Some physics issues in robotics

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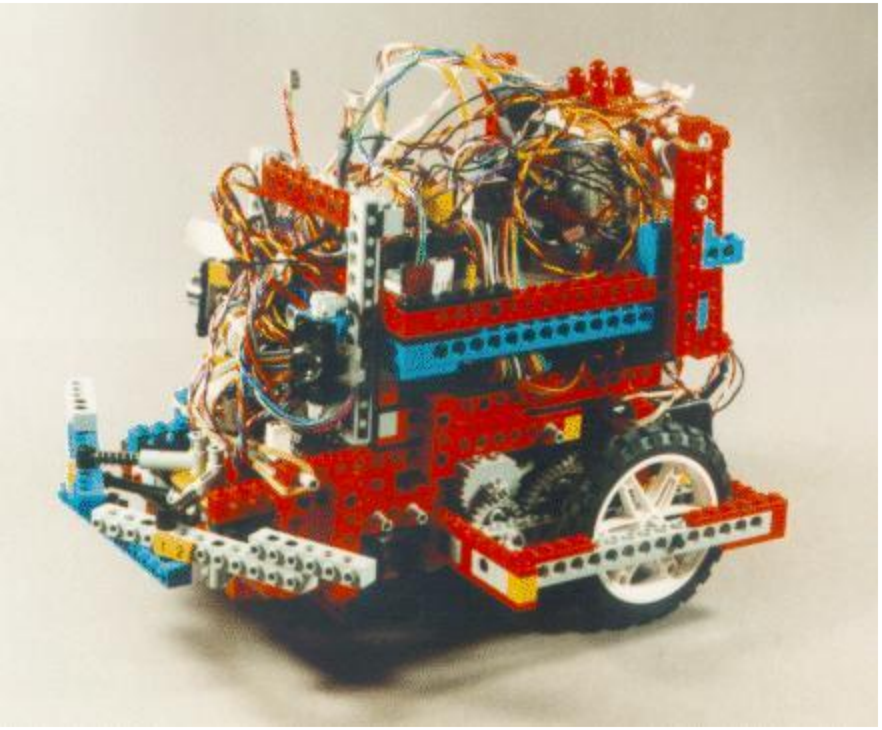
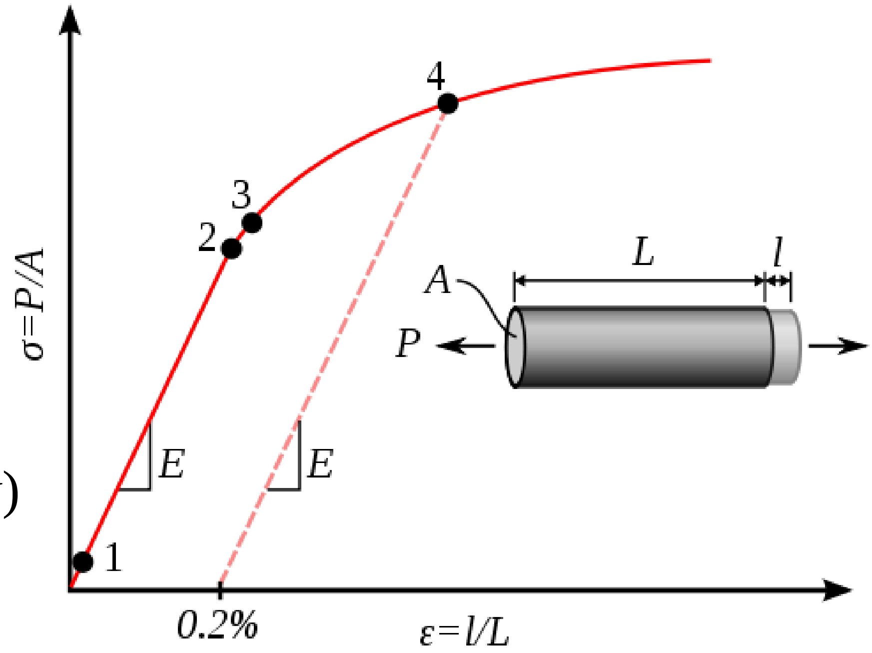


Some physics issues in robotics: (1) Strength

- A robot that falls apart due to forces experienced in normal operation is no use (and certainly not autonomous!)
- The strength of a structure is the stress required to break it: depends on load distribution and the material of the parts*

- Strength of material is the stress required to break it
- Stress σ is force per unit area
- Strain ε is % deformation under stress

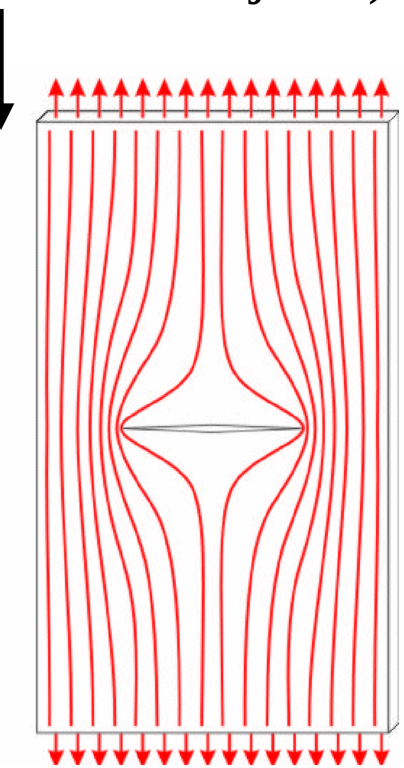
- Stress/strain (E) defines elasticity:
  - Note a material or structure can be stiff and strong (steel), stiff and weak (biscuit), flexible and strong (rubber) or flexible and weak (jelly)
- Area under curve is 'strain energy': resilience (toughness) is amount of strain energy a material can absorb without permanent damage



*James E. Gordon, "Structures, or Why things don't fall down", Pitman, London, 1979

Some physics issues in robotics: (1) Strength

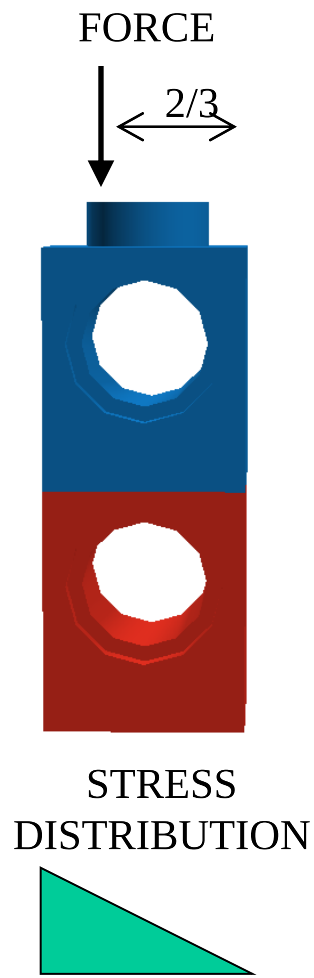
- Strength of a structure is depends on whether *any* point (or joint) is under sufficient stress to break



- The distribution of stress depends on the geometry of the structure and distribution of load
  - E.g. stress at the tip of a crack of length *L* and tip radius *r*

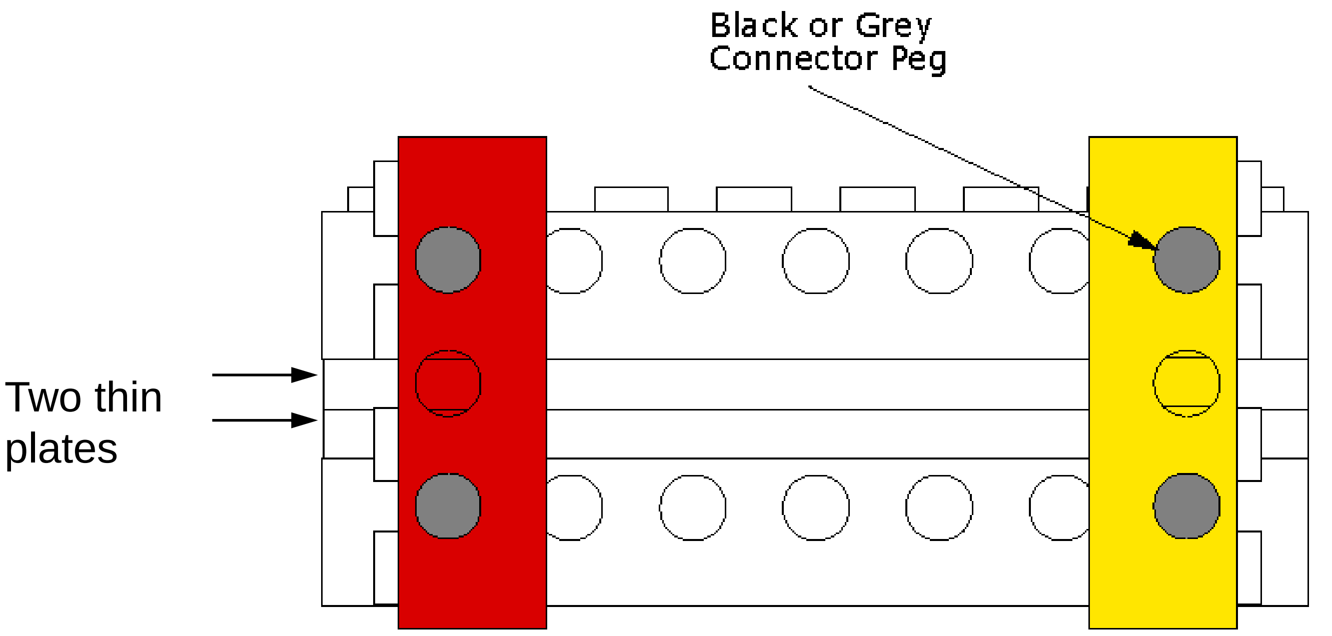
$$s(1+2\sqrt{\frac{L}{r}})$$

- Also the direction of forces may lead to a lack of stability
  - E.g. if outside ‘middle third’



Some physics issues in robotics: (1) Strength

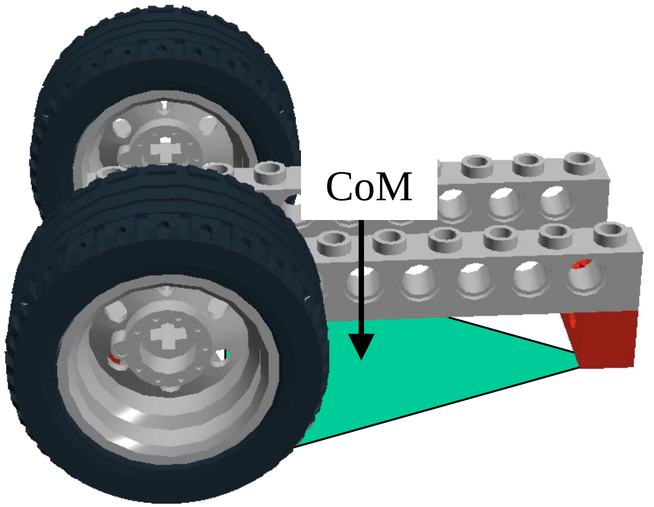
- Try to have smooth force lines, e.g. straight compression or tension, and appropriate balance
- Use short path/small number of components to transmit forces
- Top tip for Lego: use bracing



Some physics issues in robotics: (2) Stability

- Usually want structure as a whole to be statically stable, i.e. no net torque due to gravity

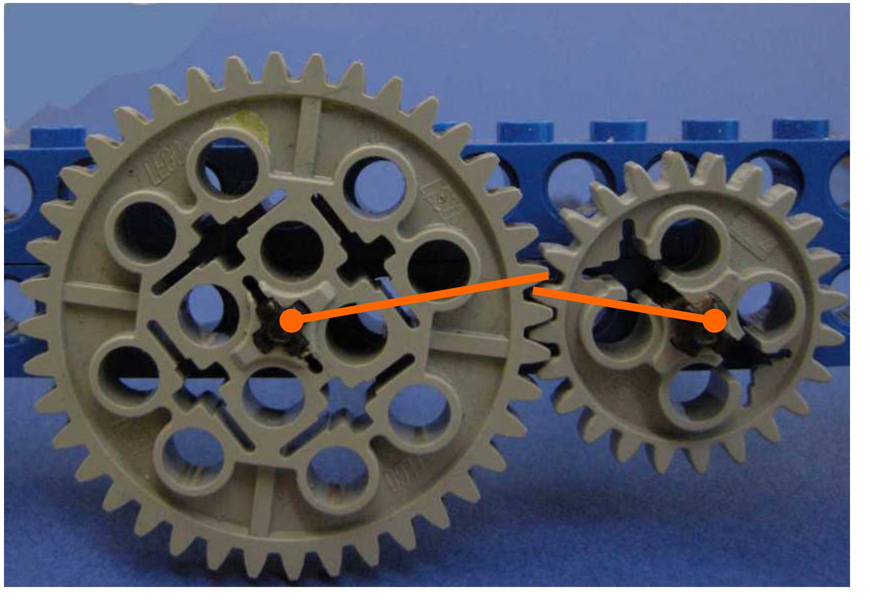
- Depends on centre of mass: force of gravity through centre of mass to ground must fall within base of support.
  - Minimum three points for base of support
  - Wider base of support and lower centre of mass will reduce potential tipping due to inertia
- Rotating around the centre of mass requires the least work



Some physics issues in robotics: (3) Power

- Have fixed amount of power, i.e. rate of work or force x distance/second
- Hence fundamental tradeoff between speed and force (torque) of your robot

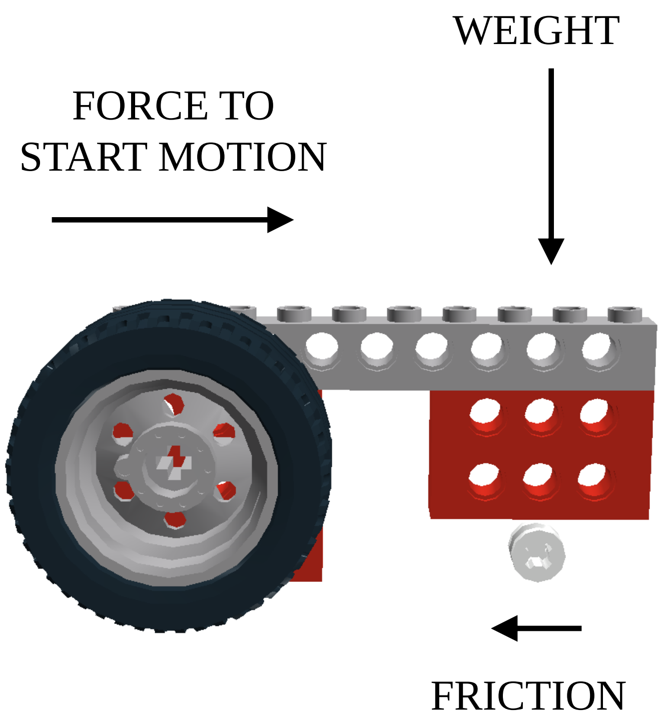
- Primarily determined by the gear ratio r_p/r_f where r_p is radius of the powered gear, and r_f the radius of the follower gear
- Gears act like levers:
  - distance/speed changes by r_p/r_f
  - Force/torque changes by r_f/r_p
- Same ratio can be calculated by counting teeth on each gear



Some physics issues in robotics: (4) Friction

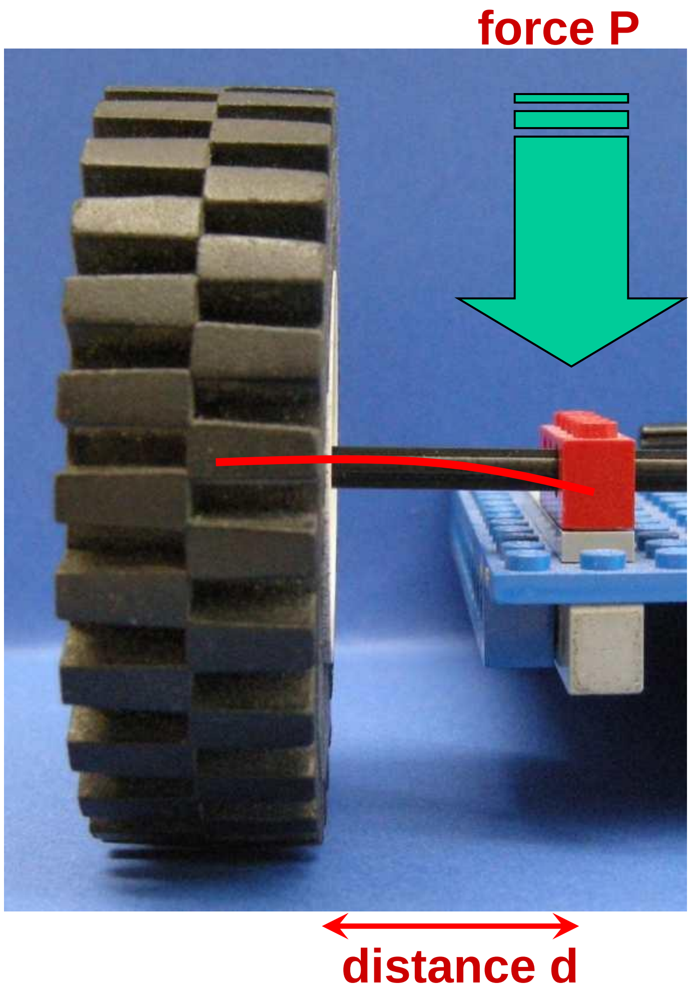
- Robot efficiency will depend on how much energy is dissipated through inefficient mechanisms and friction

- E.g. using differential drive and third sliding contact point
  - Force to reach threshold of motion = μN where μ is co-efficient of friction, N normal force
  - Force transferred to ground via wheel is also proportional to $\mu_{wheel}N$
  - N = mass x gravity → so should reduce mass resting on the sliding contact and increase mass resting on drive wheels
  - μ depends on surfaces → should make sliding contact smooth, tire rough
  - N.B. does not depend on area of contact



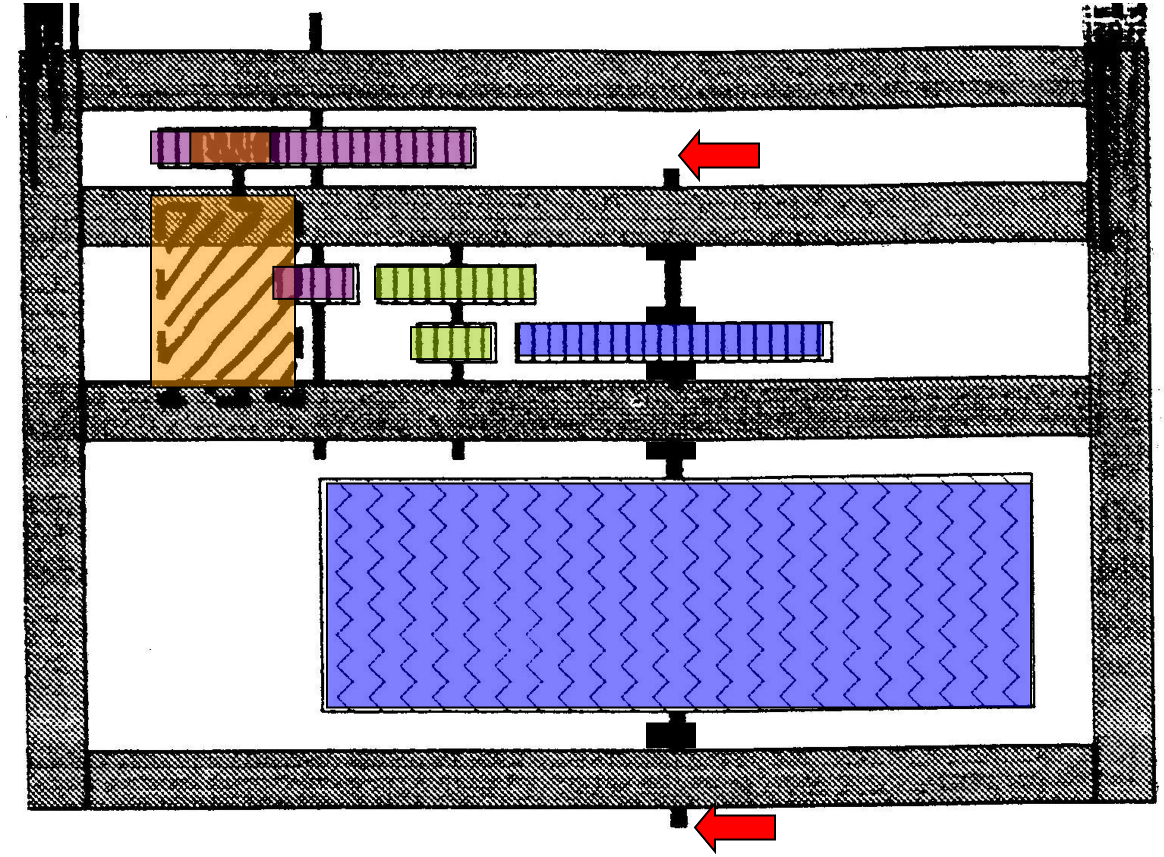
Some physics issues in robotics: (4) Friction

- Want gear train to interlock precisely → needs to be in stiff structure (i.e. doesn't deform under load)
- Want to minimise friction of rotation
  - Avoid any direct contact of gear or wheel to frame
  - Minimise the bend in the axle beams
    - Bend is proportional to dP/I, where I is beam inertia, depending on shape and material of beam
    - Reduce mass
    - Reduce distance
    - Add supports (opposing forces)



Gearing example

- Both ends of axle supported
- Gear/wheel not touching surface, well aligned



Motor ⟶ 8:40 ⟶ 8:24 ⟶ 8:40 ⟶ Wheel

1:5 x 1:3 x 1:5 =1:75

Lower ratio (e.g. 1:25) increases velocity but decreases acceleration.