UNIVERSITÀ DEGLI STUDI DI PADOVA

Introduction to LOCOMOTION

Prof. Emanuele Menegatti
Intelligent Robotics Course

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

A mobile robot can move and sense, and must process information to link these two. In this lecture we concentrate on robot movement, or locomotion.

What are the possible goals of a robot locomotion system?

- Speed and/or acceleration of movement.
- Precision of positioning (repeatability).
- Flexibility and robustness in different conditions.
- Efficiency (low power consumption)?

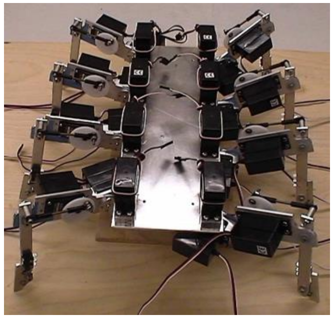
Adapted from A.Davison

Robots might want to move in water, in the air, on land, in space...?

AUV

Micro UAV

Zero-G Assistant SPHERE project



Spider

Humanoid

In this course we will concentrate on wheeled robots which move on fairly flat surfaces.

Adapted from A.Davison

- Locomotion is the act of moving from place to place.
- Locomotion relies on the physical interaction between the vehicle and its environment.
- Locomotion is concerned with the interaction forces, along with the mechanisms and actuators that generate them.

Adapted from R.Sigward

Nature produced a multitude of locomotion concepts

- Adaptation to environmental characteristic
- Adaptation to the perceived environment (e.g., size)

Concepts found in nature

- Difficult to imitate technically
- Do not employ wheels
- Sometimes imitate wheels (bipedal walking)
- The smaller living creatures are, the more likely they fly

Most technical systems today use wheels or caterpillars

- Legged locomotion is still mostly a research topic

Adapted from R.Sigward

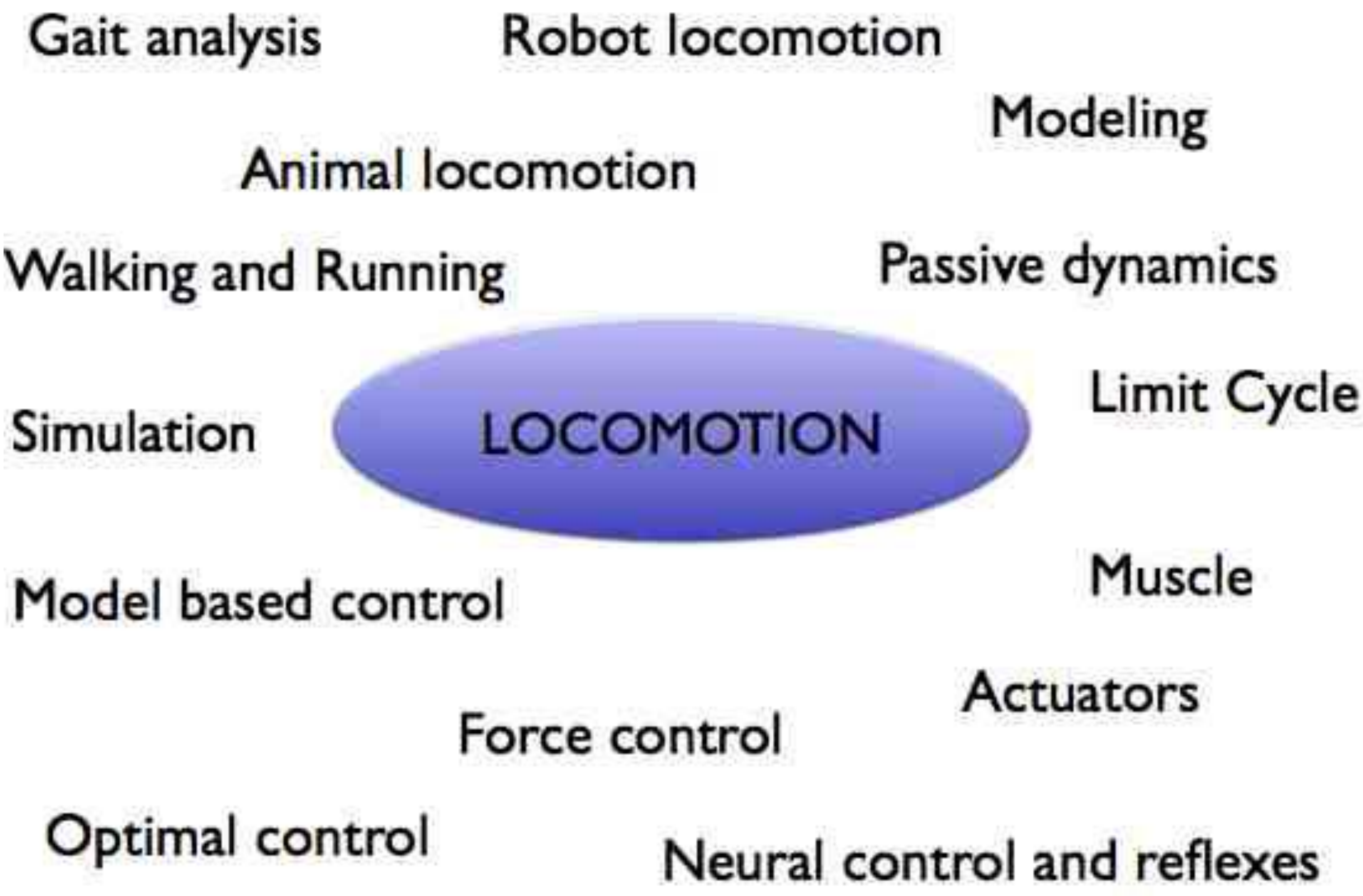
Locomotion

1. Wheeled Locomotion
2. Legged Locomotion
3. Snake Locomotion
4. Free-Floating Motion
5. Swimming Locomotion

Mobile Robot Kinematics is about

1. Models - Maneuverability - Motion Control

Adapted from R.Sigward



Adapted from R.Sigward

Friction & Direction

Design & Control

Actuation & Sensing

Animal & Machine

Adapted from R.Sigward

Stability

- *Number of contact points*
- *Center of gravity*
- *Static versus Dynamic stabilization*
- *Inclination of terrain*

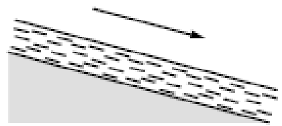
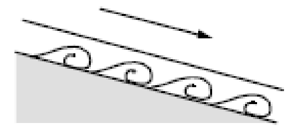
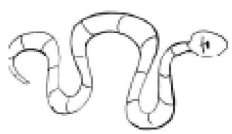
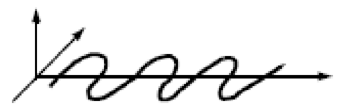
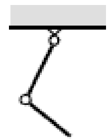
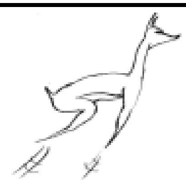
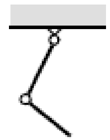
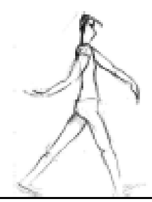
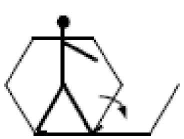
Contact

- *Contact point or area*
- *Angle of contact*
- *Friction*

Environment

- *Structure*
- *Medium*

Adapted from R.Sigward

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) 

Adapted from R.Sigward

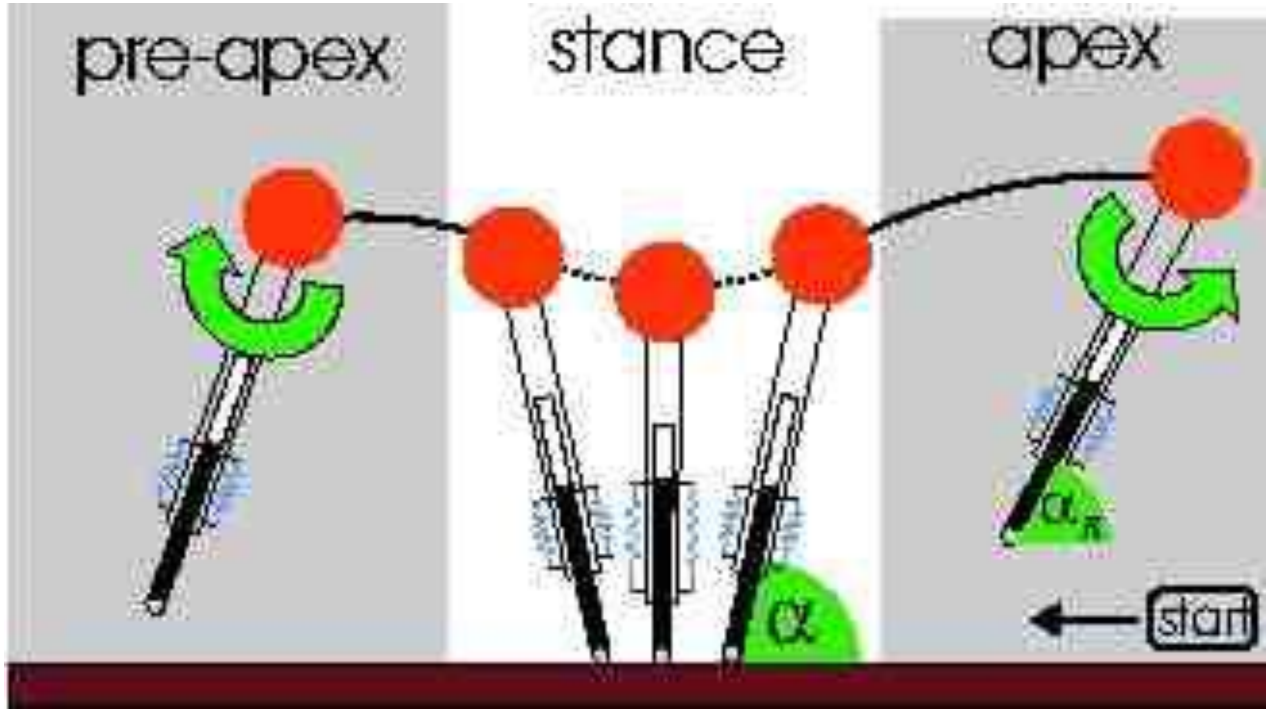
- Many locomotion concepts are inspired by nature
- Most natural locomotion concepts are difficult to imitate technically
- Rolling, which is NOT found in nature, is most efficient

Adapted from R.Sigward

Locomotion via **Climbing**

Adapted from R.Sigward

Locomotion via **Hopping**



Adapted from R.Sigward

Locomotion via **Sliding**


Adapted from R.Sigward

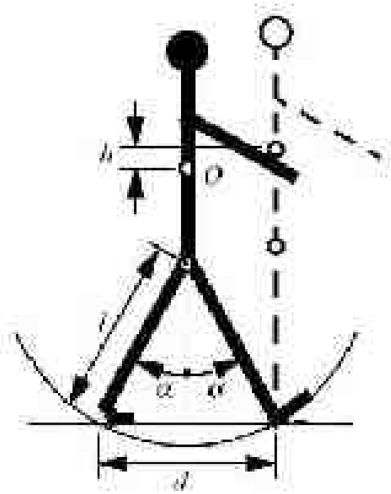
- Concepts found in nature

  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

Adapted from R.Sigward

- Nature inspired
- The movement of walking biped is close to rolling

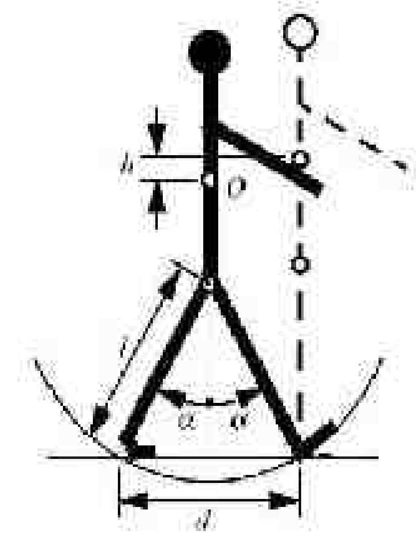


- Number of legs determines stability of locomotion

Adapted from R.Sigward

WALKING OF A BIPED

- Not to far 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.

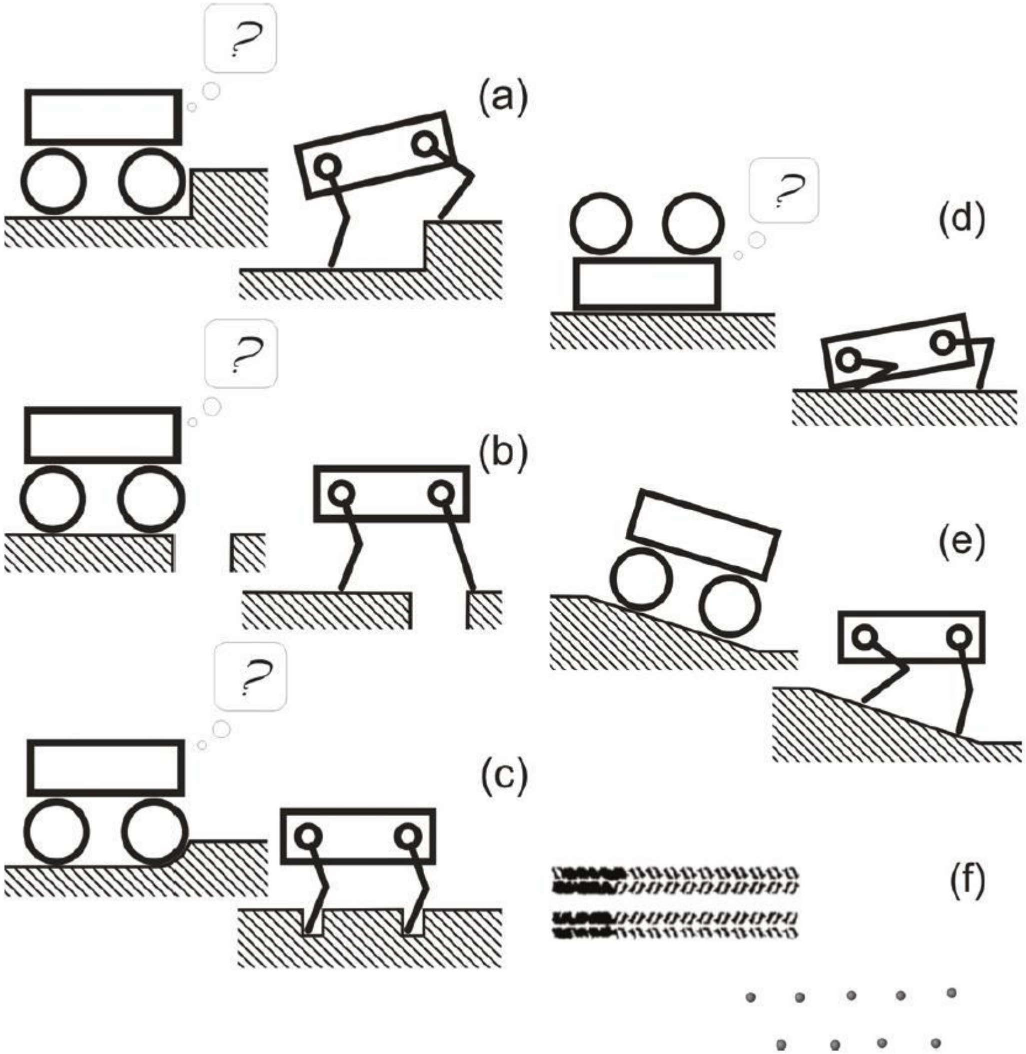
Adapted from R.Sigward

WHY LEGGED ROBOTS?

Legged systems can overcome many obstacles that are not reachable by wheeled systems!

But it is quite hard to achieve this since:

- many DOFs must be **controlled** in a coordinated way
- the robot must **see** detailed elements of the terrain

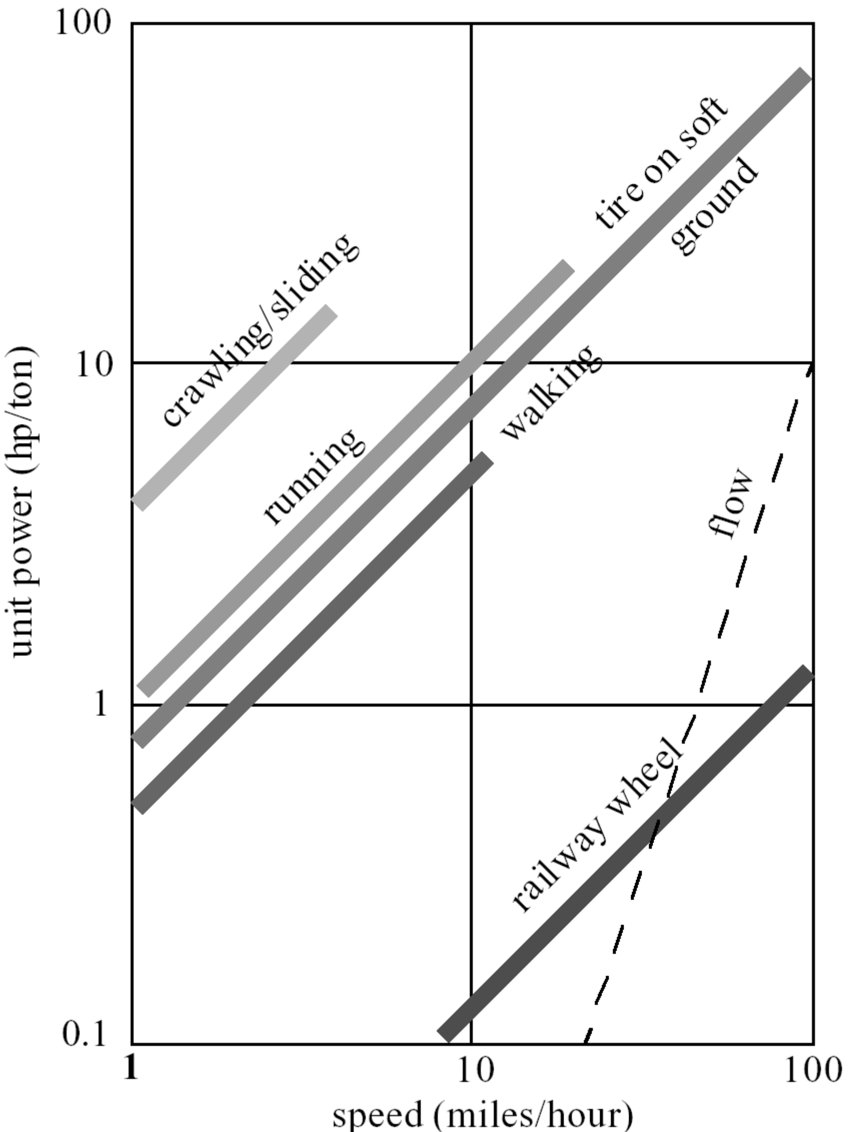


Adapted from R.Sigward

Walking or rolling?

- number of actuators
- structural complexity
- control expense
- energy efficient
- terrain (flat ground, soft ground, climbing..)
- movement of the involved masses

  1. walking / running includes up and down movement of COG
  2. some extra losses



Adapted from R.Sigward

Generation of motions for walking

- Manual motion design
  - classical slider based motion editors
- Control based
  - ZMP and inverse pendulum based control (for walking)
- Learning algorithms
  - Motion is specified in a parametric way (e.g., CPG) !
  - Parameters are determined by search algorithms (e.g., GA, RL)
- Motions are obtained from human data
  - Learning by watching/imitation
  - Motion retargeting

Adapted from R.Sigward

Case Study: Passive Dynamic Walker

- Forward falling combined with passive leg swing

- Storage of energy: potential kinetic in combination with low friction

Adapted from R.Sigward

EFFICIENCY COMPARISON

$$COT = c_{mt} = |\text{mech. energy}| \,/\, (\text{weight x dist. traveled})$$

COT = the energy cost of transport per unit distance (CoT; J·kg^{-1}·km^{-1})

$c_{mt}^{est.} \approx 1.6$

Collins *et al.* 2005

$c_{mt} \approx 0.31$

$c_{mt} \approx 0.055$

Collins *et al.* 2005

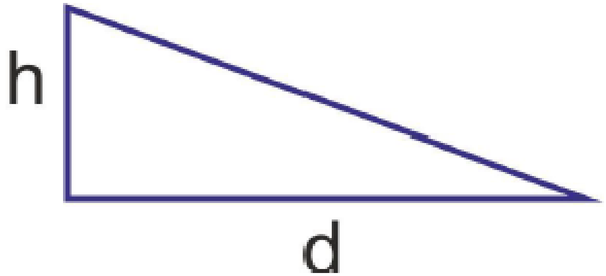
Adapted from R.Sigward

Inverted pendulum

- Static walking can be represented by inverted pendulum
- Exploit this in so-called passive dynamic walkers

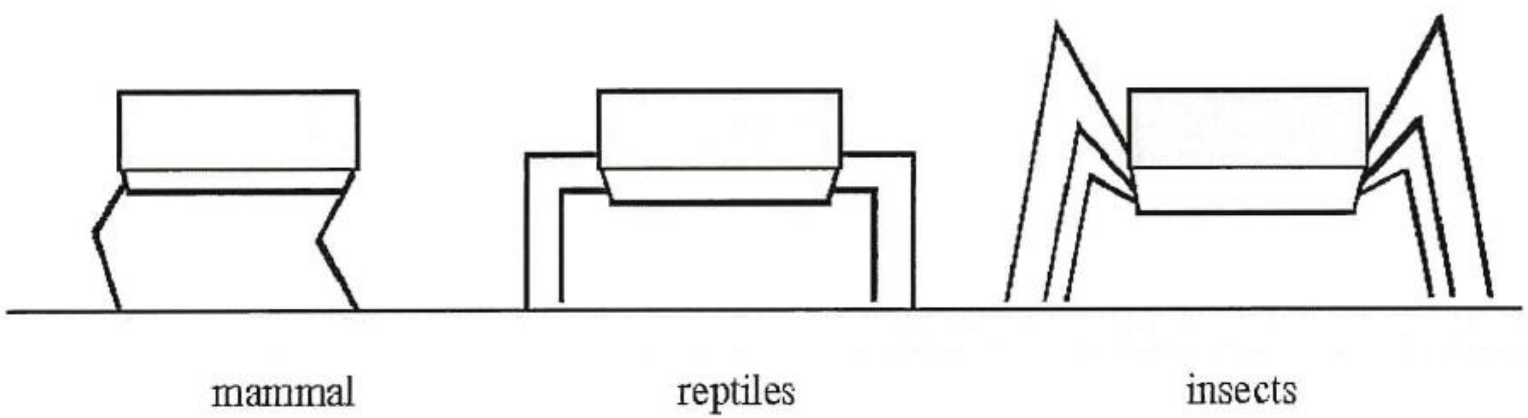
Energetically very efficient

$$COT = \frac{E_{used}}{m \cdot g \cdot d} = \frac{m \cdot g \cdot h}{m \cdot g \cdot d} = \frac{h}{d}$$



Adapted from R.Sigward

- 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 must learn for quite a while until they can stand or walk on two legs.*



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