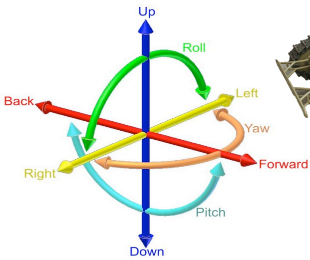
Mobility 2
DoFs, Wheels, and Wings



Many slides adapted from slides © R. Siegwart, ETH Zürich – Autonomous Systems Laboratory

Today

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- Last time: walking (mostly)
- More mobility terminology
- A bit more about wheels
- Wings/propellers
- Other mobile actuators
  - Walking wheels, passive flight, swimming, …
- Why are we talking about this?

A Note on Bipedalism

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- Two-legged walking is a static or dynamic gait?
- Dynamic (you need at least 4 legs for static)
- Every step "drops" a foot against the floor
  - You basically fall forward onto that foot
- Balance and control are difficult
- Large forces on joints with every step
  - A person-sized bipedal robot with titanium joints needs hip and knee replacements constantly!

Degrees of Freedom (formally)

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- DoFs: # of independent parameters that define the state of a physical system.
  - Fine, but it underdefines "state"

In robotics: any of…

- The number of independently controlled actuators.
- Possible changes of orientation of some set of parts:
  - Now includes "the whole robot".
  - Pitch, yaw and roll.
- Possible changes of position:
  - Translation in x, y, z.

Pose DoFs: Pitch, Roll, Yaw

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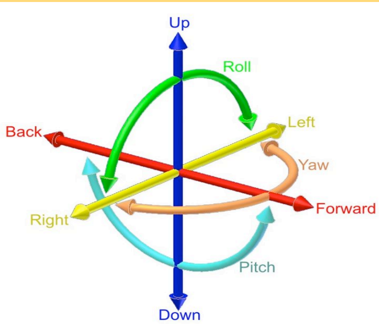

https://en.wikipedia.org/wiki/Six_degrees_of_freedom

Wheels

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- Most appropriate solution for most applications
- Three wheels guarantee stability
- With more than three wheels an appropriate suspension is required
  - Why?
- Selection of wheels depends on the application

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More About Omni Wheels

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- Swedish (Mecanum, Ilon, Omni) wheel
  - Three degrees of freedom
  - Rotation around the (motorized) wheel axle, (sometimes motorized) rollers, contact point

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Omni Movement

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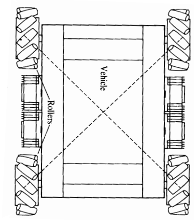
- Alternating left and right-handed rollers
  - Wheel applies force at right angles to the wheelbase diagonal
  - Can move in any direction by varying speed, direction of rotation of each wheel
- Types of motion
  - All four wheels in same direction: forward or backward
  - Wheels on one side opposite to other side: rotation
  - Wheels on one diagonal opposite direction to wheels on other diagonal: sideways movement



https://en.wikipedia.org/wiki/Mecanum_wheel

Maneuvering and Control

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- Two more axes of characterization
- Maneuverability
  - How many different maneuvers a robot can do
    - "An act or instance of changing direction"
    - "To change the position of by a maneuver"
    - "To steer in various directions as required"
  - Most maneuverable?
- Controllability
  - How easy it is to get the robot to do what you intend
    - Mechanically: e.g., slippage
    - Programmatically: e.g., 4 independently controlled wheels moving in unison
- Maneuverability and controllability ≈ inverse correlation

Slip/Skid

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- Q: How do you turn a tank?
  - Treads are "wheels" with large surface contact
  - Violate the "point contact" assumption
  - What's the difficulty?
- A: Rotate treads opposite directions
  - How can this work?
- What are the tradeoffs?
  - Friction on flat surfaces
  - High torque requirements
  - Tread wear / Terrain damage
  - Odometry

Arrangements

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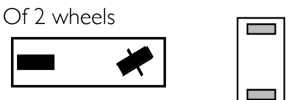
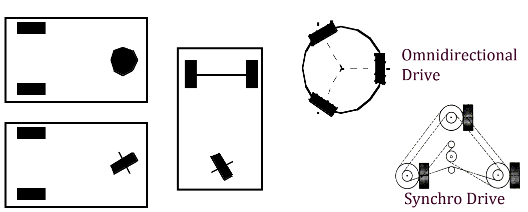
- Of 2 wheels



- Of 3 wheels



Arrangements

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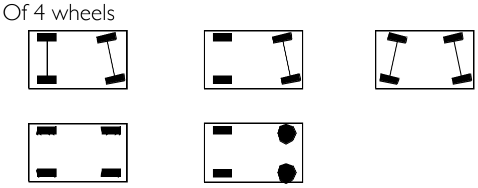
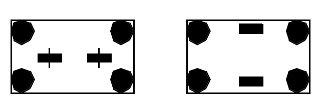
- Of 4 wheels



- Of 6 wheels



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Caterpillar

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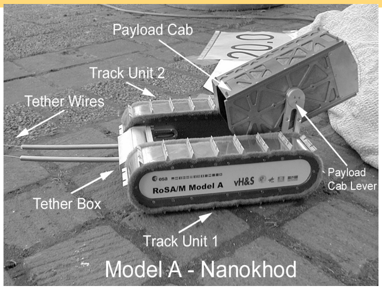

- The NANOKHOD II, European Space Agency (ESA)
- May eventually go to Mars

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Walking Wheels

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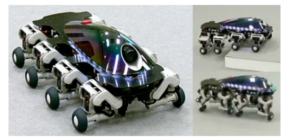
- Active or passive
- Roll and lift/release
- Roll and rollover



Halluc II, Chiba Inst. Of Tech.

Passive: the Shrimp

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- Passive locomotion on rough terrain
- 6 wheels
  - One fixed wheel in the rear
  - Two bogies on each side
  - Front wheel, spring suspension
- ≈ 60 cm long, 20 cm tall
- Highly stable in rough terrain
- Climbs obstacles up to 2x wheel diameter

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Shrimp "Walking"

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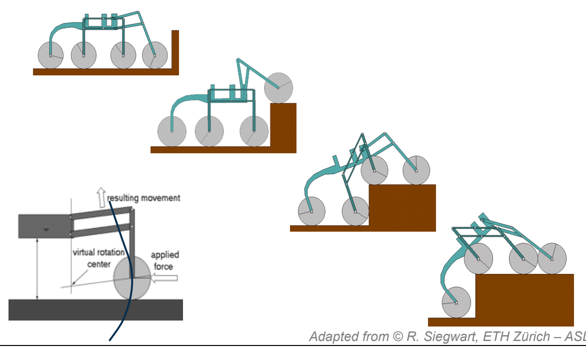

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Active

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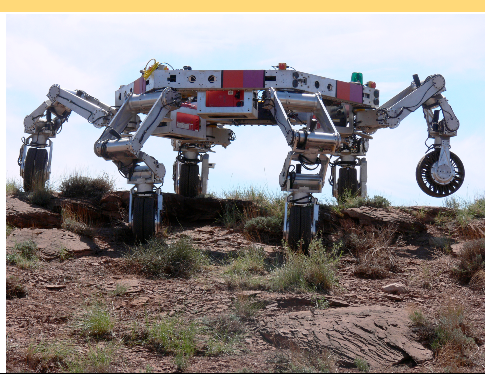

Use Case

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- What could walking wheels be really good for?

www.youtube.com/watch?v=O7otewMk9pc

Flying

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- Advantages
  - Rough terrain
  - Ground-inaccessible areas
  - Z-axis maneuverability
  - Perspective for mapping & sensing
  - Flying is cool
- Disadvantages
  - Control problems
  - Z-axis controllability
  - Weight & scaling laws
  - Flying is dangerous

3D Position DoFs

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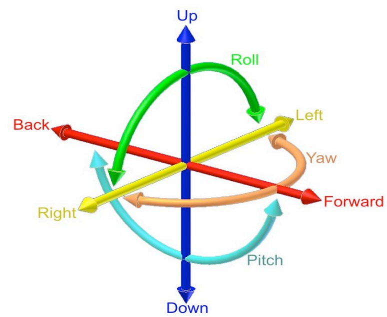
- Pitch
- Roll
- Yaw



https://en.wikipedia.org/wiki/Six_degrees_of_freedom

Pitch, Yaw, Roll

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https://www.youtube.com/watch?v=rlVw-SNU8cM

Types of Flyers

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- Fixed wing (sometimes with flaps)
- Flapping wing
- Rotors/props
  - Axial (single)
  - Coaxial (reversed)
  - Tandem (two non-coaxial)
  - Quadcopters (+)
- Lighter-than-air

https://robotics.eecs.berkeley.edu/~ronf/Ornithopter/index.html

Disadvantages

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- Fixed wing (sometimes with flaps)
  - Aerodynamics change drastically when miniaturized
  - Forward-only flight
- Flapping wing
  - Complex movements not perfectly understood
  - Scaling laws, wingspan, flapping speed
  - Hovering possible (but not guaranteed)
- Lighter-than-air
  - Slow, subject to wind and air conditions, temperature sensitive
- Rotors/props
  - Dangerous and/or fragile if contacted

Quadcopters

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- Most popular by far
- Advantages
  - Hovering
  - VTOL
  - Maneuverability
  - Simple construction
    - No tilt-rotors
- Disadvantages
  - Stabilization & control
    - But, largely automated now
  - Fragility (rotors)

Scaling

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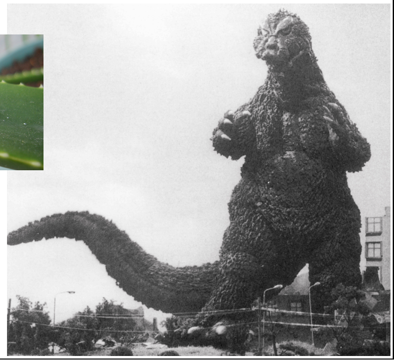

The Square-Cube Law

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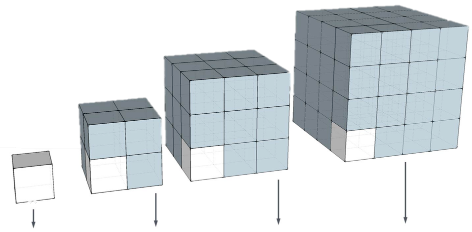
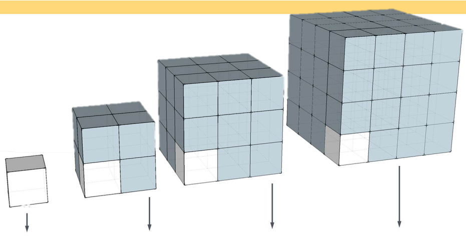
- Volume increases as a cube function, but support area increases as a square function
- How much weight is each cube supporting?



The Square-Cube Law

27



Volume:

Area/face:

Force/cube:

Scaling

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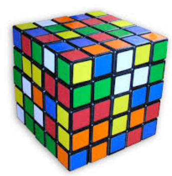
- The upshot: if you just make something bigger, the material must be stronger to do the same task!
- Implications
  - For miniaturization
  - For power
  - For heat dissipation
  - For structural strength



	Small	Large
Area	54	150
Volume	27	125

☹

WWGD?

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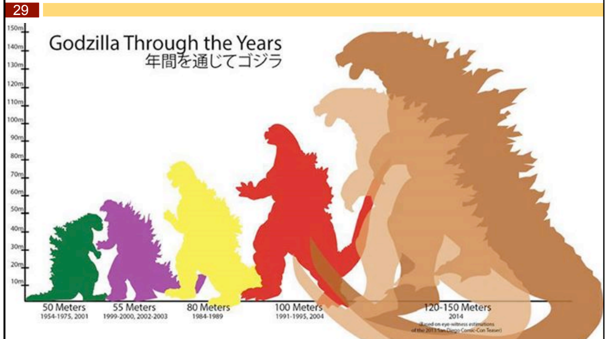

https://imgur.com/gallery/UKjhm

Wings and Scaling

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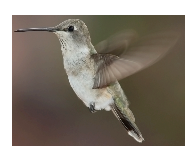
- What we care about: lift
  - Upward-acting force on an aircraft wing or airfoil
  - Directly opposes gravity's pull on mass (holds robot up)
    - As well as various friction forces
- Interrelating factors producing lift
  - Wing area: directly related
  - Flap speed: indirectly correlated
- Scaling
  - Wingspan/speed scale logarithmically with mass



Other Choices

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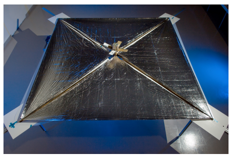

Mobile Efficiency

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- Cost of transportation – how much energy to move the robot itself?
- Depends heavily on terrain and task
  - On flat terrain: tires
  - On uneven or soft terrain: legs
  - Hovering in still air: blimps
  - For fast flight: wings
  - For material efficiency: fixed wings
  - In water: swimming or propulsion
  - Other (lots)

Transportation Costs

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- Leg lift and carry
- Deceleration
- Contact friction
- Internal friction
- Damping
- …

Odometry (Dead Reckoning)

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Sneak peek!

- The robot can move
  - I can move, I can move!
- So… now where am I? ← localization problem
  - Use proprioceptive sensors to *estimate* location
- Dead reckoning
  - Given motion sensors or known commands, estimate change in position over time
- Fundamentally open loop
  - Sensitive to errors