DD2426 – Robotics and Autonomous Systems
Lecture 2: Locomotion

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Course admin

- Forming teams
- Competition date
- First lab session this afternoon 15-17 in room 1535
  - Take the stairs to the 5th floor entering from Oscars Backe 2
  - Take a right on the 5th floor instead of going into the corridor where the computer rooms are.
- Most of you should have a working card by then

Forming teams

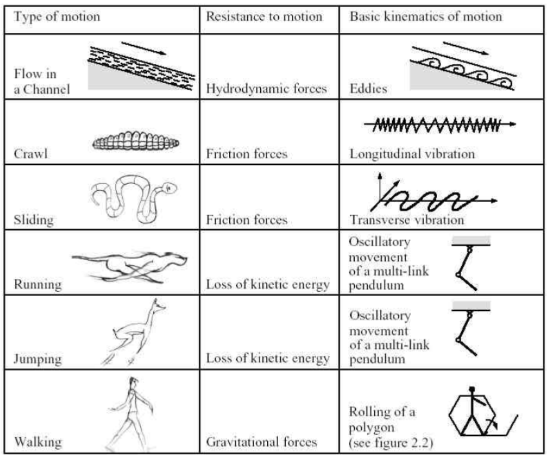
- 8 teams
- 4 people per team
- Use break for last minute match making

Competition date?

- Results of the poll
  - 15 votes: May 15
  - 13 votes: May 14
  - 5 votes: May 13

Locomotion

- Need locomotion to move the robot
- Many different ways



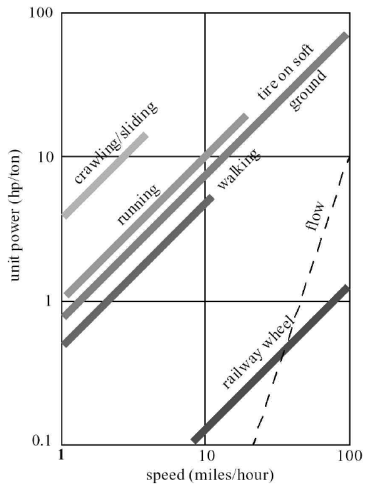
Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel	Hydrodynamic forces	Eddies
Crawl	Friction forces	Longitudinal vibration
Sliding	Friction forces	Transverse vibration
Running	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum
Jumping	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum
Walking	Gravitational forces	Rolling of a polygon (see figure 2.2)

Nature vs man-made

- Most of the mechanisms for locomotion has equivalent in nature
- One important exception: the powered wheel!
- Difficult to replicate small and light things like insects
- Biological energy storage and the muscular and hydraulic activation systems much better than man-made systems

Locomotion mechanisms: Power vs speed

- The wheel is the most efficient mechanism
- Movement up/down of CoG costs



Key issues for locomotion

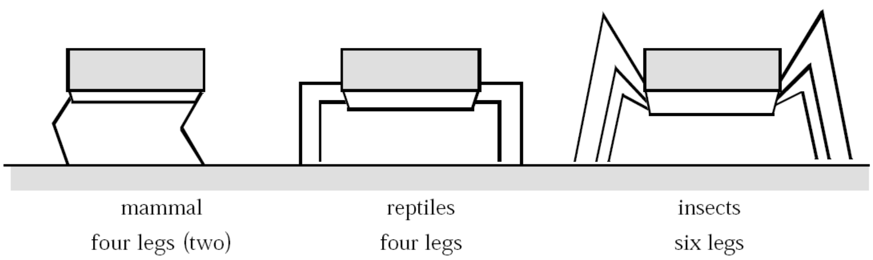
- Stability
  - Number/geometry of contact points
  - Center of gravity
  - Static/dynamic stability
  - Inclination of terrain
- Contact characteristics
  - Contact point/path size and shape
  - Angle of contact
  - Friction
- Environment type
  - Structure
  - Medium (water, air, soft or hard ground, . . .)

Legged locomotion

- Point contacts between robot and ground
- Potential for handling rough terrain well
- Only contact points need to be ok, ground in between does not matter
- Main disadvantages: Power and mechanical complexity

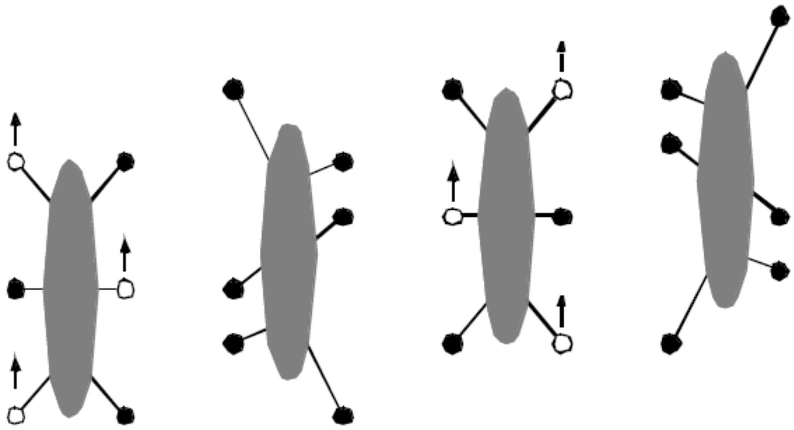
Leg configuration and stability

- Fewer legs gives more complicated problem in many aspects
- Stability requires (at least) three legs when standing still (statically stable)
- Criteria for static stability?



Statically stable walking

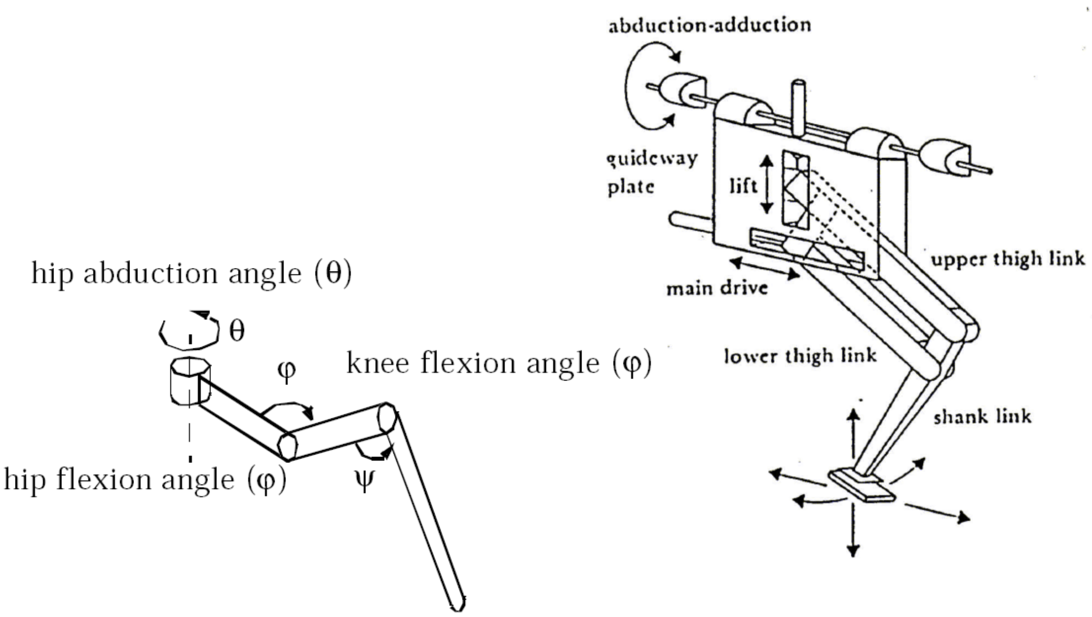
- Move the legs in groups of 3 legs



Leg design

- Need at least 2 DOF to move leg forward
  - lift
  - swing
- Robot legs often have 3 joints
- A fourth ankle joint can improve walking
- More DOFs increase complexity, weight and power requirements
- Human leg has more than 7 DOFs plus toes

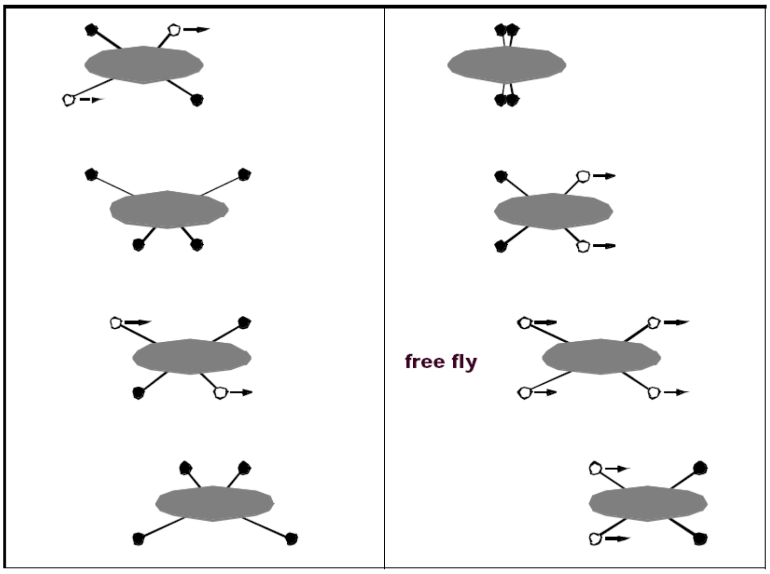
Leg design cont'd



Gait

- Gait = sequence of lift and release events for the individual legs
- More legs gives more possible gaits
- $N = (2k - 1)!$, N number of possible gaits, k number of legs

Example gaits for quadrupeds



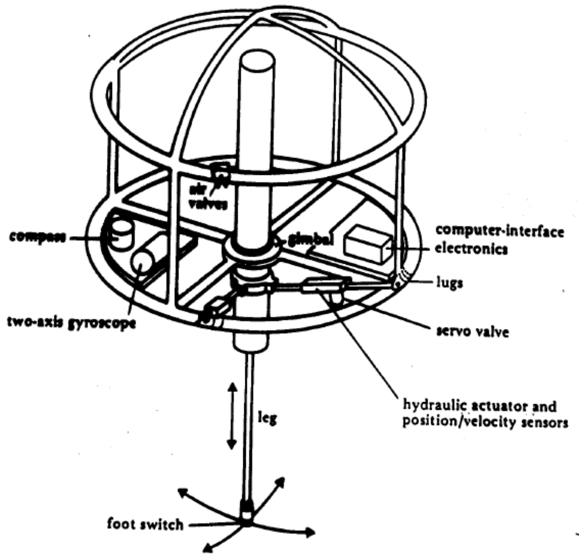
Changeover Walking　　　　Galloping

One leg robots

- Need to hopp to move
- Could in principle handle quite rough terrain
- Balance the major challenge
- Static stability not possible
- Need to actively control the balance to achieve dynamic stability

Example: One leg robots

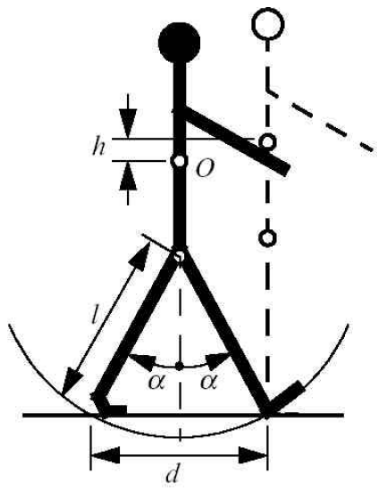
- The Raibert hopper from MIT



- Required large off-board hydraulic pump
- Springs can capture kinetic energy and help increase efficiency

Biped walking

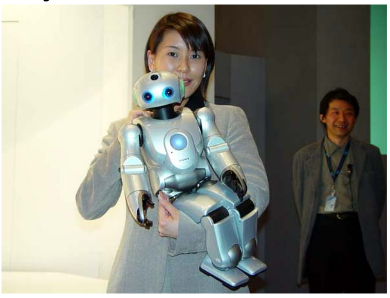
- Biped walking can be approximated by a rolling polygon
- Smaller steps gives closer to rolling circle



Movie: Rimless wheel walker

Two legged robots (Bipeds)

- Lots of them demonstrated over the ten years
- Sony and Honda has invested millions in humanoids lately



Sony SDR-4X

Honda Asimo

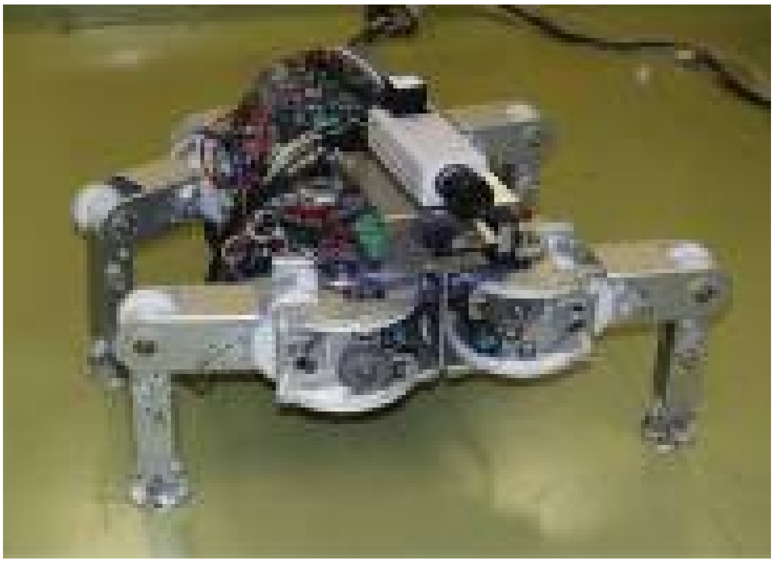
- Sony movies: walk push ball
- Asimo movies: History falling
- Movie: Small soccer players

Four legged robots (Quadrupeds)

- Can be statically stable when standing still
- Walking still challenging
- Example Sony Aibo

- Example: Bouncing quadruped

The Titan VIII Quadruped



Six legged robots (Hexapods)

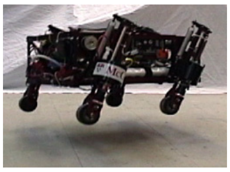
- Popular config as stability is simpler to achieve
- Genghis from MIT is one of the classic hexapods

- PlusTech walking harvester (movie I II)

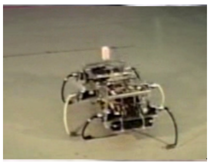
Some of Martin Buehler's robots

- ScoutII: Only one motor per leg with spring (gallops 1.3m/s)

- PAW: A Wheel on each leg, can walk, drive, gallop, etc



- RHex: Can navigate very rough terrain

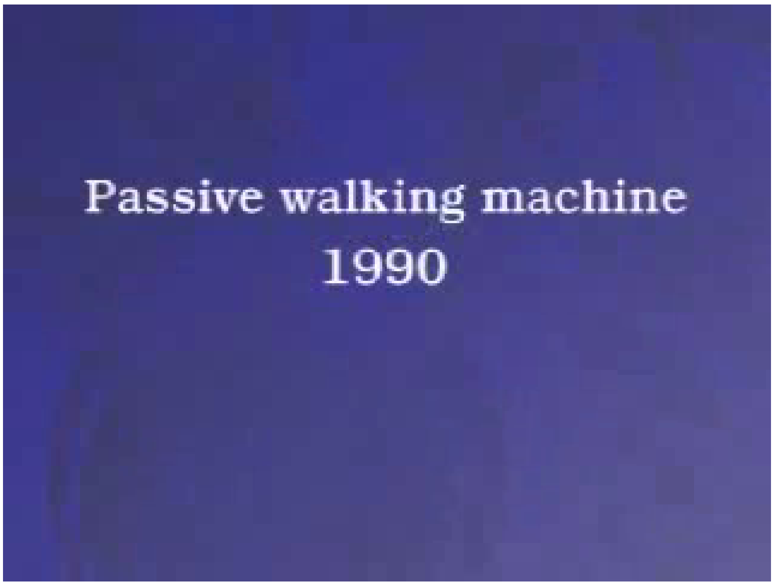



- Check out http://www.martinbuehler.net/projects.html

Boston Dynamics

- Martin is now director of robotics at Boston Dynamics
- One of their robot is "BigDog"
  - 1m long, 0.7m tall and has
  - trotted at 3.3 mph
  - climbed a 35 degree slope
  - carried ≈54kg load

Passive walking I



Passive walking II

- Can design walking robots that are entirely passive
- Potential energy is used as energy source

Movies: I II III

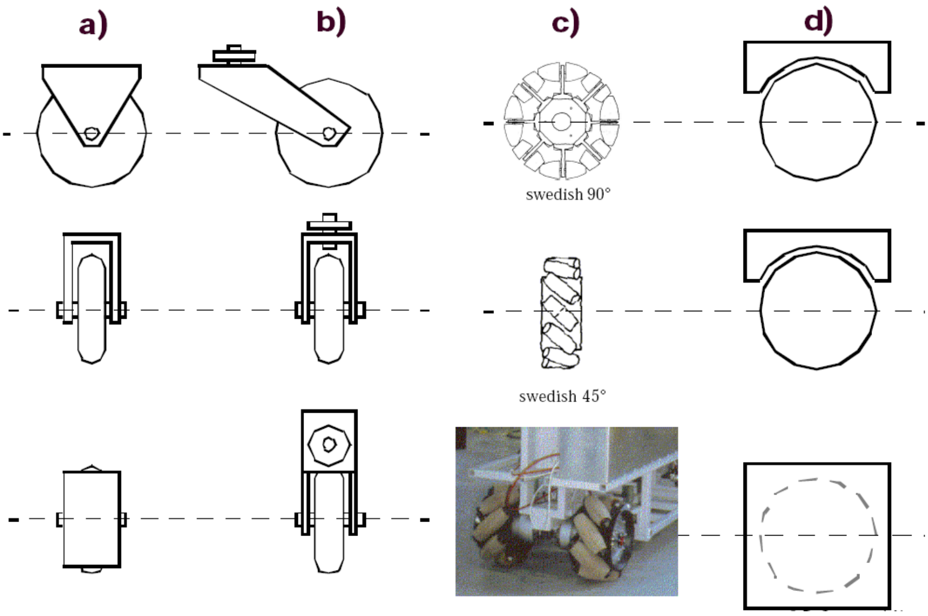
Wheeled locomotion

- Most popular means of locomotion in robotics (and other vehicles)
- Simple to implement and highly efficient
- Bigger wheels gives better handling of rough terrain
- Wheeled robots typically designed so that balance is not an issue
- There are exceptions like the 2-wheeled Segway (movie I II)

Some design issues for wheeled locomotion

- Traction
- Maneuverability
- Control
- Stability

Wheel design



Standard wheel (a)

- Typically 2 DOFs
  - Rotation around wheel axle (gives translation)
  - Rotation around the vertical axis around the contact point
- Motion

Castor wheel (b)

- 2 DOFs
  - Rotation around wheel axle (gives translation)
  - Rotation around the offset vertical axis
- Typically not motorized
- Offset creates moment that makes the wheel turn

Swedish wheel (c)

- 3 DOFs
  - Rotation around wheel axle (gives translation)
  - Rotation around rollers
  - Rotation around contact point
- Rollers are passive
- Allows for omni-directional motion

Spherical wheel (d)

- Truly omni-directional
- Technically difficult to realize
- Can be made as a "computer mouse"

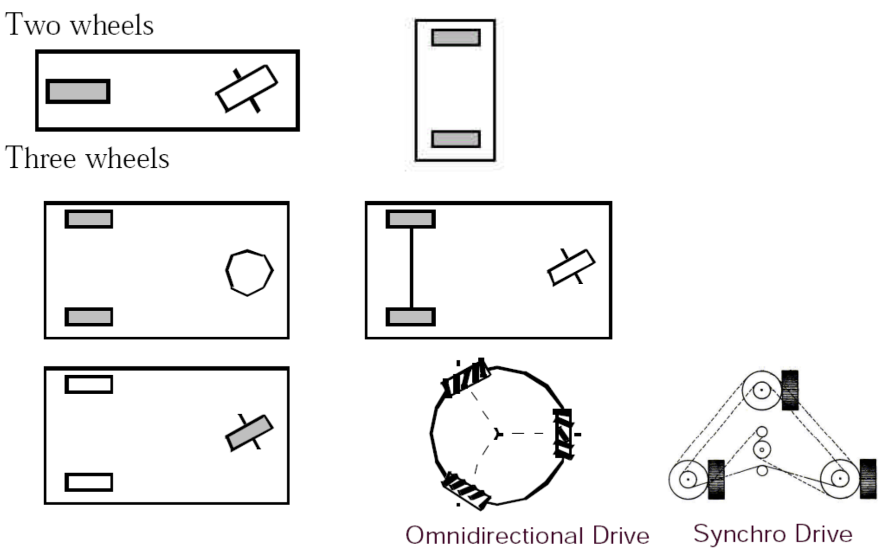
Suspension

- With more than 3 wheel you typically need suspension
- Will lose contact with ground unless perfectly flat otherwise
- Primitive solution: let the wheel itself act as suspension

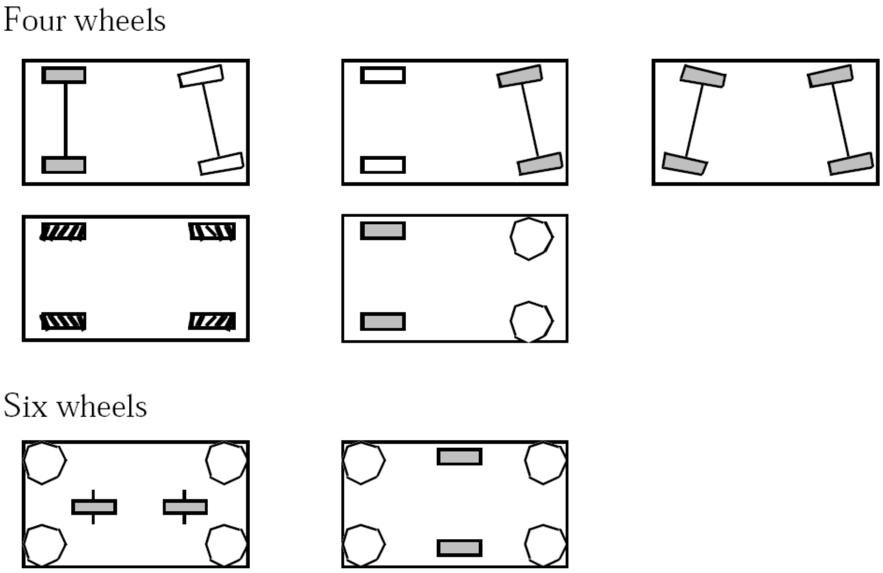
Wheel configuration

- Cars have highly standardized wheel configuration
- because they all drive in the same type of environment, the road
- Robots are highly diverse
- Application determines configuration
- Car like config (Ackerman) not very common on robot
- since it gives rather bad maneuverability

Wheel configurations with 2 and 3 wheels



Wheel configurations with 4 and 6 wheels



Stability

- Need 2 wheels to get stability (if CoG below axle)
- 3 wheel for conventional design to get stability
- More than 3 wheel requires suspension

Maneuverability

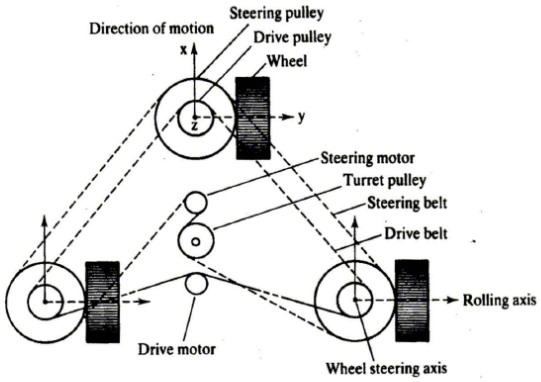
- Highest level of maneuverability means omni-directional
- Can move in any direction in the plane independent of the robot orientation
- Typically implemented with Swedish or spherical wheels (Tribolo)
- Can also be achieved with motorized castor wheels (Nomadics XR4000)
- Circular (or close to) robots with differential drive simpler to implement and are highly maneuverable (Scout)

Controlability

- What you gain in maneuverability you have to pay for in control effort
- Often quite difficult to control omni-directional robot
- To make car move straight, lock the wheel forward
- To make a differential drive move forward you need to control the motors to move exactly as fast
- More driven wheels give even hard problem
- Nomadics XR4000 with 4 motorized castor wheels $\Rightarrow$ has to control 8 motors

Example: Synchro drive

- One motor for translation
- One motor for rotation
- Wheels mechanically coupled
- Turns without turning body
- For example Nomad200 robot

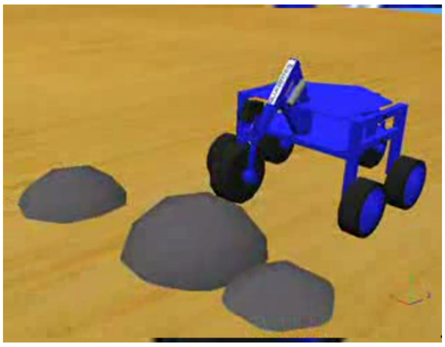


Slip/skid locomotion

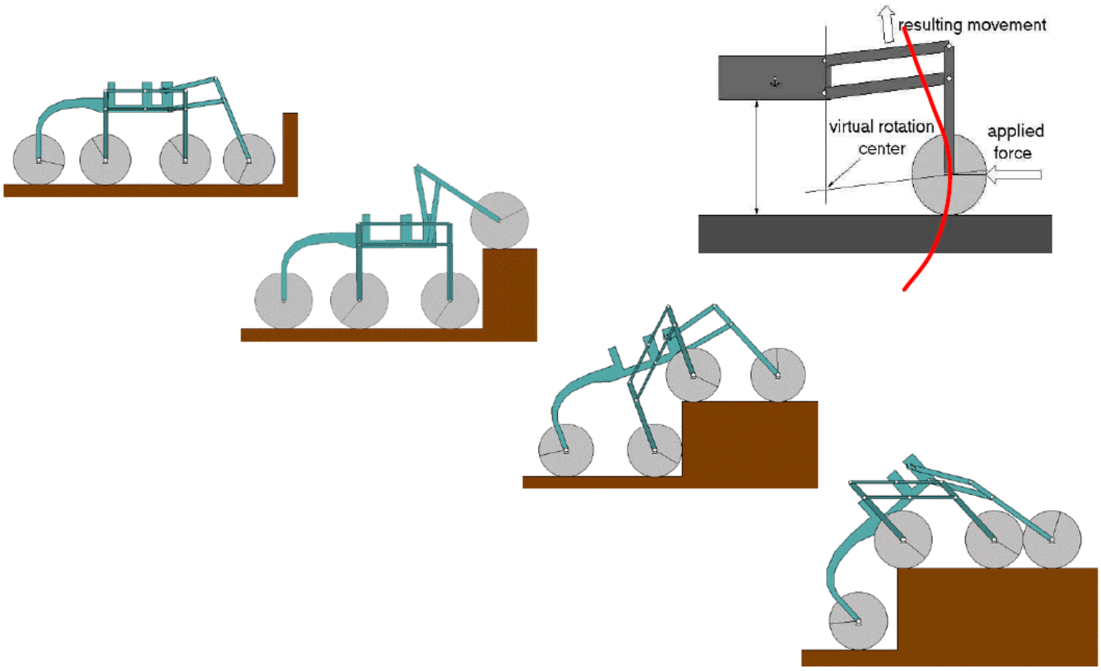
- More common for outdoor platforms
- Wheels or tracks
- Turn by applying different speed to wheels
- Skidding/slipping makes it hard to predict motion
- Extremely energy inefficient when friction is high

Shrimp

- 6 motorized wheels
- Can overcome obstacles twice the wheel diameter



Shrimp cont'd



More examples of robot locomotion

- Planes
- Blimps
- Helicopters
- Swimming
- Crawling