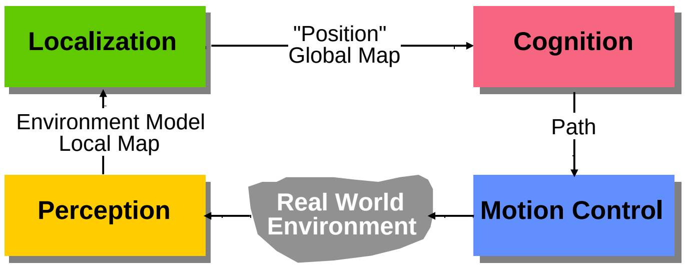
# Locomotion Concepts

- Concepts
- Legged Locomotion
- Wheeled Locomotion








# Locomotion Concepts: Principles Found in Nature

| 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) |





# Locomotion Concepts

- Concepts found in nature
  - *difficult to imitate technically*
- Most technical systems use wheels or caterpillars
- Rolling is most efficient, but not found in nature
  - *Nature never invented the wheel !*
- However, the movement of a walking biped is close to rolling

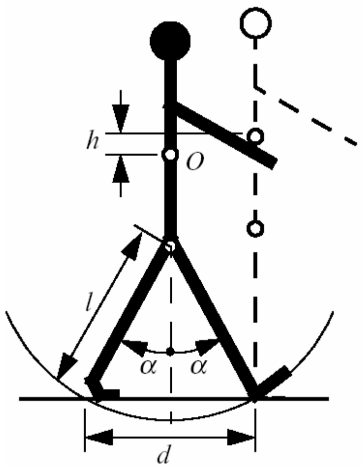




# Walking of a Biped

wm_pw.qt

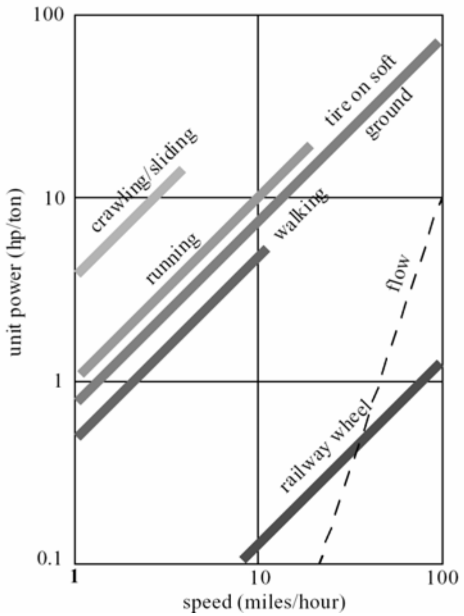
steve_angle.qt




- Biped walking mechanism
  - *not to fare from real rolling.*
  - *rolling of a polygon with side length equal to the length of the step.*
  - *the smaller the step gets, the more the polygon tends to a circle (wheel).*
- However, fully rotating joint was not developed in nature.

## Walking or rolling?

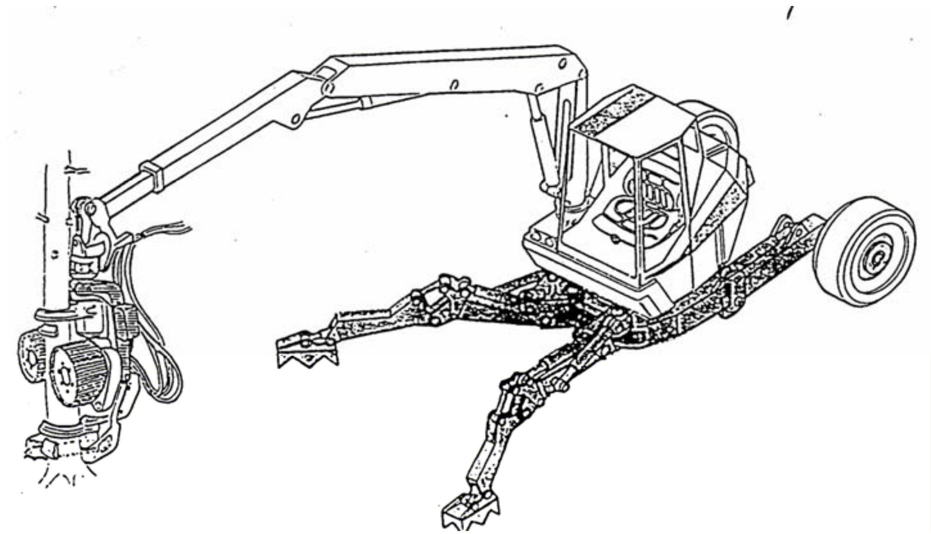
- number of actuators
- structural complexity
- control expense
- energy efficient
  - *terrain (flat ground, soft ground, climbing..)*
- movement of the involved masses
  - *walking / running includes up and down movement of COG*
  - *some extra losses*








## RoboTrac, a hybrid wheel-leg vehicle







## Characterization of locomotion concept

- Locomotion
  - *physical interaction between the vehicle and its environment.*
- Locomotion is concerned with *interaction forces*, and the *mechanisms* and *actuators* that generate them.
- The most important issues in locomotion are:

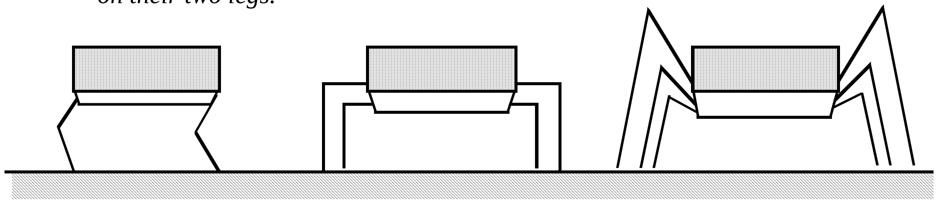
- stability
  - *number of contact points*
  - *center of gravity*
  - *static/dynamic stabilization*
  - *inclination of terrain*
- characteristics of contact
  - *contact point or contact area*
  - *angle of contact*
  - *friction*
- type of environment
  - *structure*
  - *medium (water, air, soft or hard ground)*





## Mobile Robots with legs (walking machines)

- The fewer legs the more complicated becomes locomotion
  - *stability, at least three legs are required for static stability*
- During walking some legs are lifted
  - *thus loosing stability?*
- For static walking at least 6 legs are required
  - *babies have to learn for quite a while until they are able to stand or even walk on their two legs.*



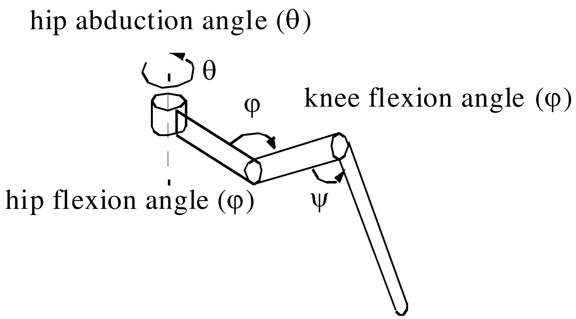
## Number of Joints of Each Leg (DOF: degrees of freedom)

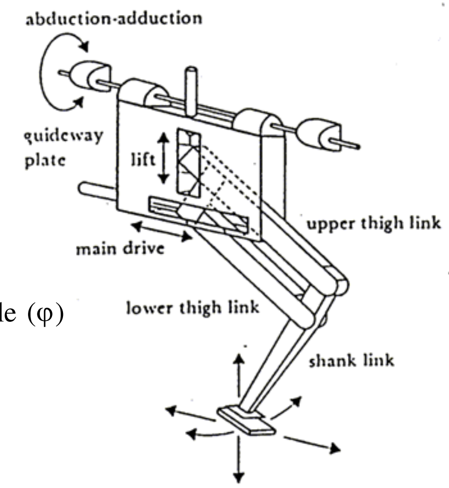
- A minimum of two DOF is required to move a leg forward
  - *a lift and a swing motion.*
  - *sliding free motion in more then only one direction not possible*
- Three DOF for each leg in most cases
- Fourth DOF for the ankle joint
  - *might improve walking*
  - *however, additional joint (DOF) increase the complexity of the design and especially of the locomotion control.*





## Examples of Legs with 3 DOF








## The number of possible gaits

- The gait is characterized as the sequence of lift and release events of the individual legs
  - *it depends on the number of legs.*
  - *the number of possible events N for a walking machine with k legs is:*

$$N = (2k - 1)!$$

- For a biped walker (k=2) the number of possible events N is:

$$N = (2k - 1)! = 3! = 3 \cdot 2 \cdot 1 = 6$$

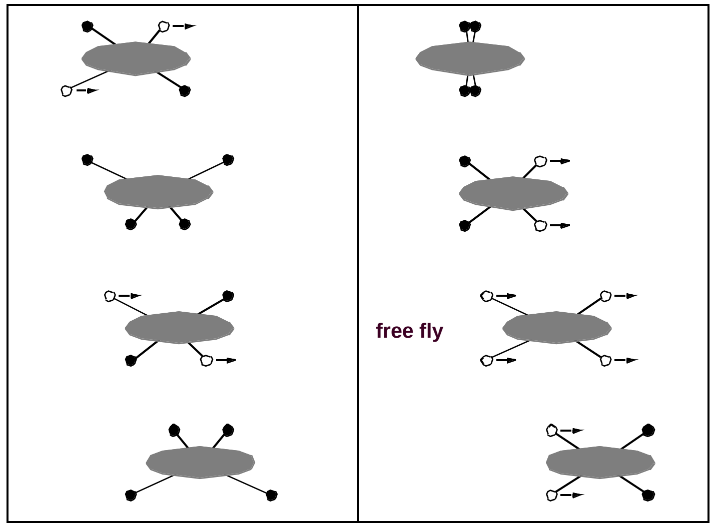
  - *The 6 different events are:*
    *lift right leg / lift left leg / release right leg / release left leg / lift both legs together / release both legs together*
- For a robot with 6 legs (hexapod) N is already

$$N = 11! = 39.916.800$$



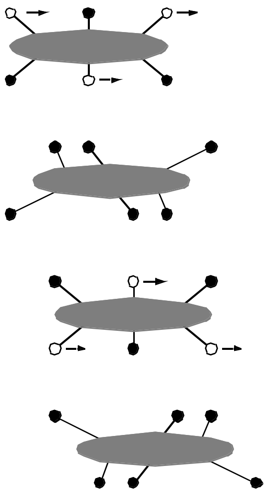


## Most Obvious Gaits with 4 legs




Changeover Walking    Galloping

# Most Obvious Gait with 6 legs (static)

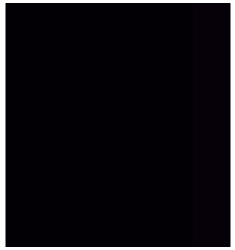


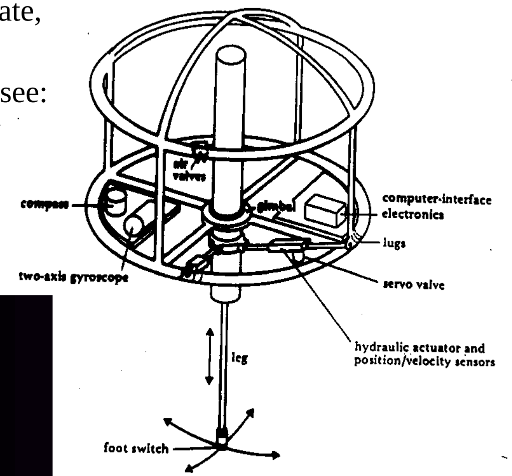




# Examples of Walking Machines

- No industrial applications up to date, but a popular research field
- For an excellent overview please see: *http://www.walking-machines.org/*



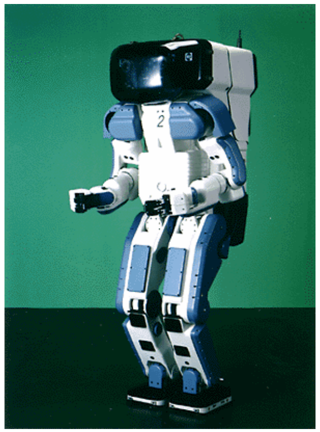

***The Hopping Machine***

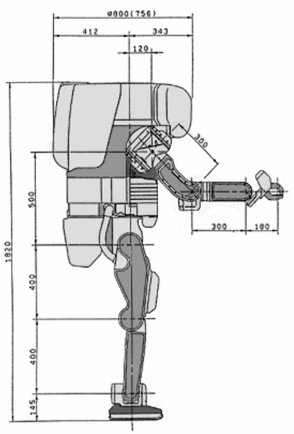




# Humanoid Robots

- P2 from Honda, Japan
  - *Maximum Speed: 2 km/h*
  - *Autonomy: 15 min*
  - *Weight: 210 kg*
  - *Height: 1.82 m*
  - *Leg DOF: 2*6*
  - *Arm DOF: 2*7*

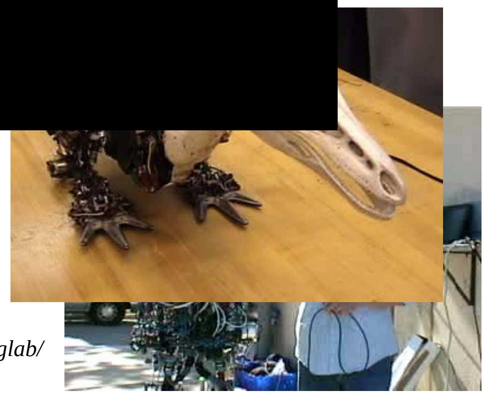






# Bipedal Robots

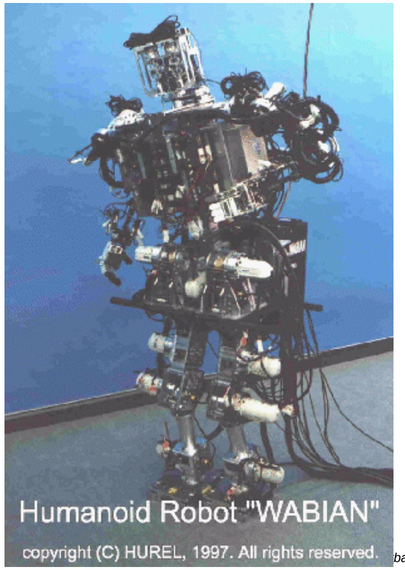
- Leg Laboratory from MIT
  - *Spring Flamingo the bipedal running machine*
  - *“Troody” Dinosaur like robo*[redacted]
  - *“M2” Humanoid robot*



*more infos : http://www.ai.mit.edu/projects/leglab/*

## Humanoid Robots

- Wabian build at
  Waseda University in Japan
  - *Weight: 107 kg*
  - *Height: 1.66 m*
  - *DOF in total: **43***







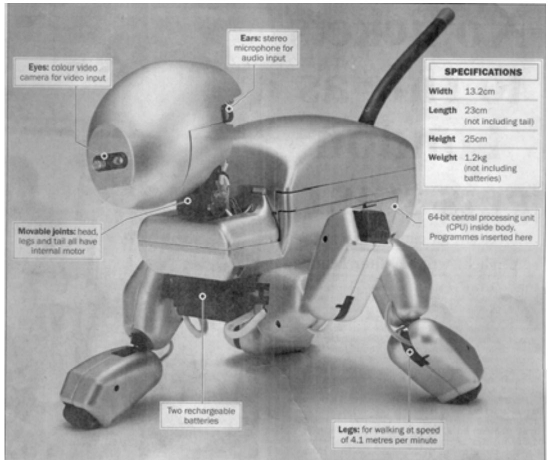

## Walking with Three Legs






## Walking Robots with Four Legs (Quadruped)

- Artificial Dog Aibo from Sony, Japan

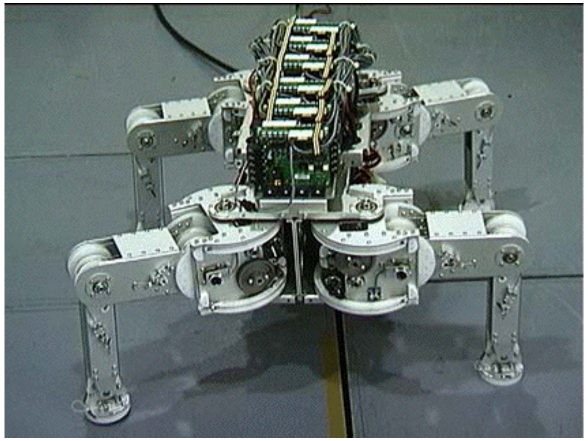
Sony's new computer canine will chase a ball or sit when asked, but cleaning up will be a thing of the past



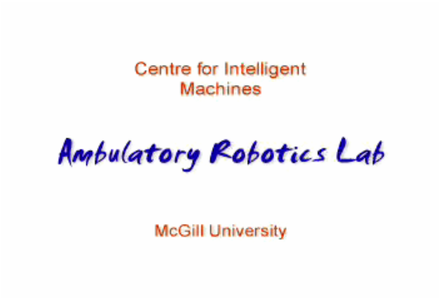


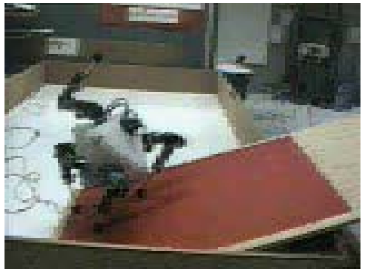
## Walking Robots with Four Legs (Quadruped)

- Titan VIII, a quadruped robot, Tokyo Institute of Technology
  - *Weight: 19 kg*
  - *Height: 0.25 m*
  - *DOF: 4*3*



## Walking Robots with Four Legs (Quadruped)





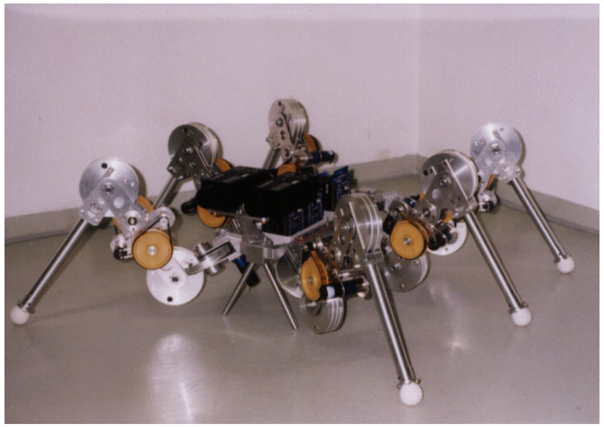


## Walking Robots with Six Legs (Hexapod)

- Most popular because static stable walking possible
- The human guided hexapod of Ohio State University
  - *Maximum Speed: 2.3 m/s*
  - *Weight: 3.2 t*
  - *Height: 3 m*
  - *Length: 5.2 m*
  - *No. of legs: 6*
  - *DOF in total: 6*3*



## Walking Robots with Six Legs (Hexapod)



- Lauron II,
  University of Karlsruhe
  - *Maximum Speed: 0.5 m/s*
  - *Weight: 6 kg*
  - *Height: 0.3 m*
  - *Length: 0.7 m*
  - *No. of legs: 6*
  - *DOF in total: 6*3*
  - *Power Consumption: 10 W*



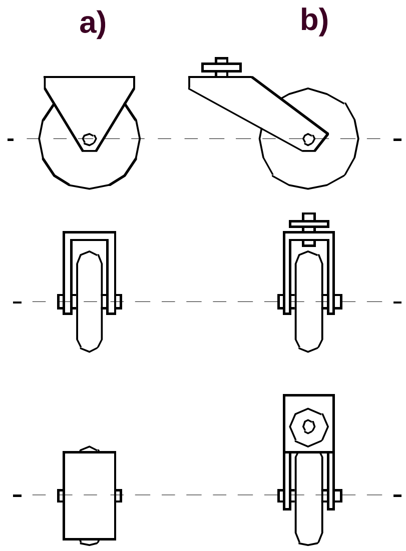


## Mobile Robots with Wheels

- Wheels are the most appropriate solution for most applications
- Three wheels are sufficient and to guarantee stability
- With more than three wheels a flexible suspension is required
- Selection of wheels depends on the application

## The Four Basic Wheels Types

- a) Standard wheel: Two degrees of freedom; rotation around the (motorized) wheel axle and the contact point
- b) Castor wheel: Three degrees of freedom; rotation around the wheel axle, the contact point and the castor axle

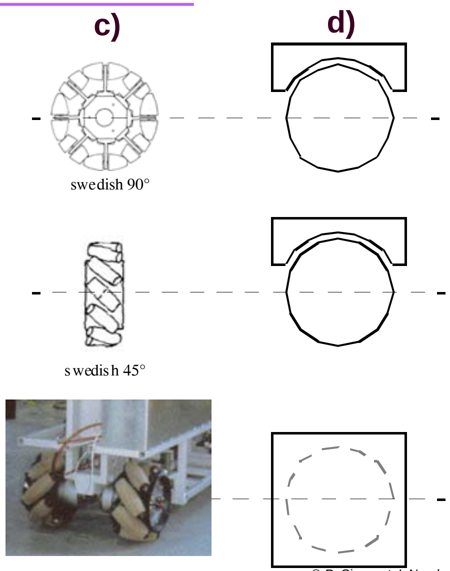







## The Four Basic Wheels Types

- c) Swedish wheel: Three degrees of freedom; rotation around the (motorized) wheel axle, around the rollers and around the contact point
- d) Ball or spherical wheel: Suspension technically not solved








## Characteristics of Wheeled Robots and Vehicles

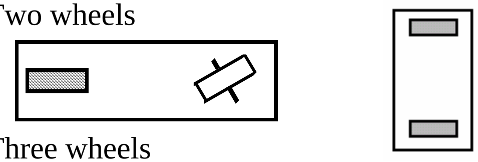
- Stability of a vehicle is be guaranteed with 3 wheels
  - *center of gravity is within the triangle with is formed by the ground contact point of the wheels.*
- Stability is improved by 4 and more wheel
  - *however, this arrangements are hyperstatic and require a flexible suspension system.*
- Bigger wheels allow to overcome higher obstacles
  - *but they require higher torque or reductions in the gear box.*
- Most arrangements are non-holonomic (see chapter 3)
  - *require high control effort*
- Combining actuation and steering on one wheel makes the design complex and adds additional errors for odometry.



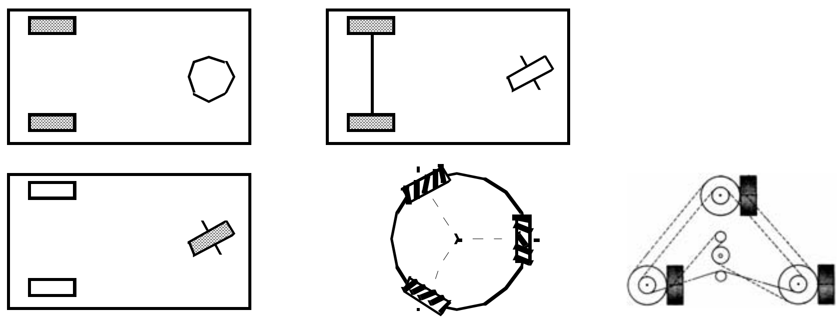


## Different Arrangements of Wheels I

- Two wheels



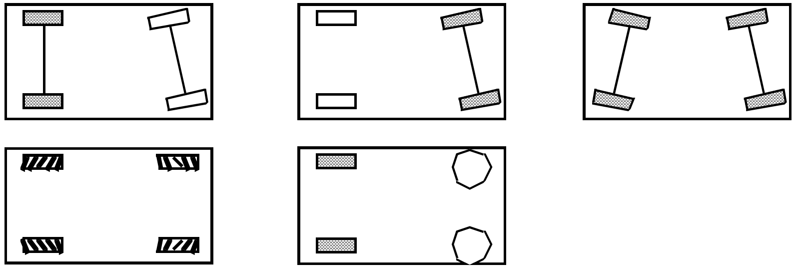
- Three wheels



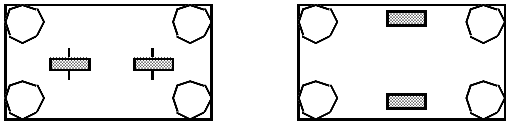
Omnidirectional Drive    Synchro Drive

# Different Arrangements of Wheels II

- Four wheels



- Six wheels







# Cye, a Two Wheel Differential Drive Robot

- Cye, a commercially available domestic robot that can vacuum and make deliveries in the home, is built by Probotics, Inc.
- **http://www.personalrobots.com/**





# ROOMBA

Cliff sensors stop Roomba from falling down stairs

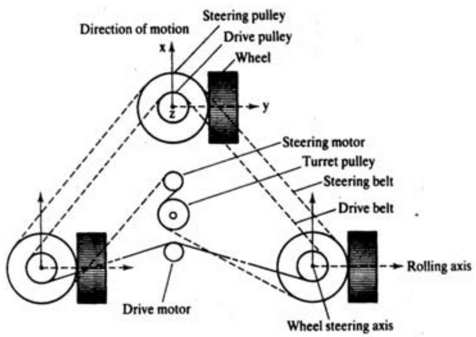
http://www.irobot.com



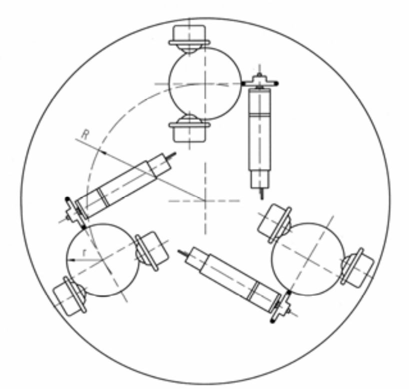


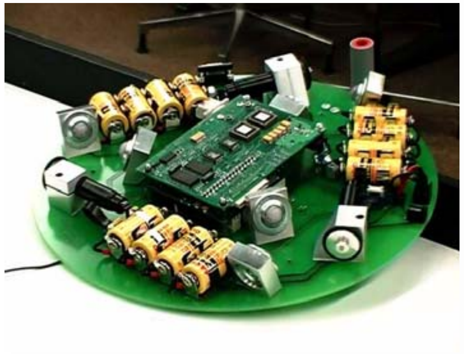
# Synchro Drive

- All wheels are actuated synchronously by one motor
  - *defines the speed of the vehicle*
- All wheels steered synchronously by a second motor
  - *sets the heading of the vehicle*
- The orientation in space of the robot frame will always remain the same
  - *It is therefore not possible to control the orientation of the robot frame.*



## Tribolo, Omnidirectional Drive with 3 Spheric Wheels



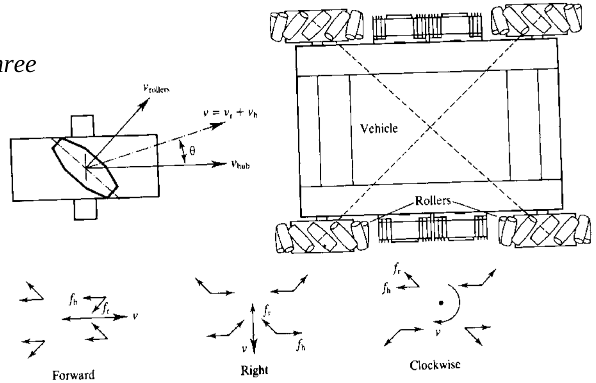






## Uranus, CMU: Omnidirectional Drive with 4 Wheels

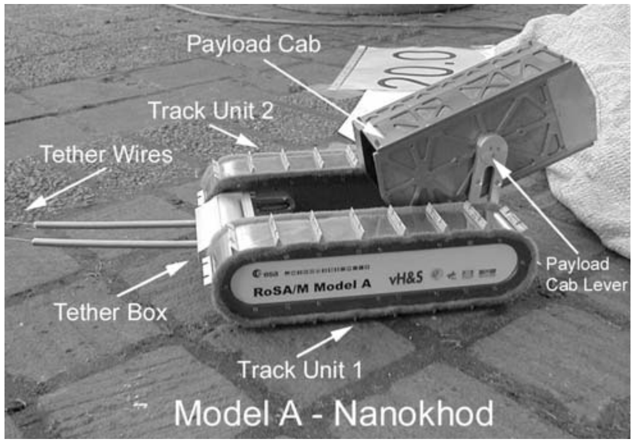
- Movement in the plane has 3 DOF
  - *thus only three wheels can be independently controlled*
  - *It might be better to arrange three swedish wheels in a triangle*








## Caterpillar




- The NANOKHOD II, developed by von Hoerner & Sulger GmbH and Max Planck Institute, Mainz for European Space Agency (ESA) will probably go to Mars





## Stepping / Walking with Wheels

- SpaceCat, and micro-rover for Mars, developed by Mecanex Sa and EPFL for the European Space Agency (ESA)

*EPFL_Space Cat*

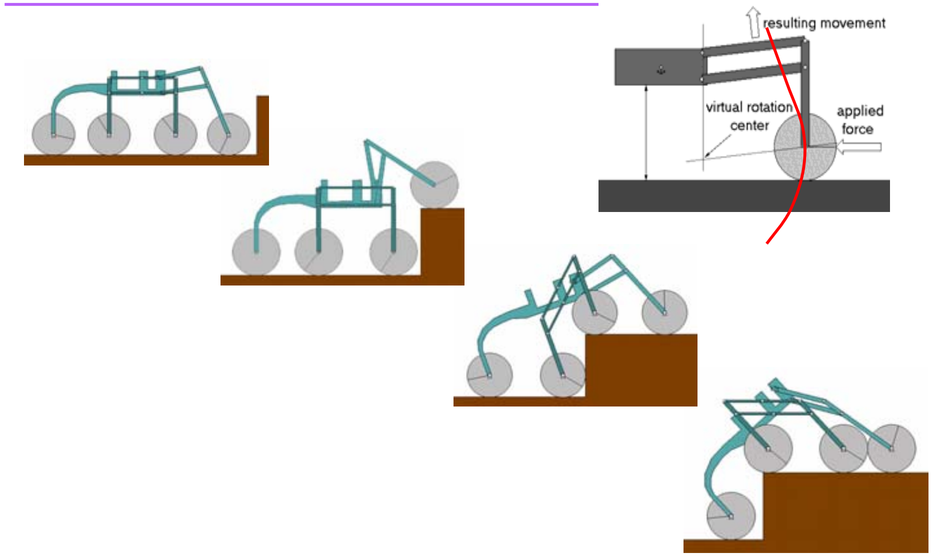
# SHRIMP, a Mobile Robot with Excellent Climbing Abilities

- Objective
  - *Passive locomotion concept for rough terrain*
- Results: The Shrimp
  - *6 wheels*
    - *one fixed wheel in the rear*
    - *two boogies on each side*
    - *one front wheel with spring suspension*
  - *robot sizing around 60 cm in length and 20 cm in height*
  - *highly stable in rough terrain*
  - *overcomes obstacles up to 2 times its wheel diameter*





# The SHRIMP Adapts Optimally to Rough Terrain








# The Personal Rover