Introduction to Robotics

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- Walking robots and especially Hexapods

Short Review of Locomotion

- Two basic ways of using effectors:
  - to move the robot around => locomotion
  - to move other object around => manipulation
- These divide robotics into two mostly separate categories:
  - mobile robotics
  - manipulator robotics

Review: Locomotion

- Many kinds of joints and actuators can be used to move a robot around.
- The obvious categories are:
  - **legs** (for walking/crawling/climbing/jumping/hopping)
  - **wheels** (for rolling)
  - **arms** (for swinging/crawling/climbing)
  - **flippers** (for swimming)
  - …
- While most animals use legs to get around, legged locomotion is a *very difficult* robotic problem, especially when compared to wheeled locomotion.

Locomotion

- First, any robot needs to be stable
  (i.e., not *wobble* and *fall over* easily).
- There are two kinds of stability:
  - **static**
  - **dynamic.**
- A ***statically stable*** robot can stand still without falling over.
  - This is a useful feature, but a difficult one to achieve:
    - it requires that there be **enough legs/wheels** on the robot to provide sufficient static points of support.

Locomotion

- For example, **people are *not* statically stable**.
- In order to stand up, which appears effortless to us, we are actually using active control of our balance.
- Achieved through nerves and muscles and tendons.
- This balancing is largely unconscious:
  - it must be learned,
  - so that's why it takes babies a while to get it right,
  - certain injuries can make it difficult or impossible.

Locomotion

- ***With more legs, static stability becomes quite simple.***
- In order to remain stable, ***the robot's Center Of Gravity (COG) must fall under its polygon of support***.
- This polygon is basically the projection between all of its support points onto the surface.
- So in a **two-legged robot**, the polygon is really a line.
- Thus the center of gravity cannot be aligned in a stable way with a point on that line to keep the robot upright.
- Consider now a three-legged robot:
  - with its legs in *a tripod organization,*
  - and its body above,
- Such robot produces a stable polygon of support.
- It is thus statically stable.
  - See the Robix tripod robot, it works!

Stability of standing and walking

- But what happens when a statically stable robot lifts a leg and tries to move?
- Does its center of gravity stay within the polygon of support?
- It may or may not, depending on the geometry.
- For certain *robot geometries*, it is possible (with various numbers of legs) to always stay statically stable while walking.
- This is very safe, but it is also very slow and **energy inefficient.**

Polygon of Support

- In two-legged robots/creatures, the polygon of support is very small, much smaller than the robot itself, so static stability is not possible (unless the feet are huge!)
- As more legs are added, and the feet spread out, the polygon gets larger
- Three-legged creatures can use a tripod stance to be statically stable

Statically Stable Walking

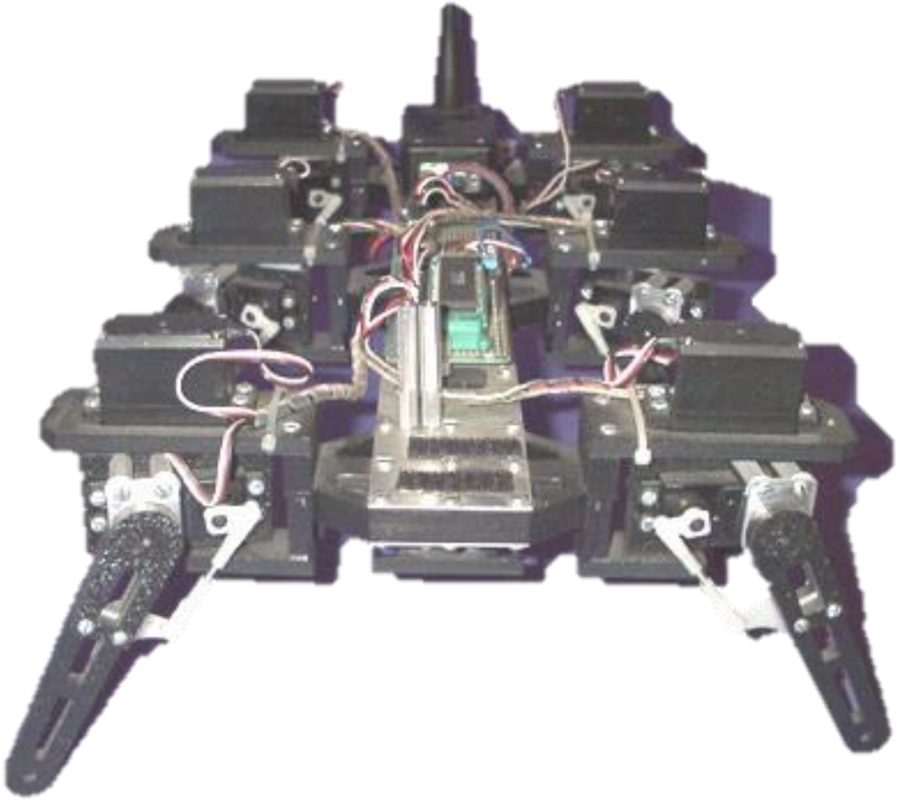
- *Three legs are enough to balance, but what about walking?*

- If a robot can stay continuously balanced while walking, it employs statically stable walking
- Impossible with 3 legs; as soon as one is off the ground, only 2 are left, which is unstable
- *How many legs are needed for statically stable walking?*

Good Numbers of Legs

- Since it takes 3 legs to be statically stable, it takes at least 4 to walk statically stable
- Various such robots have been built
- 6 legs is the most popular number as they allow for a very stable walking gait, <u>***the tripod gait***</u>
- 3 legs are kept on the ground, while the other 3 are moved forward

The Tripod Gait



The Tripod Gait

- If the same three legs move at a time, this is called the ***alternating tripod gait***
- if the legs vary, it is called ***the ripple gait***
- All times, a triangle of support stays on the ground, and the COG is in it
- This is very stable and thus used in most legged robots

Tripod Gait in Biology

- Cockroaches and many other 6-legged insects use the alternating tripod gait
  - Note: numerous insects have 6 legs
- Insects with more than 6 legs (e.g., centipedes and millipedes), use the ripple gate
- Insects can also run very fast by letting go of the ground completely every once in a while, and going airborne…

Dynamic Stability

- Statically stable walking is very energy inefficient
- As an alternative, dynamic stability enables a robot to stay up while moving
- This requires active control
  - (i.e., the inverse pendulum problem)
- Dynamic stability can allow for greater speed, but requires harder control

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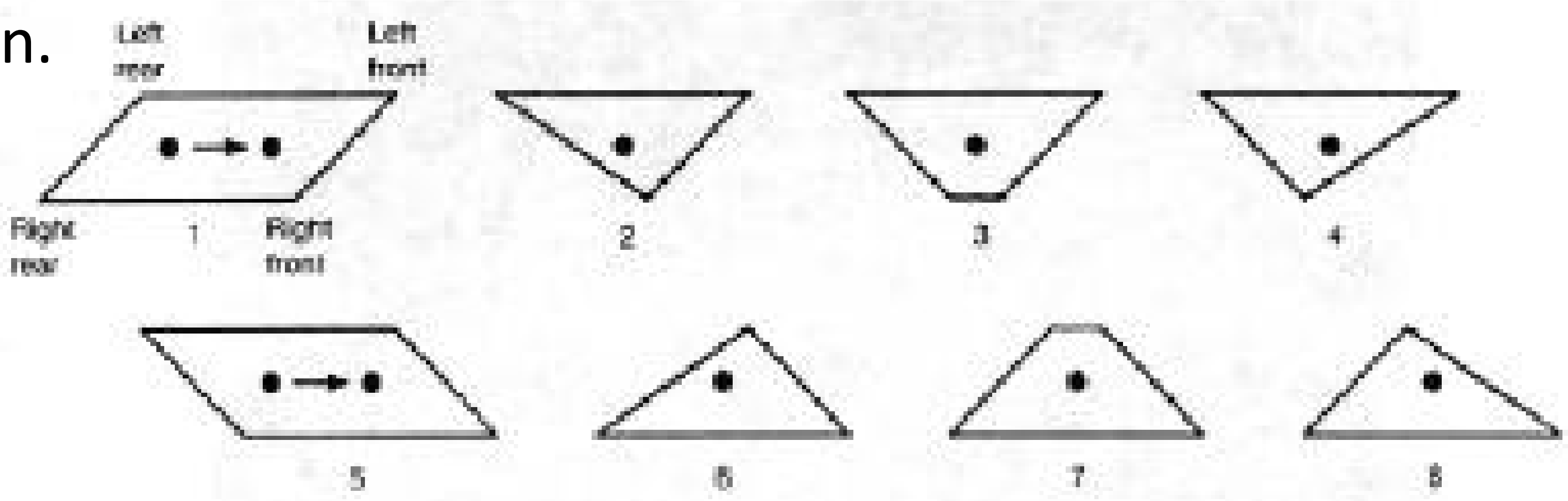
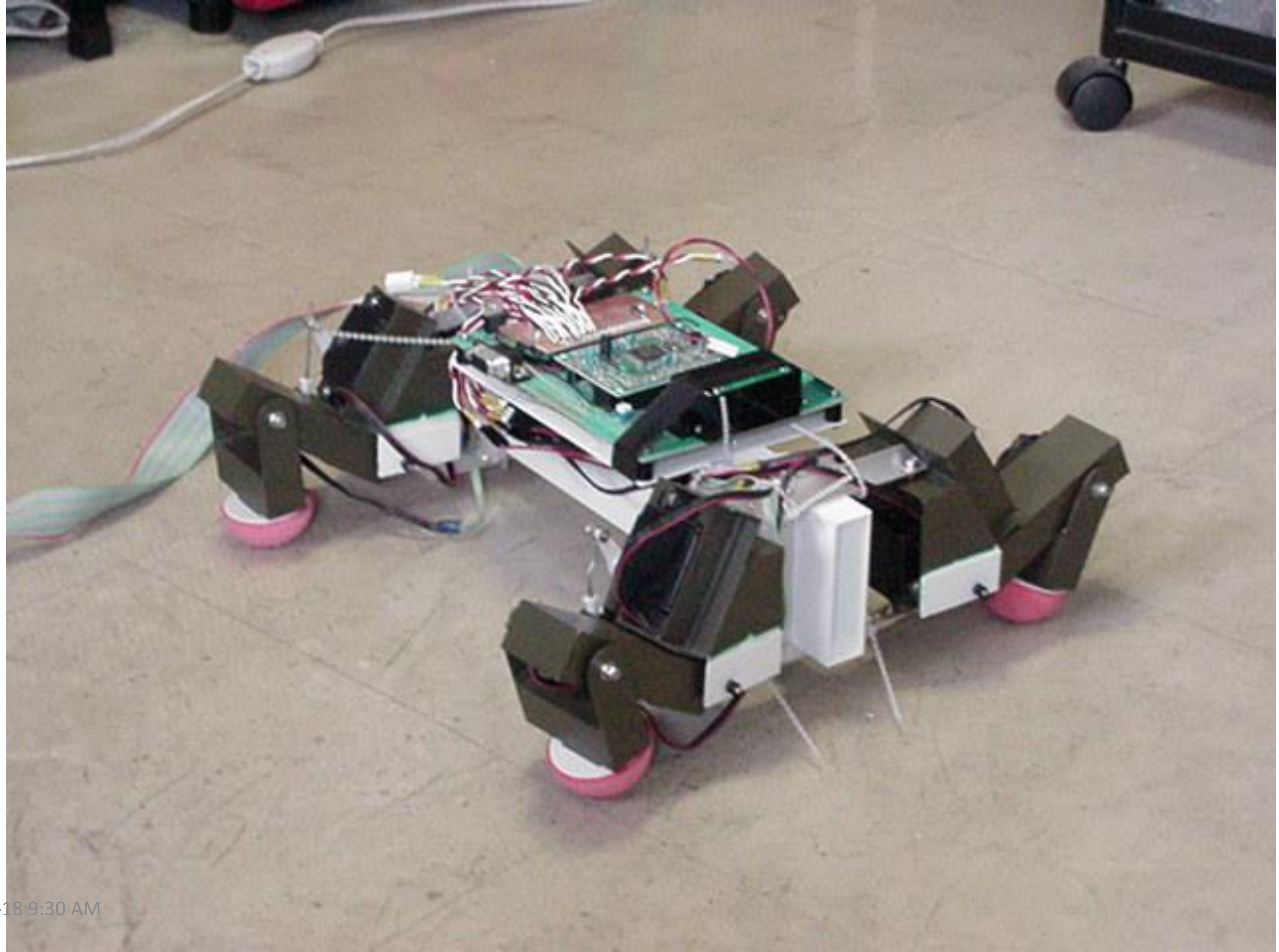
Static Stability

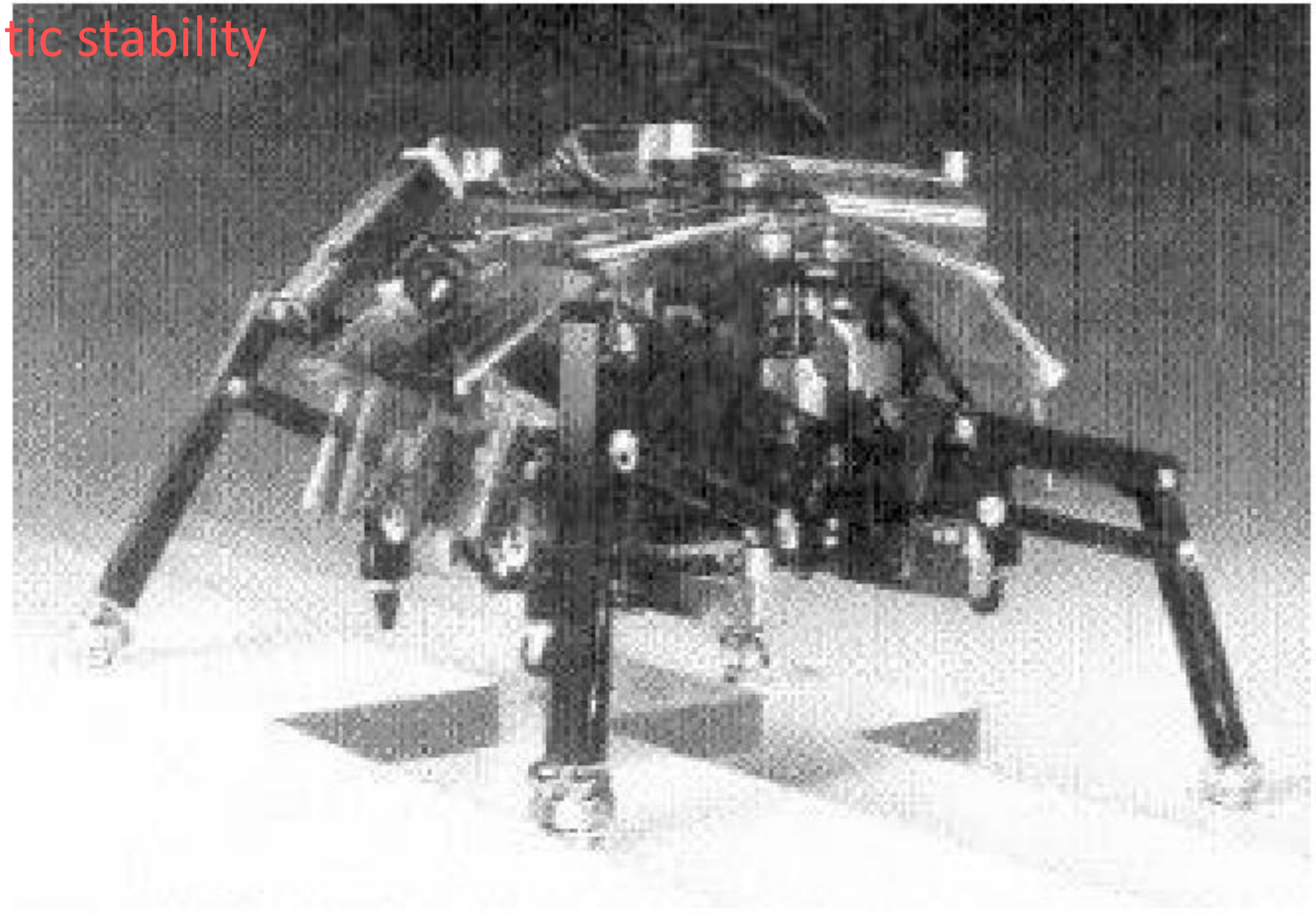
- Sequence of support patterns provide by feet of a quadruped walking.
- Body and legs move to keep the projection of the center of mass within the polygon defined by a feet.
- Each vertex is a support foot.
- Dot is the projection.





Titan IV

- TITAN IV (1985)
- The name is an acronym for "Tokyo Institute of Technology, Aruku Norimono (walking vehicle)".
- Demonstrates static stability



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Stability of standing and walking

- A ***basic assumption*** of the static gait (statically stable gait) is that the weight of a leg is negligible compared to that of the body,
  - so that the total center of gravity (COG) of the robot is not affected by the leg swing.
- Based on this assumption, the conventional static gait is designed so as to maintain the COG of the robot inside of the support polygon.
- This polygon is outlined by each support leg's tip position.

Stability of standing and walking

- The alternative to static stability is ***dynamic stability*** which allows a robot (or animal) to be stable while moving.
- For example, one-legged hopping robots are dynamically stable:
  - they can hop in place or to various destinations, and not fall over.
- But **they cannot stop and stay standing**
  - (this is an *inverse pendulum* balancing problem).

A Stable Hopping Leg

- Robert Ringrose of MIT AAAI97.
- Hopper robot leg stands on its own,
- hops up and down,
- maintaining its balance and correcting it.
- forward, backward left, right, etc., by changing its center of gravity.

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Stability of standing and walking

- A statically stable robot can:
  - use dynamically-stable walking patterns - it is fast,
  - use statically stable walking - it is easy.
- A simple way to think about this is by *how many legs are up in the air* during the robot's movement (i.e., gait):
  - 6 legs is the most popular number as they allow for a very stable walking gait, the **tripod gait** .
  - if the same three legs move at a time, this is called the **alternating tripod gait.**
  - if the legs vary, it is called the ***ripple gait.***

Hexapod walking

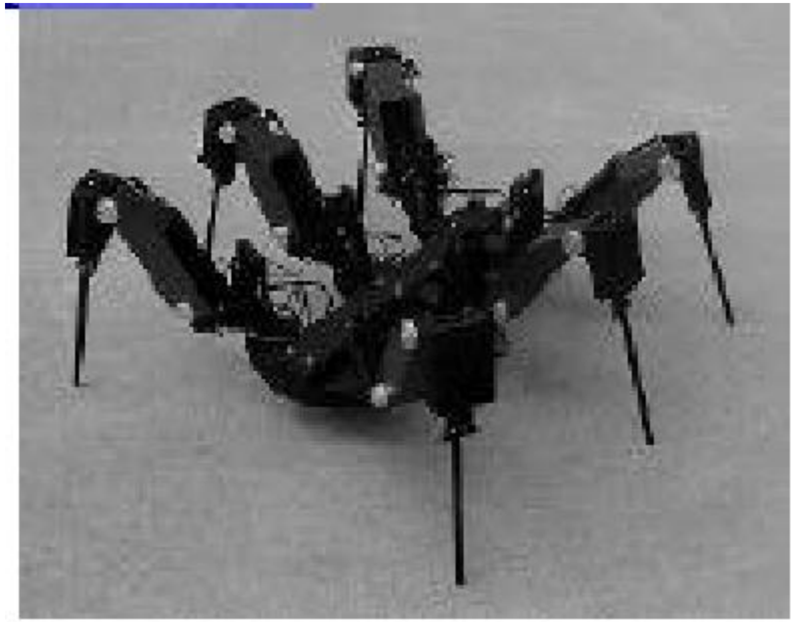
- A rectangular 6-legged robot can lift three legs at a time to move forward, and still retain static stability.
- How does it do that?
- It uses the so-called ***alternating tripod gait***, a biologically common walking pattern for 6 or more legs.
- Characteristic of this gait:
  - one middle leg on one side and two non-adjacent legs on the other side of the body lift and move forward at the same time,
  - the other 3 legs remain on the ground and keep the robot statically stable.

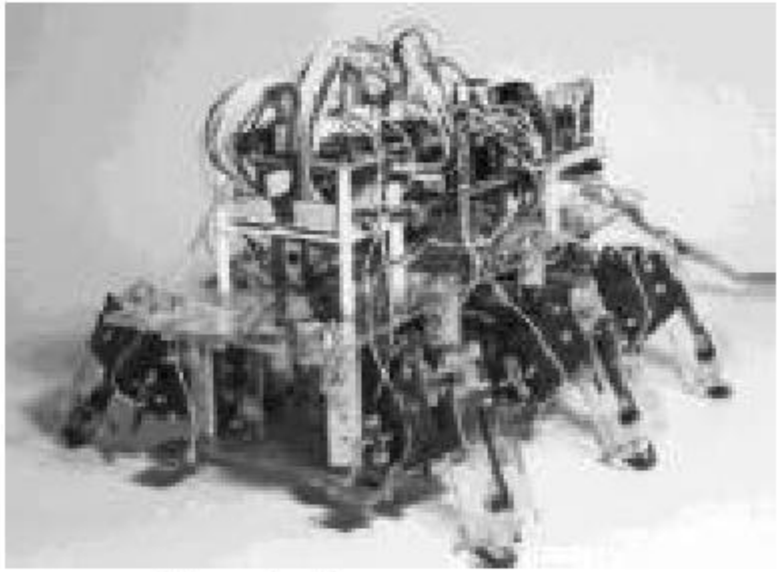
Hexapod and Insect walking

- **Roaches** move this way, and can do so very quickly.
- **Insects** with more than 6 legs (e.g., centipedes and millipedes), use the ripple gate.
  - However, when these insects run really fast, they switch gates to actually become airborne (and thus not statically stable) for brief periods of time.

Hexapods

- Biologically inspired
  - insects
- Potentially very stable as the motion of one leg usually does not affect vehicle stance.
- Fairly simple to come up with a control algorithm

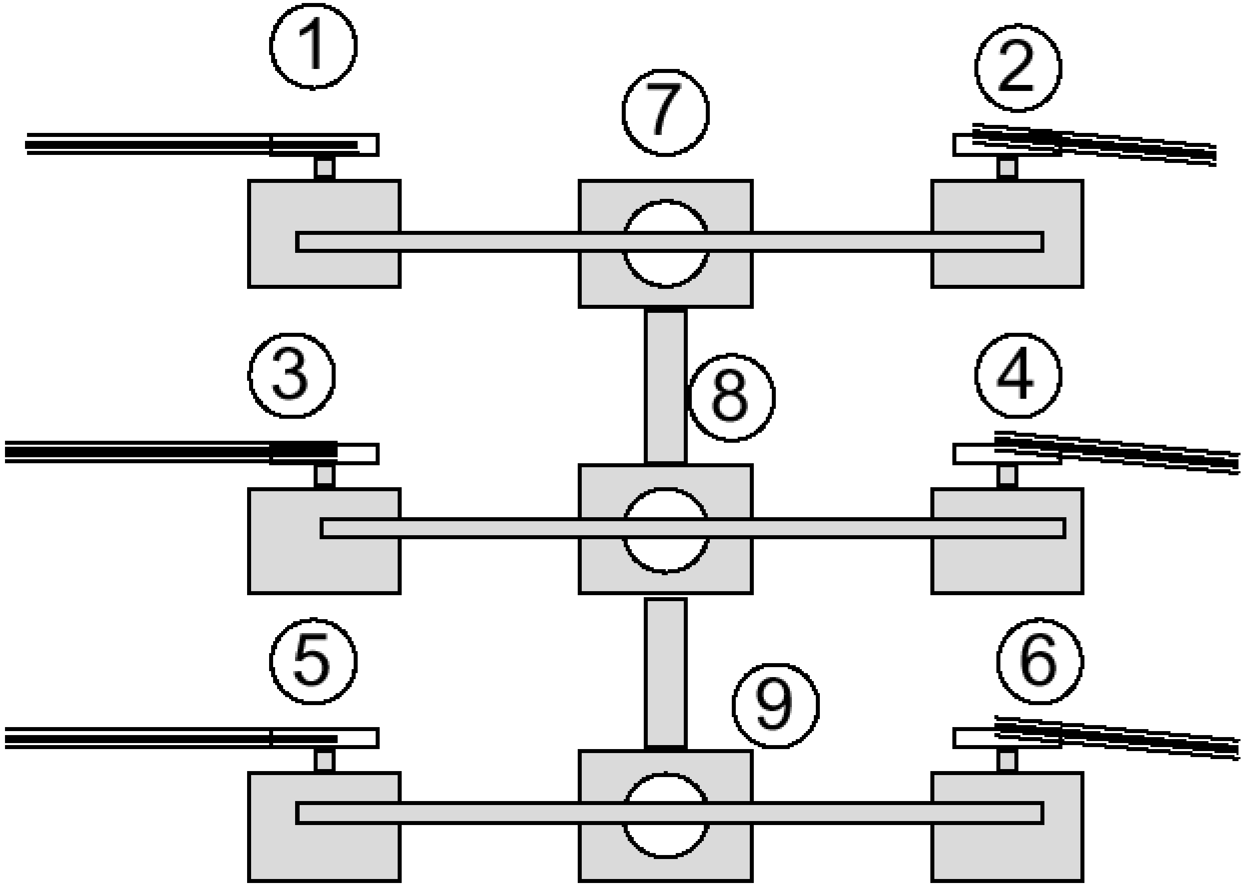




Build your own hexapod

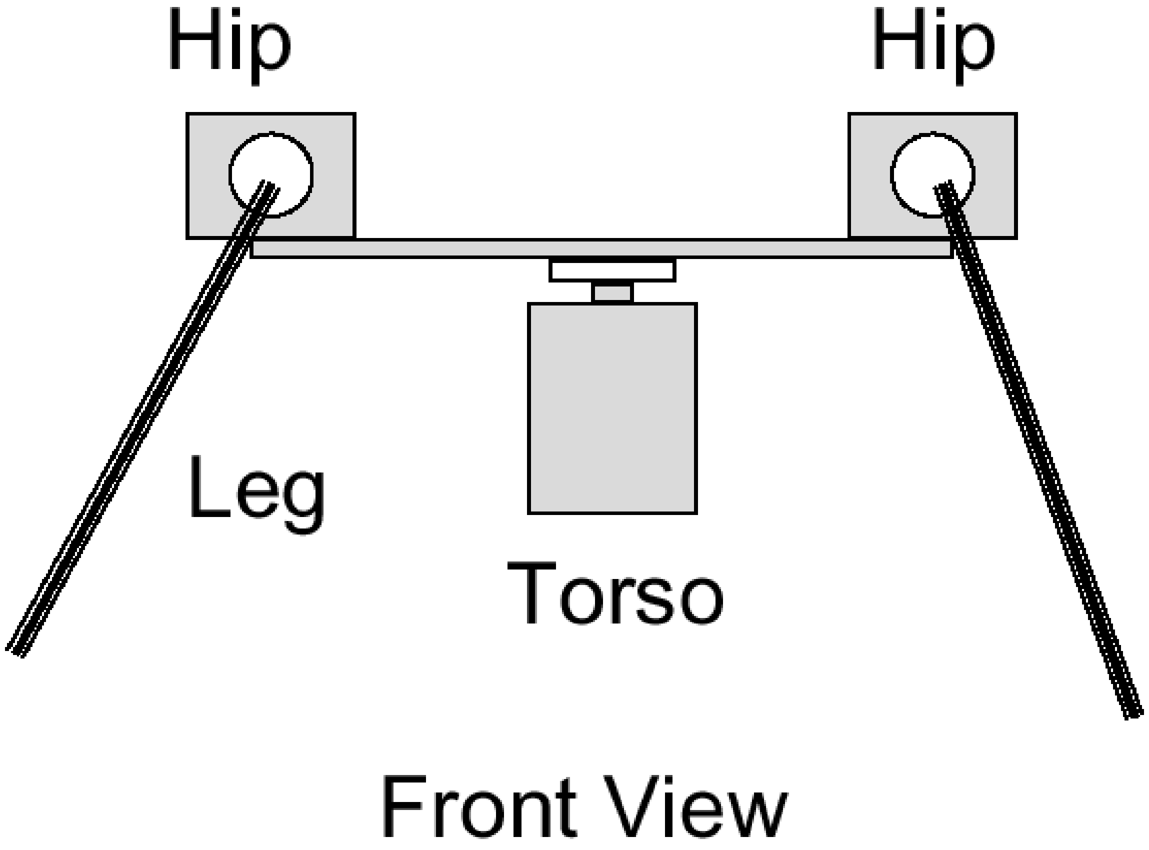
- Provides a statically stable gait
- Basic hexapod walker can be built with 9 servos (or fewer)
- Problems with this design

9 servo hexapod



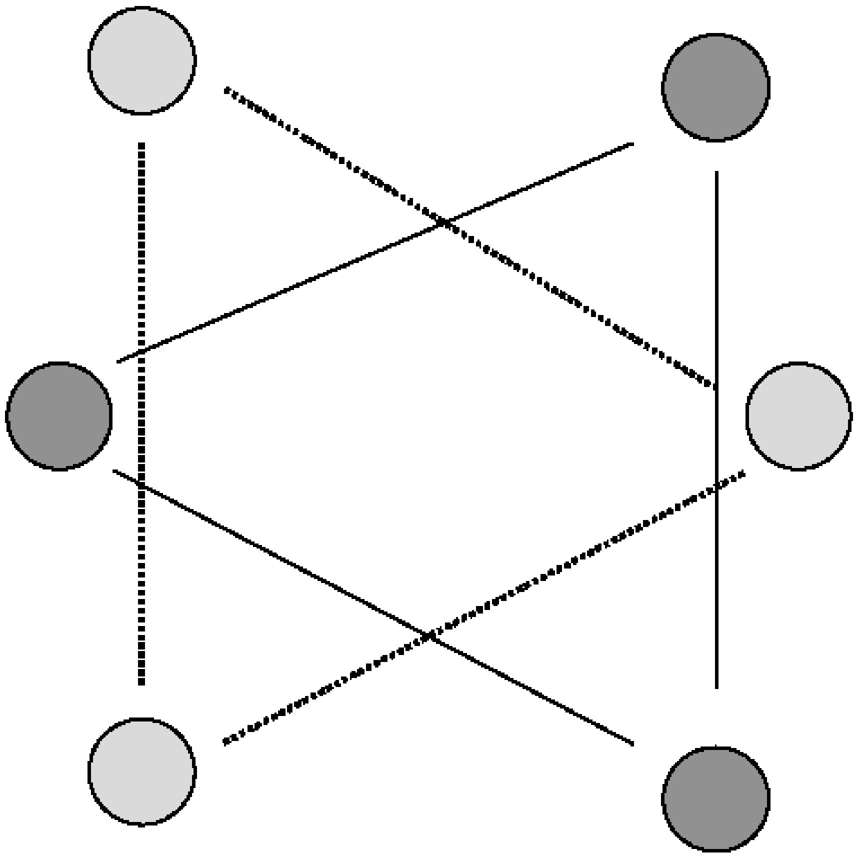
Hexapod Walking Continued

- **Torso servo supports a strut which supports two hip servos.**
- **Legs are lifted and dropped by hips while side to side motion achieved by torsos.**



Alternating Tripod Gait

- **Walking gaits were first reported by D.M. Wilson in 1966.**
- **A common gait is the "alternating tripod gait".**
- **Commonly used by certain insects while moving slowly.**



A Walking Algorithm

Step 1

- **legs 1,4,and 5 down, legs 2,3 and 6 up.**

Step 2

- **rotate torso 7 and 9 counter-clockwise, torso 8 clockwise.**

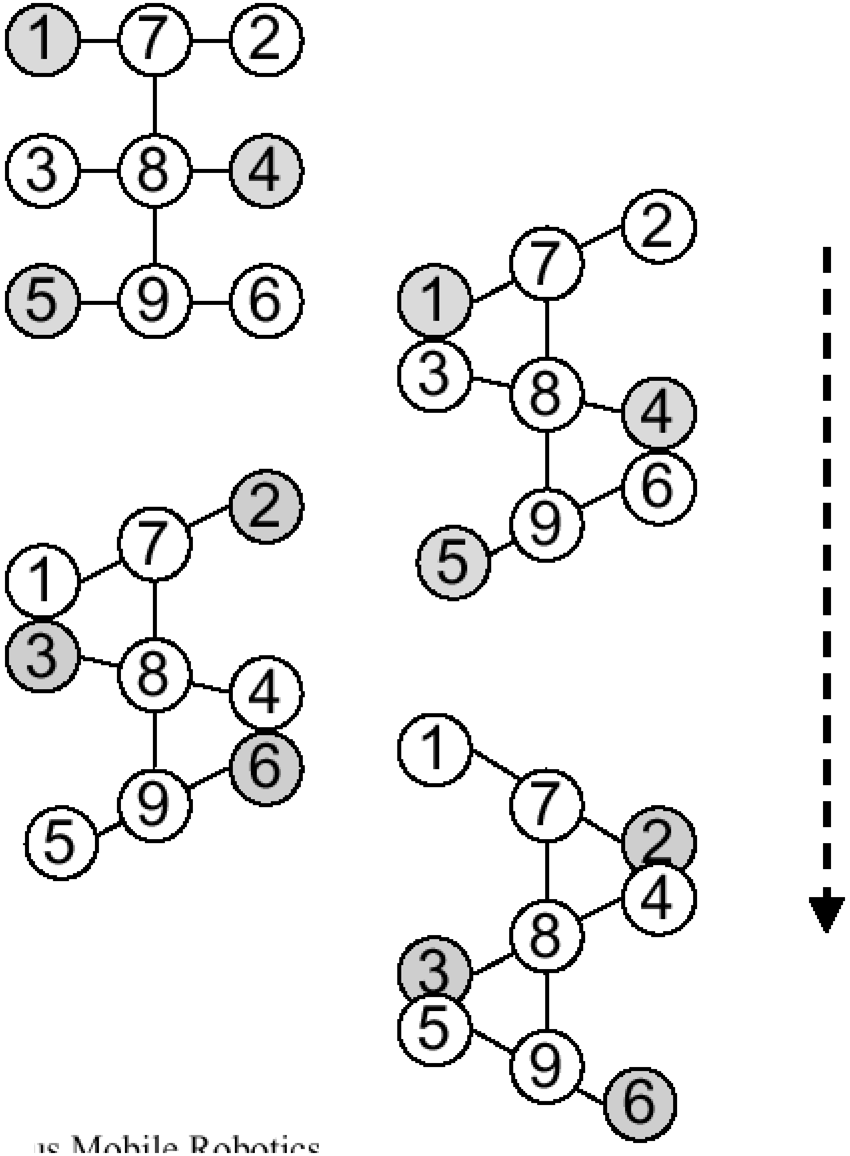
Step 3

- **legs 1,4 and 5 up,**
- **legs 2,3, and 6 down.**

Step 4

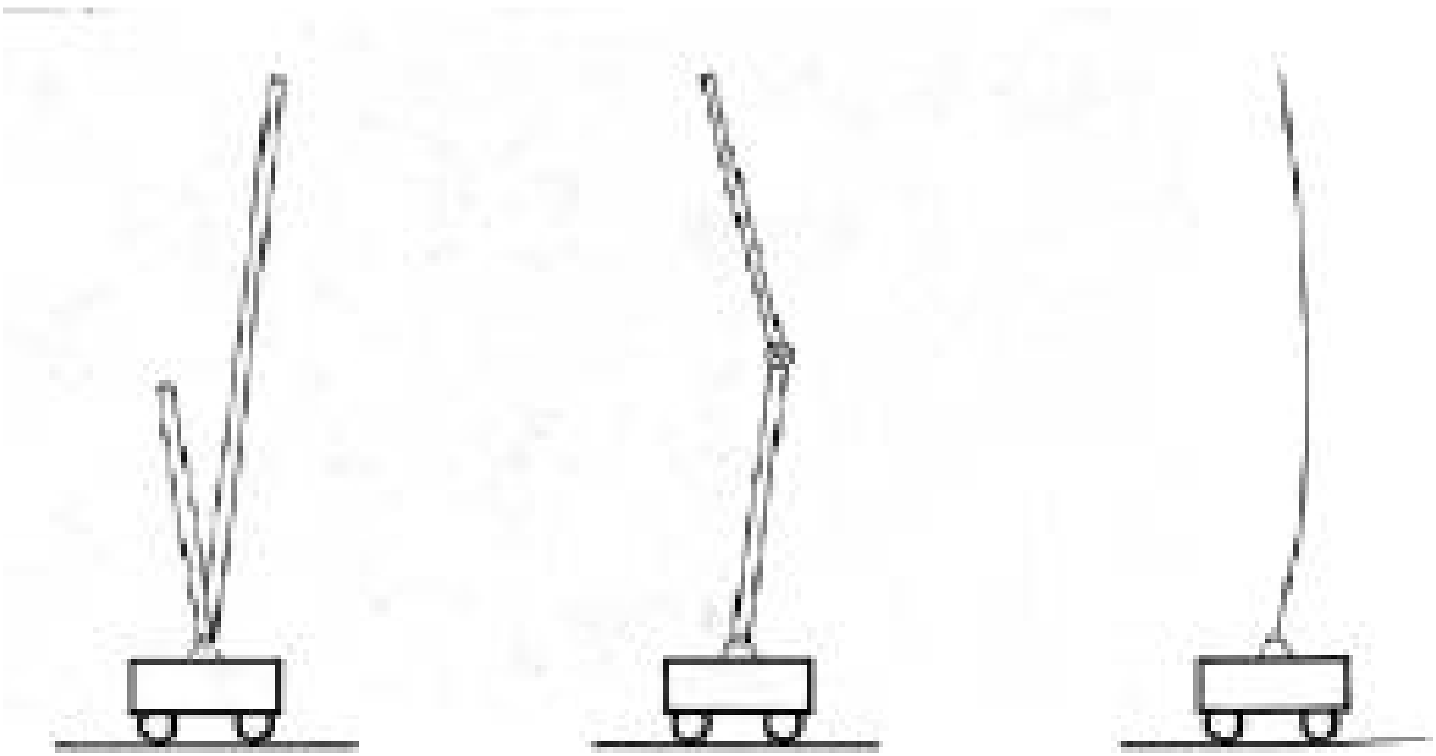
- **rotate torso 7 and 9 clockwise, torso 8 counter-clockwise.**

Goto step 1



Active (dynamic) Stability

- Inverted pendulum balanced on cart.
- Only one input, the force driving the cart horizontally, is available for control.



Hexapod walking

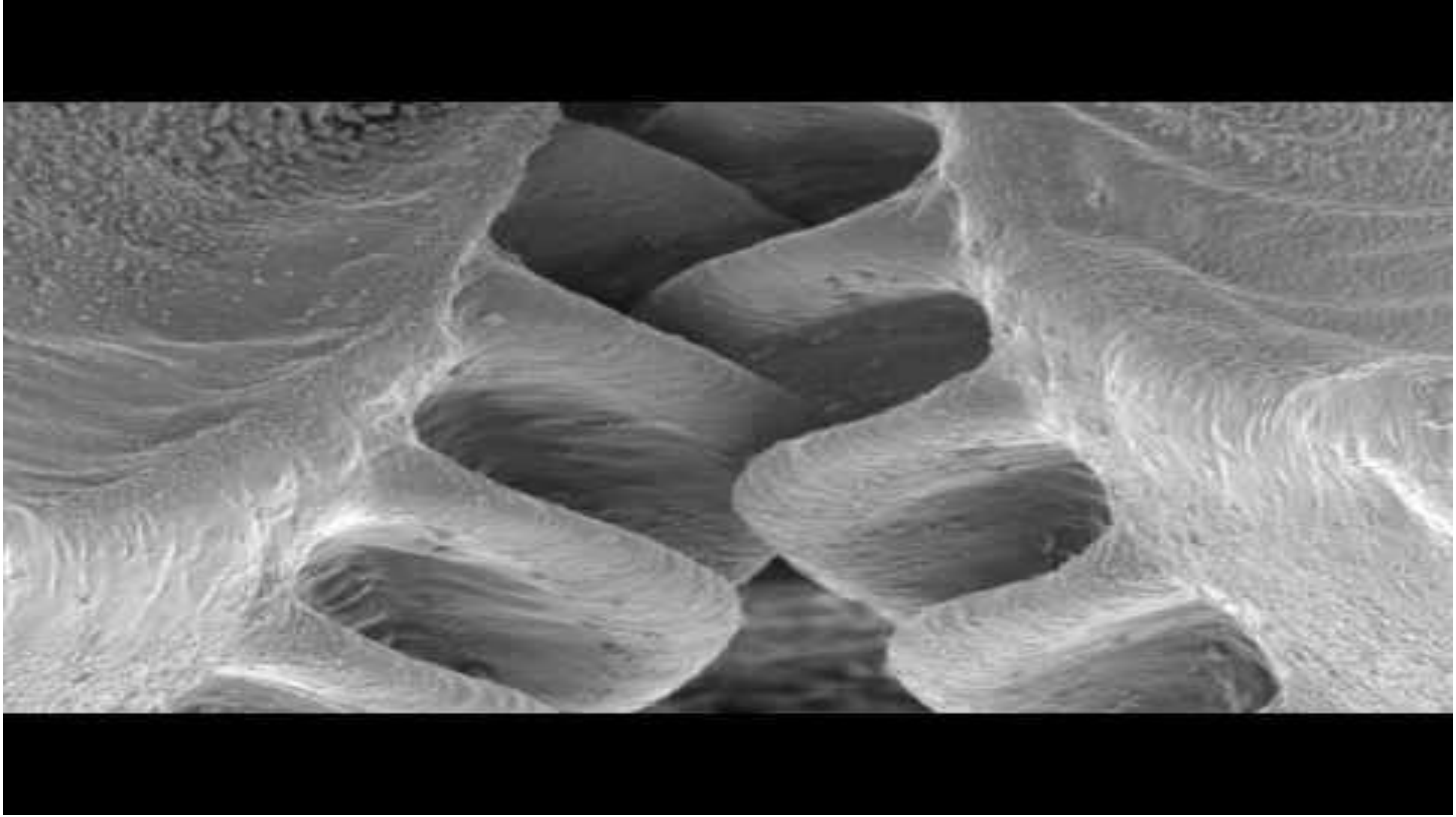
- Statically stable walking is very ***energy inefficient***.
- As an alternative, dynamic stability enables a robot to stay up while moving.
- This requires active control (i.e., the inverse pendulum problem).
- Dynamic stability can allow for greater speed, but requires harder control.
- Balance and stability are very difficult problems in control and robotics.
- Thus, when you look at most existing robots, **they will have wheels or plenty of legs (at least 6).**
- **What about wheels AND legs?**

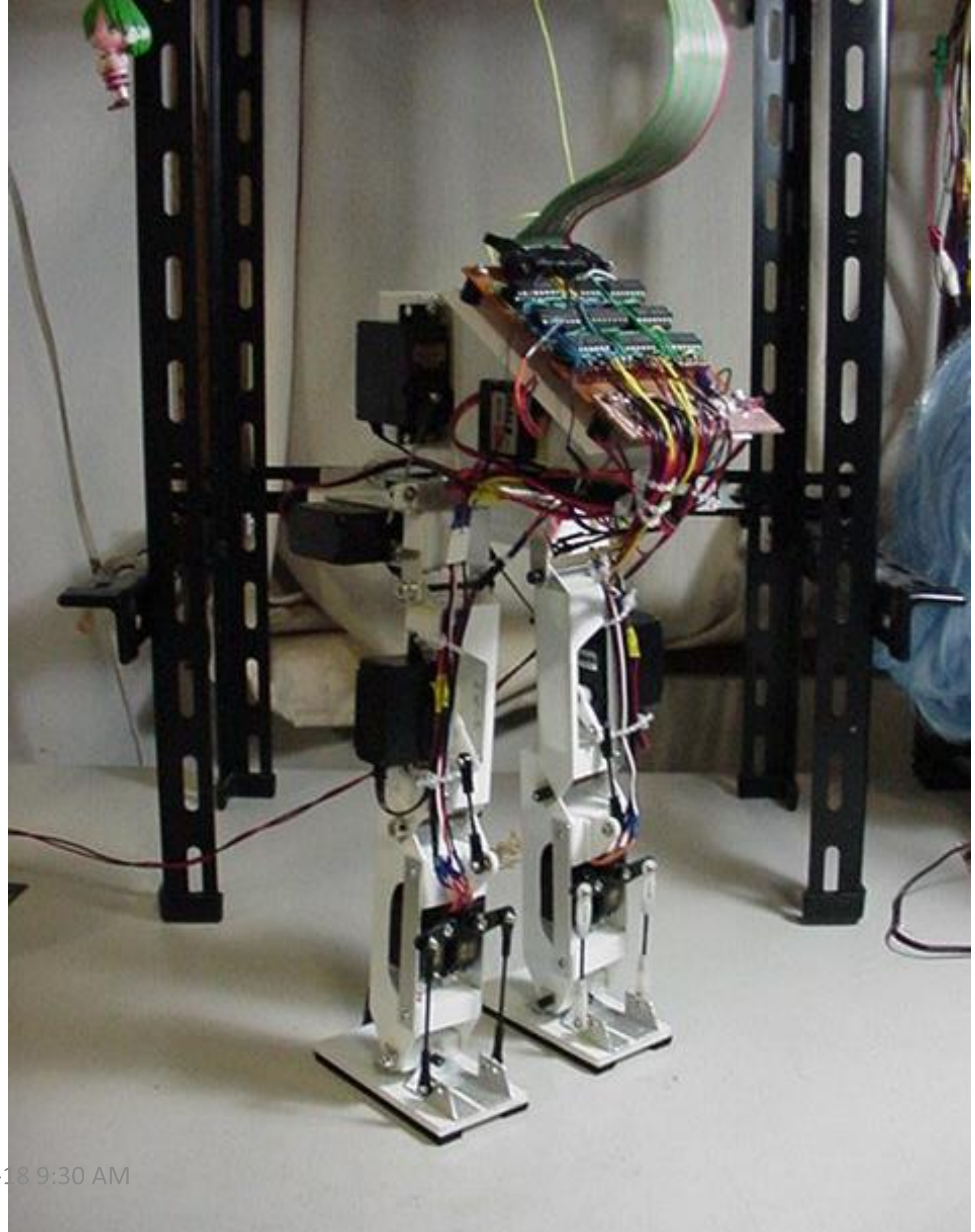
Hot Research

- Research robotics, of course, is studying:
  - single-legged,
  - two legged,
  - three-legged,
  - four-legged,
  - and other
- dynamically-stable robots, for various scientific and applied reasons.
- Biology research, entertainment.

Why wheels were not evolved by Nature?

- **Wheels** are more efficient than legs.
- They also do appear in nature, in certain bacteria, so the common myth that biology cannot make wheels is not well founded.
- However, evolution favors lateral symmetry and **legs are much easier to evolve**, as is abundantly obvious.
- However, if you look at population sizes, insects are most populous animals, and they all have many more than 2 legs.





Experimental Biped

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Wheels v. Legs

- Because balance is such a hard control problem, most mobile robots have wheels, not legs, and are statically stable
- Wheels are more efficient than legs, and easier to control
- There are wheels in nature, but legs are by far more prevalent, though in terms of population sizes, more than 2 legs (i.e., insects abound)

Why Choose Legs?

- Better handling of rough terrain.
  - Only about 1/2 of the world's land mass is accessible by artificial vehicles.
- Use of isolated footholds that optimize support and traction.
  - e.g. a ladder.
- Active suspension
  - decouples path of body from path of feet
  - payload free to travel despite terrain.

Legged Robot: Versatility

- Less energy loss
- Potentially less weight
- Can traverse more rugged terrain
- Legs do less damage to terrain (environmentally conscious)
- Potentially more maneuverability