Locomotion | **Legged Robotics**
Autonomous Mobile Robots

Marco Hutter

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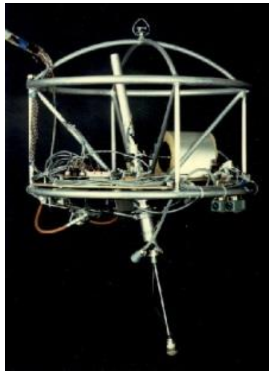
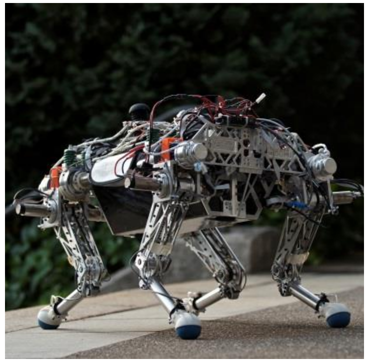
Different types of legged robots


Raibert Hopper
[http://www.ai.mit.edu/projects/leglab]

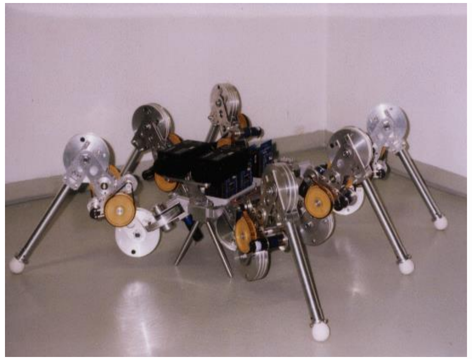
1


Asimo
[http://www.honda.asimo.com]

2


StarlETH, ETH Zurich

4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6


T8
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8

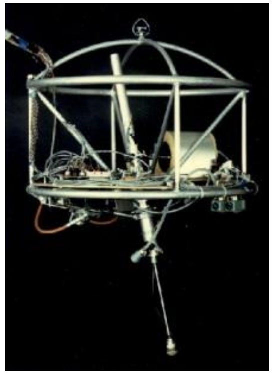

ZineDyn, KAIST

n

- The number of legs influences
  - Mechanical complexity
  - Control complexity

- Analogy in Nature
  - Insects can walk directly upon birth
  - Most mammals require several minutes to stand
  - Humans require more than a year to walk on two legs

Static and dynamic gaits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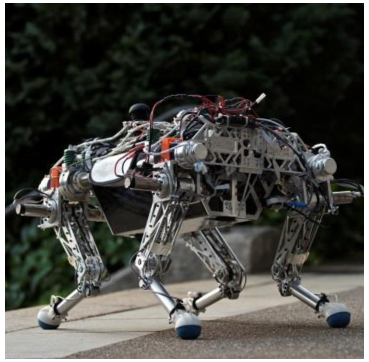
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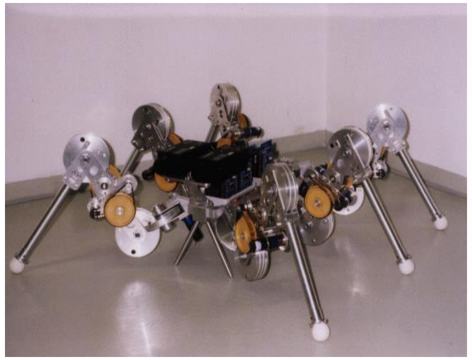
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1 2 4 6 8 n

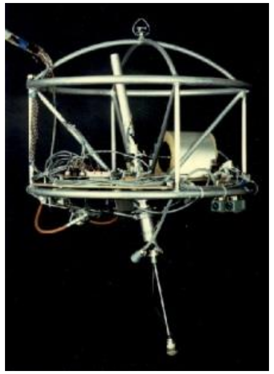
dynamic gaits

- "System is stabilized on a limit cycle"
- Falls over if stopped

static gaits

- "System is statically stable"
- Does NOT fall if stopped

Static and dynamic stability



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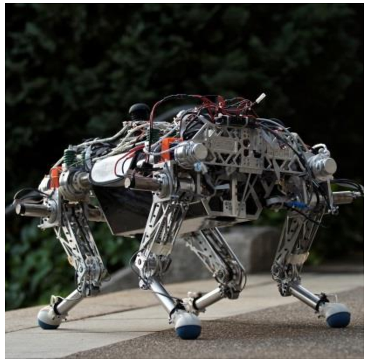

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dynamic gaits

- "System is stabilized on a limit cycle"
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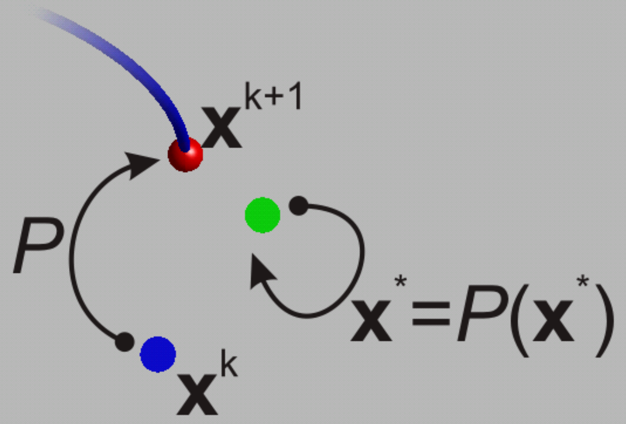
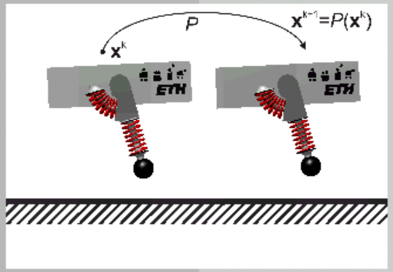
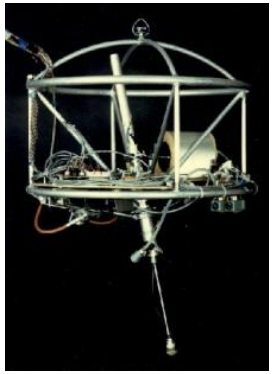
- Poincaré Map $\mathbf{x}_{k+1} = P(\mathbf{x}_k)$
- Fix-Point $\mathbf{x}^* = P(\mathbf{x}^*)$
- Linearization of mapping $\Delta\mathbf{x}_{k+1} = \frac{\partial P}{\partial \mathbf{x}}\Delta\mathbf{x}_k = \mathbf{\Phi}\Delta\mathbf{x}_k$
- The system is stable iff: $\lambda_i(\mathbf{\Phi}) < 1$





[C. David Remy, 2011]

Static and dynamic stability



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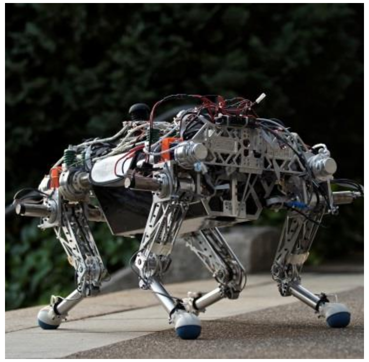

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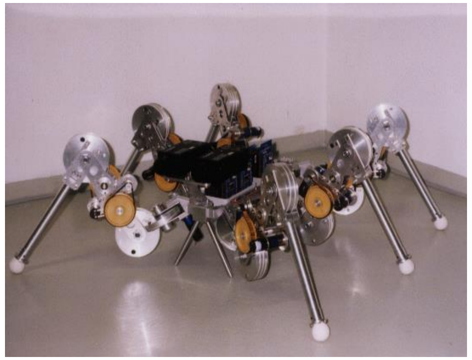

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ZineDyn, KAIST

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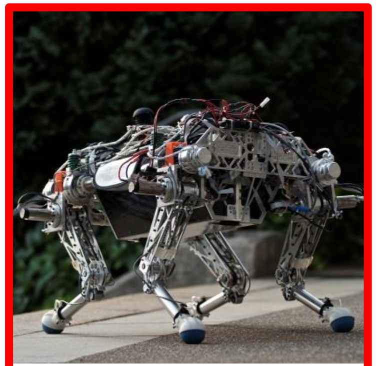
Quadrupedal robots


StarlETH, ETH Zurich

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- Point feet
  - Low mechanical complexity
  - High robustness (no actuators in feet)
- 3 DoF per leg
  - Minimal number of actuators
  - No redundancy

dynamic gaits

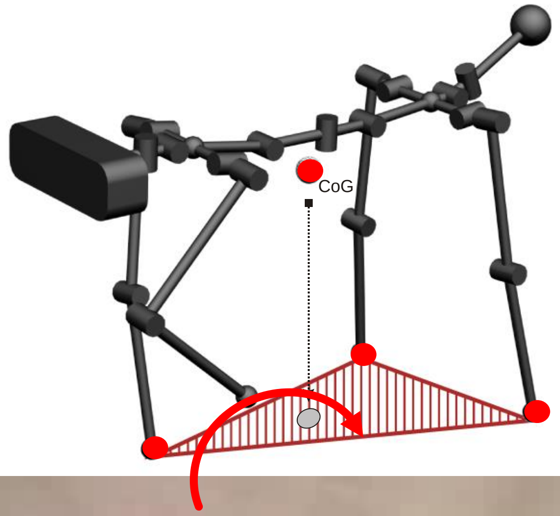
- "System is stabilized on a limit cycle"
- Falls over if stopped

static gaits

- "System is statically stable"
- Does not fall if stopped

Static locomotion

- Gait execution
  - Body weight supported by **≥3** legs
  - Move **one foot** at the time
  - CoG shifted betweeen support polygons

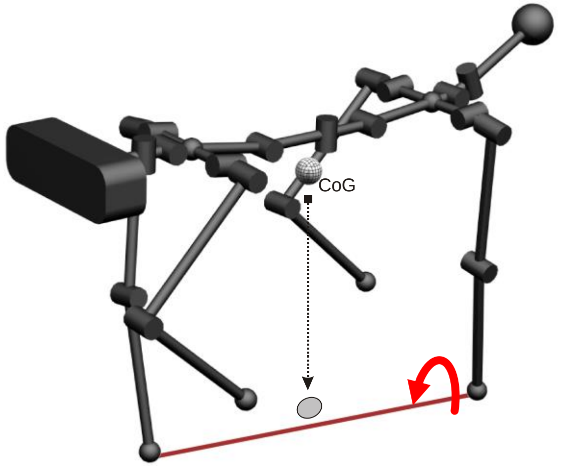


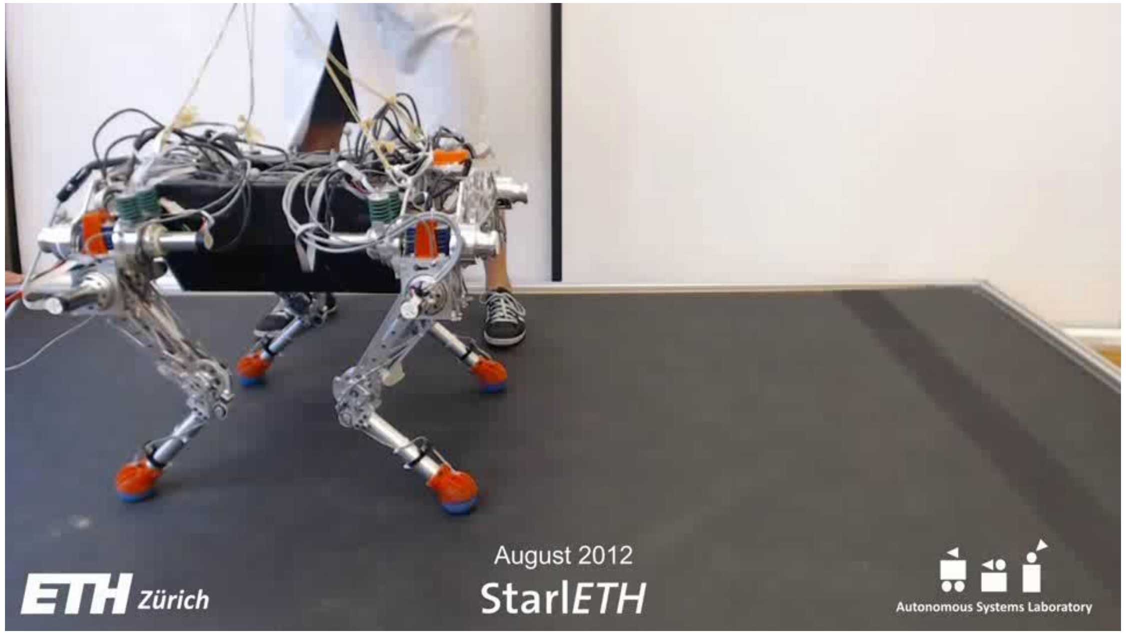
- Gait characteristics
  - Statically **stable**
  - Well-suited for climbing
  - Slow and energetically inefficient

Dynamic locomotion

- Gait execution
  - Body weight supported by **<3** legs
  - Move **multiple** feet at the time
  - Robot is balanced on a step-to-step basis

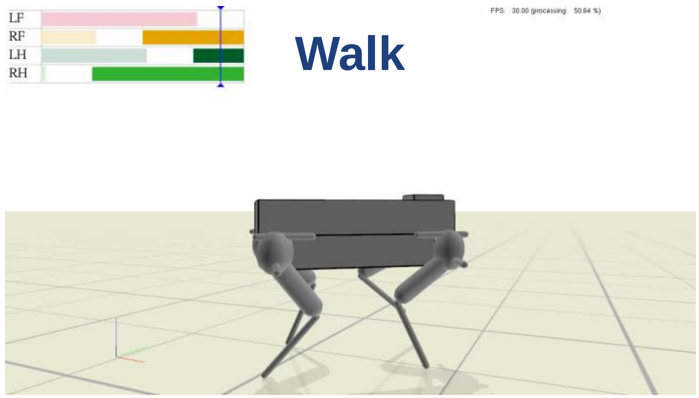
- Gait characteristics
  - Statically **unstable**
  - Well suited for fast motion
  - Fast and energetically efficient
  - Demanding for actuation and control

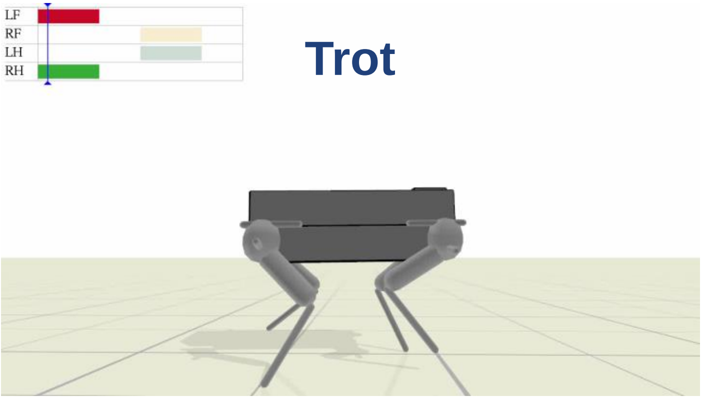


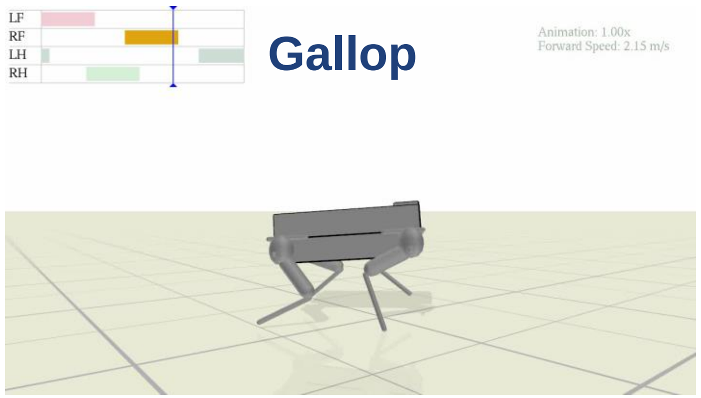


Locomotion control

1. Stepping sequence defined by gait pattern







2. Stepping location
   - Propel the robot forward and … bility
   - React to terrain elevatio… obstacles

Kinematics

3. Contact force distribution
   - Compensate gravity and … main body
   - Ensure contact stability a… optimize energetic efficiency

Dynamics