
Ballistic Phase



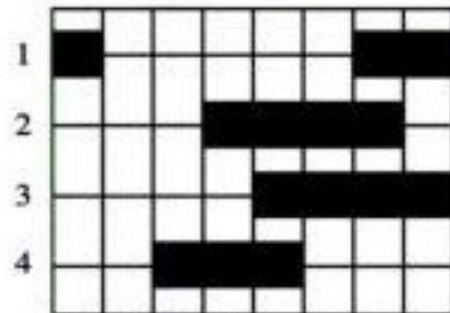
Hildebrand Gait Diagrams



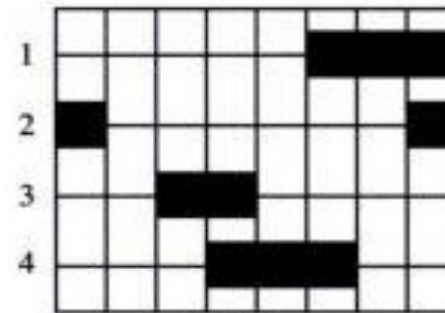
Trot



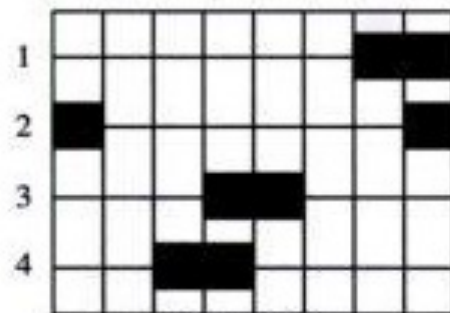
Rack



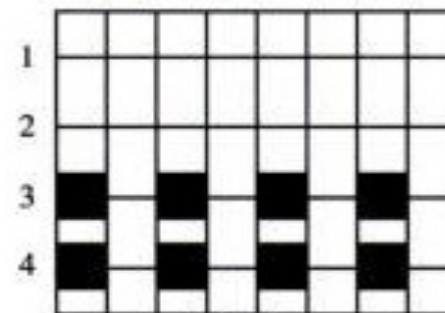
Canter



Transverse Gallop



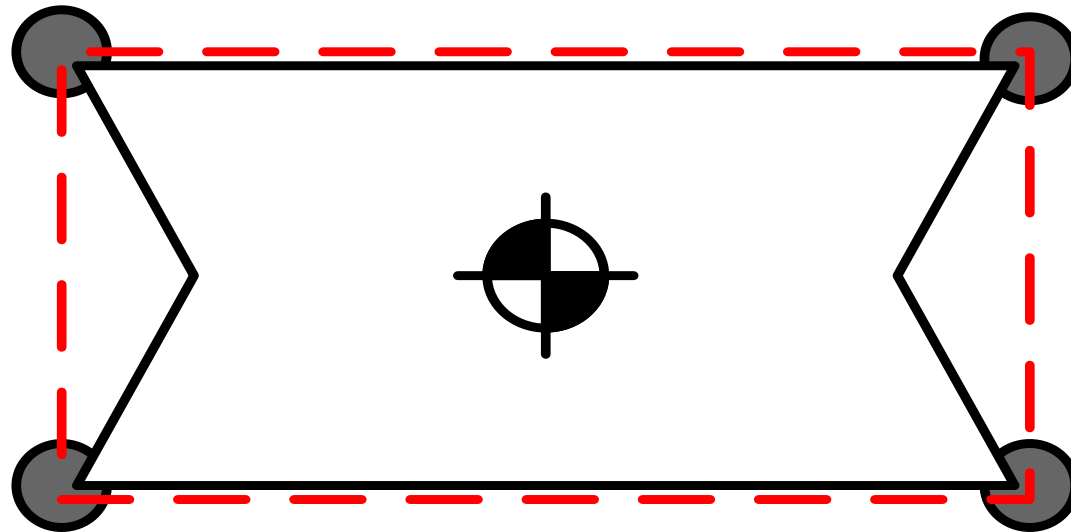
Rotary Gallop



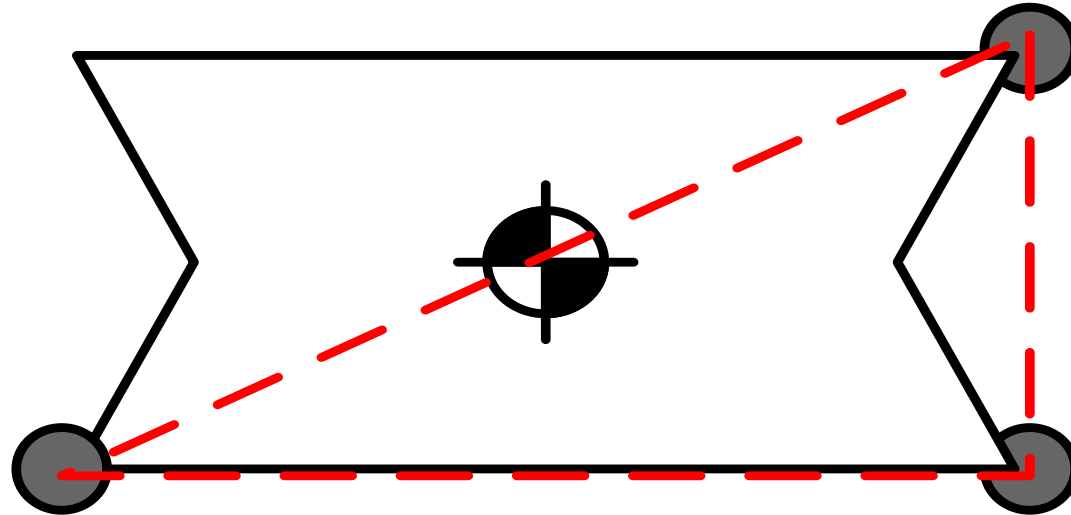
Ricochet



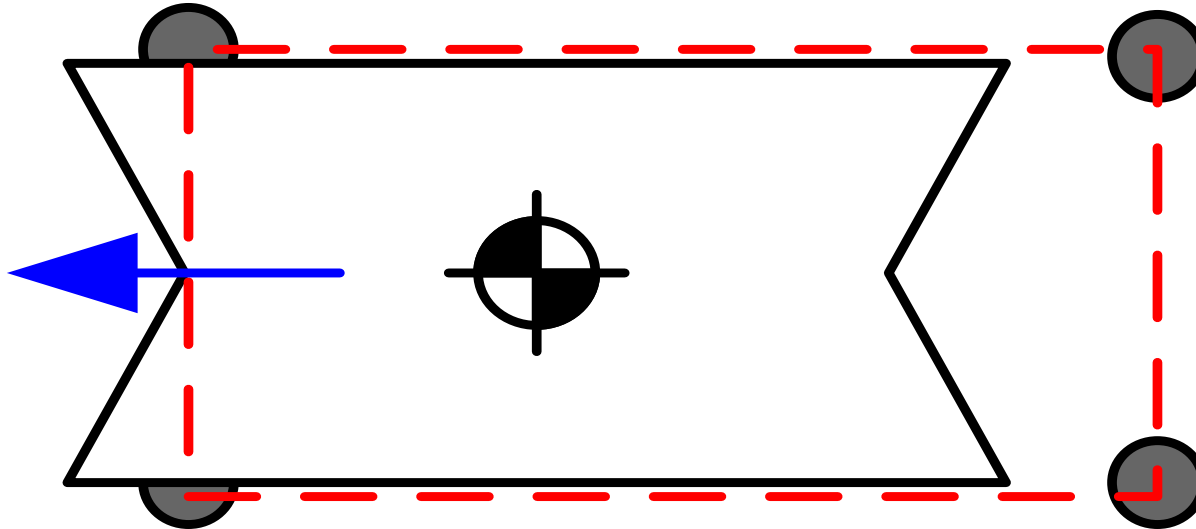
Support Polygon



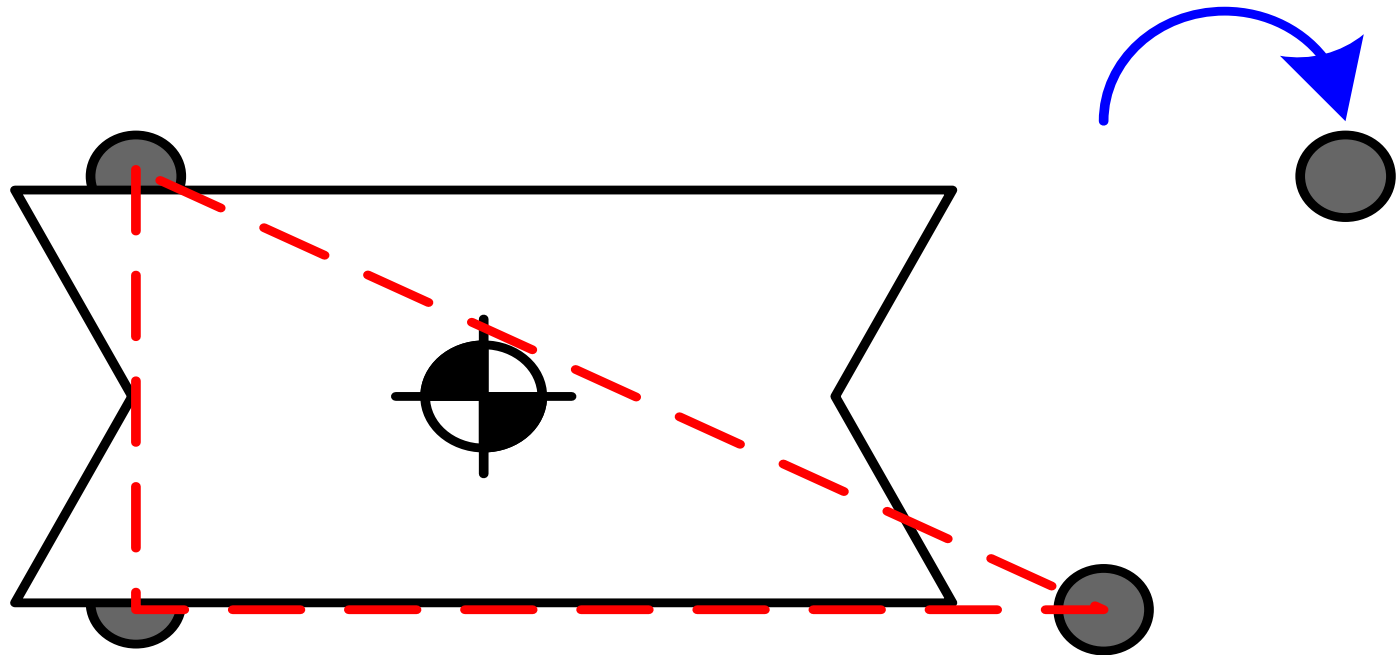
Support Polygon



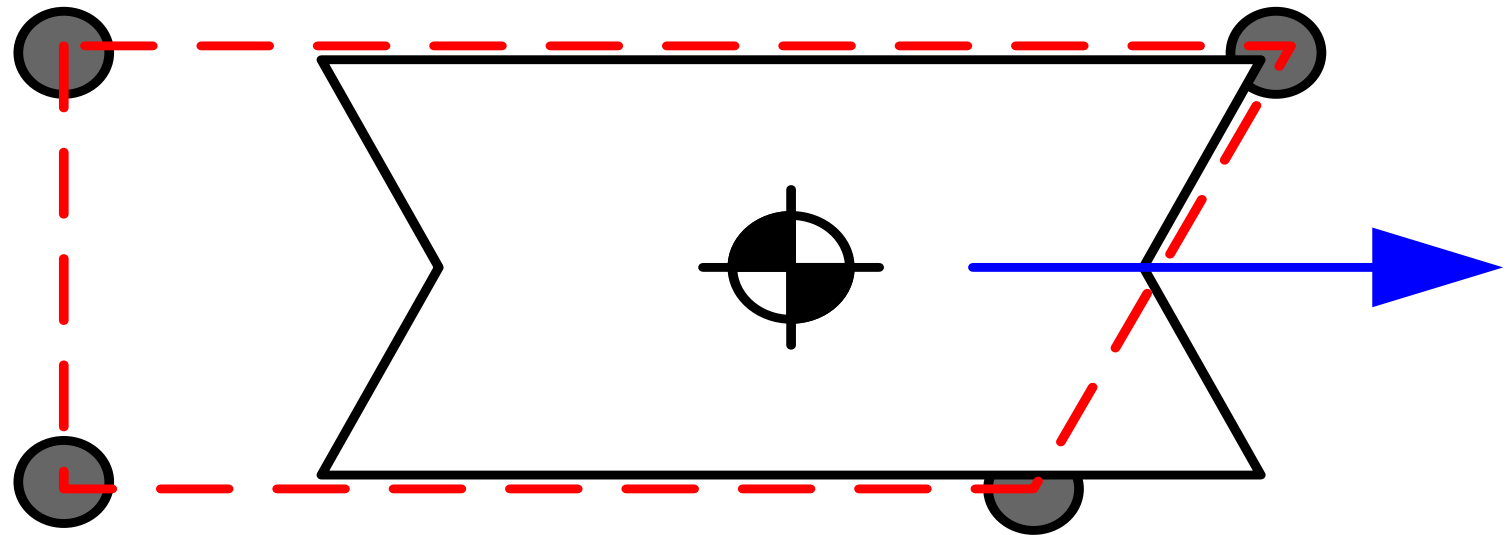
Support Polygon



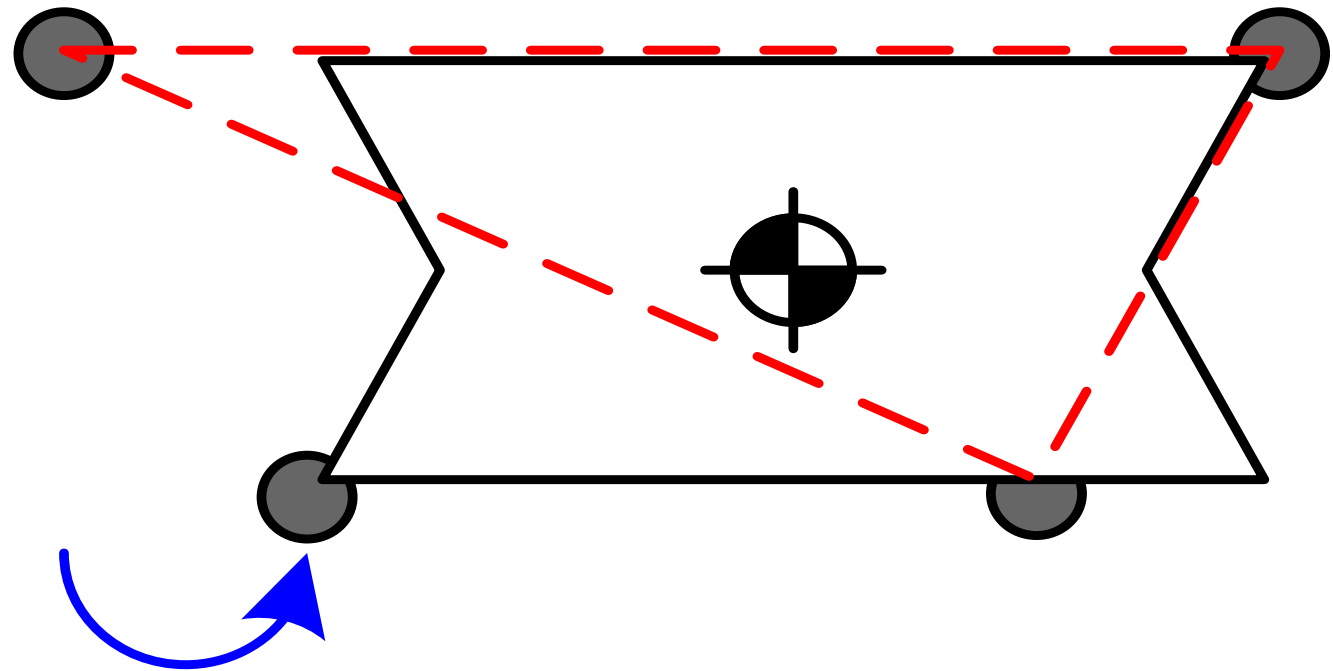
Support Polygon



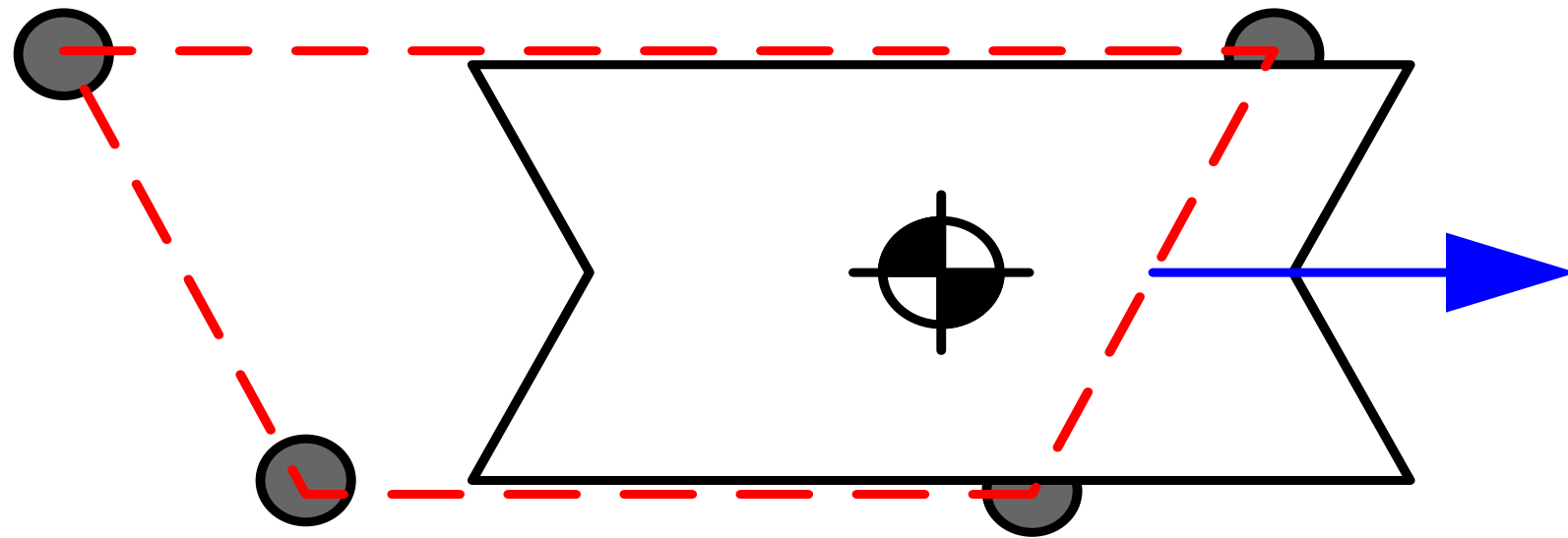
Support Polygon



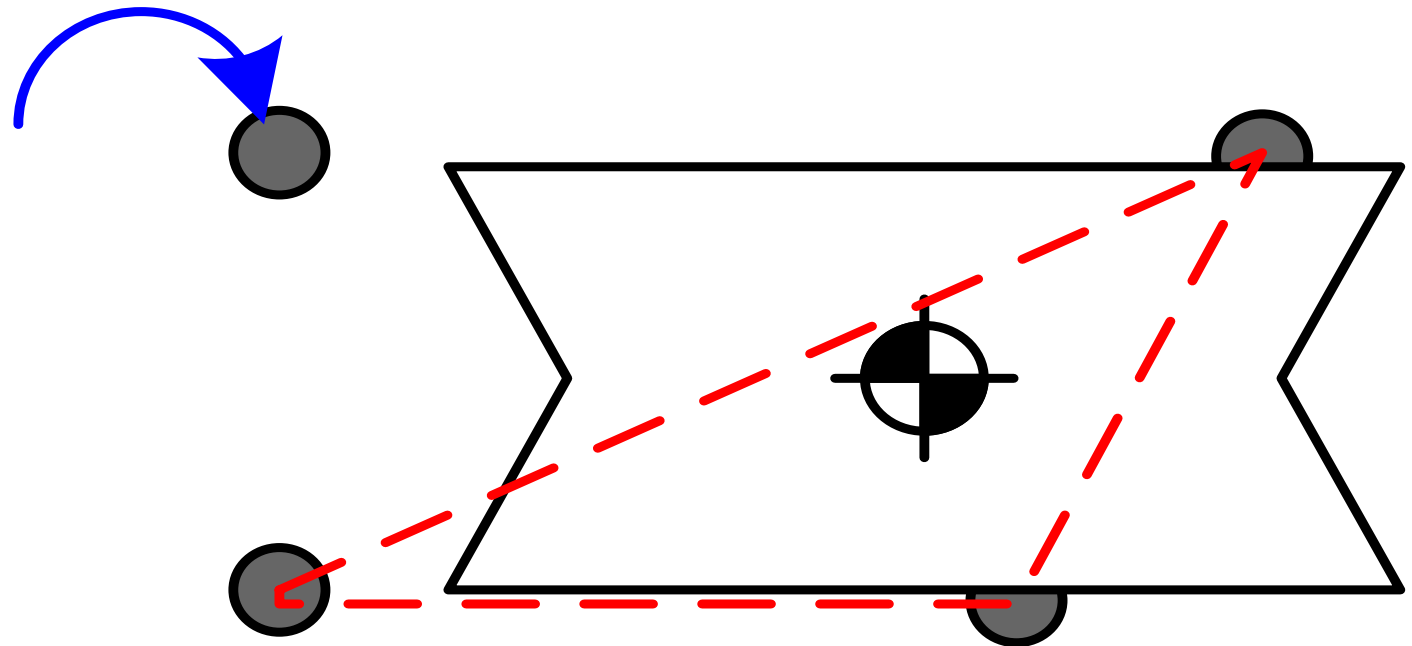
Support Polygon



Support Polygon



Support Polygon

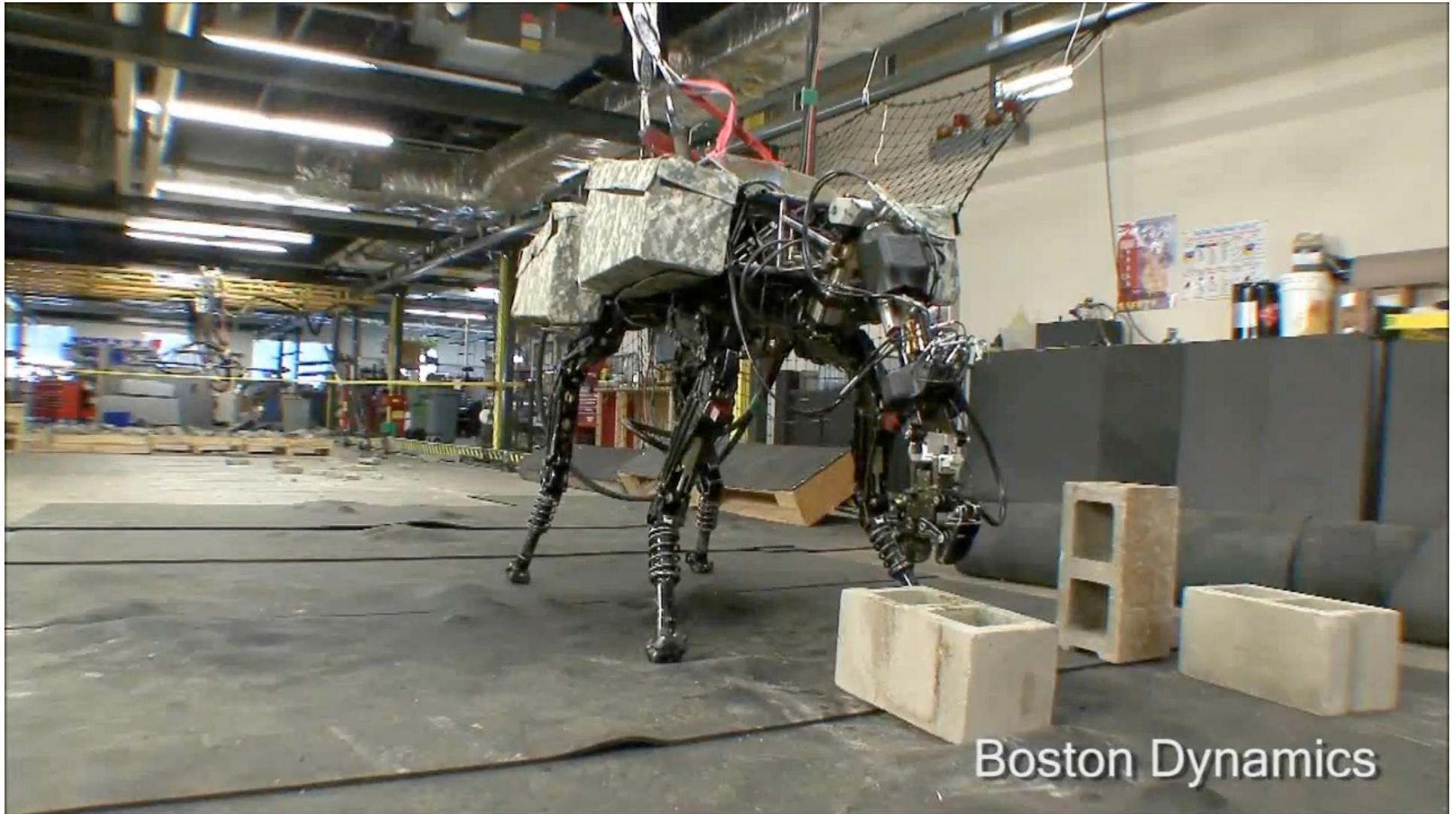


And so on...

Big Dog



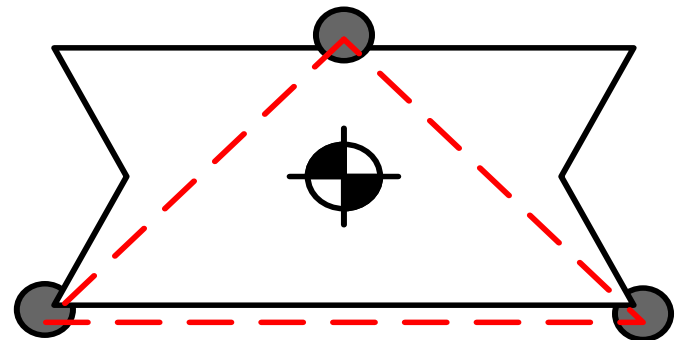
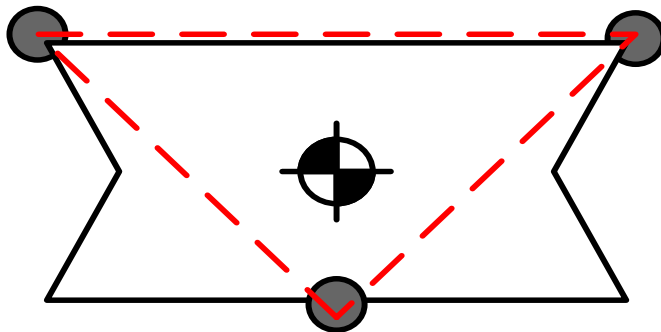
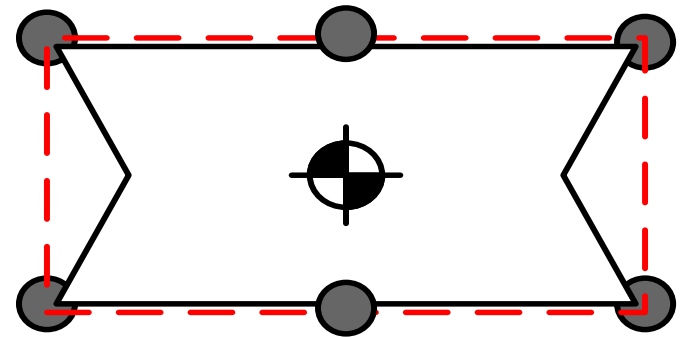
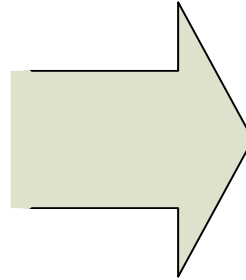
Big Dog



<https://www.youtube.com/watch?v=2jvLalY6ubc>



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)

