Last chapter

Four fundamental forces
- Gravity
- electromagnetic
- weak
- strong

Every interaction (every force) we observe is do to one of (or a combo) of these four

- Two carts collide & bounce off
- Walking on the ground & not falling thru
- Air resistance & friction

But how does this really work?

Ex: two carts colliding
- Cant be gravity
  not strong, weak
- But neither cart is charged?
  How is this an E&M interaction?
- Pull on a wire?
- Float?

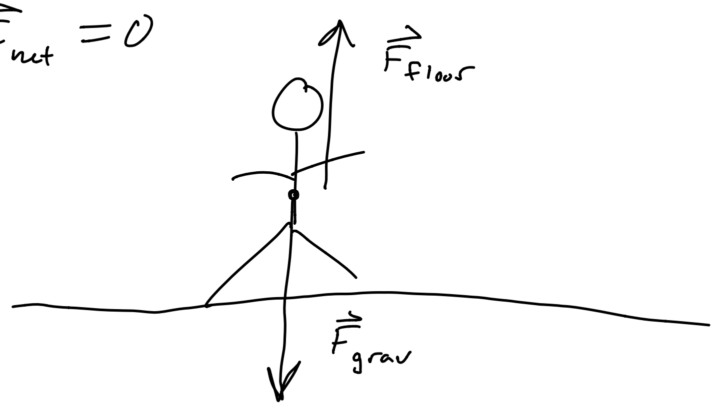
A silly example:

Dwayne "The Rock" Johnson visits class to give a guest lecture

- You notice, as he stands on the floor, he does not fall through

His momentum doesn't change at all

$\vec{F}_{net} = 0$



$$\vec{F}_{floor} + \vec{F}_{grav} = 0$$

$$\vec{F}_{floor} + \langle 0, -mg, 0 \rangle = 0$$

$m = 120$ kg

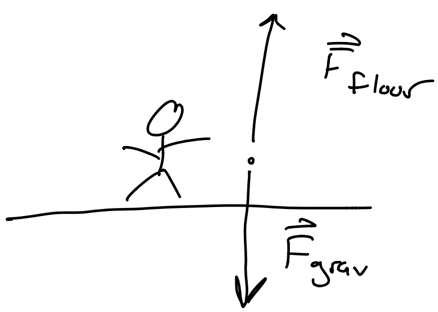
$g = 9.8$ m/s^2

$$\vec{F}_{floor} = \langle 0, 1176, 0 \rangle \text{ N}$$

After the lecture, a little kid happens to walk over that same spot

Predict:

$$\Delta \vec{p}_{kid} = \vec{F}_{net}\,\Delta t$$



$$\vec{F}_{floor} + \vec{F}_{grav} = 0$$

$$\langle 0, 1176, 0\rangle + \langle 0, -mg, 0\rangle = \vec{F}_{net}$$

$$m = 15\text{ kg}$$

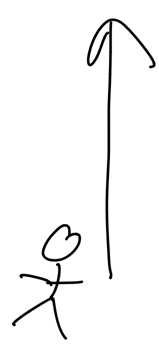
$$\vec{F}_{net} = \langle 0, 1029, 0\rangle\text{ N}$$

after 2 s

$$\Delta \vec{p} = \langle 0, 1029, 0\rangle (2)\ \text{N}\cdot\text{s}$$

$$\Delta \vec{p} = \langle 0, 2058, 0\rangle \frac{\text{kg m}}{\text{s}}$$

$$\Delta \vec{v} = \frac{\Delta \vec{p}}{m} = \langle 0, 137, 0\rangle\ \text{m/s}$$



This obviously does not happen.

The "normal force" of the floor depends on the weight of the person.

How does the floor "know"?

To answer these questions, we need to take a closer look. Shrink down + explore what happens microscopically when two objects come into contact.

Where to start?
- Contact interactions between matter

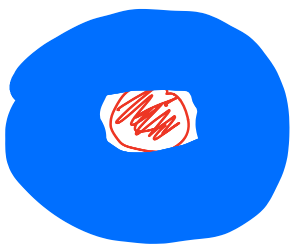
what is matter made of?

ATOMS

- Some useful properties of atoms
  - Very small ($\sim 10^{-10}$ m)
    - exact size depends on the atom
  - Are <u>always</u> moving
    - The air molecules in this room are moving at ~ 500 m/s
    - atoms in solids vibrate many times/second

- Atoms interact electrically

Simple model for an atom: a massive, positive nucleus surrounded by a light, fast moving "cloud" of electrons



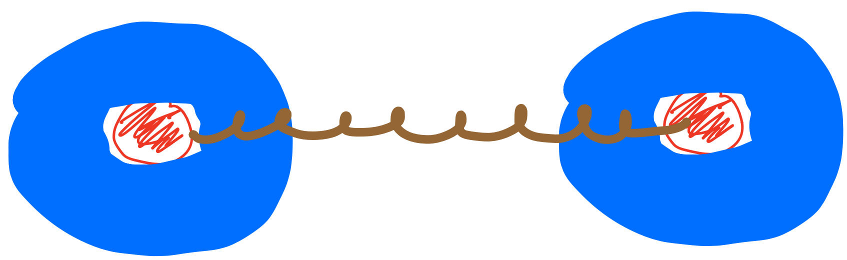
In solids atoms bond together by sharing electrons

- Electrons repel other electrons
- Protons repel other protons
- Electrons & protons attract

- Net effect
  - Bonded atoms attract if they far apart
  - Repel when they are close together

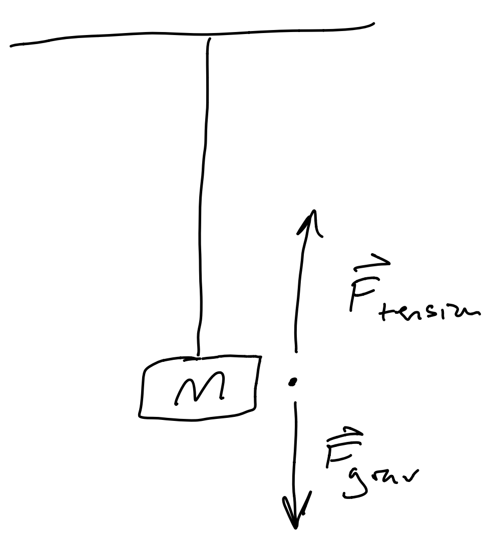
– Force of attraction/repulsion $\propto |s|$

– Upshot: Atomic bonds behave like a spring!



Ex: mass hanging from a string

what happened?

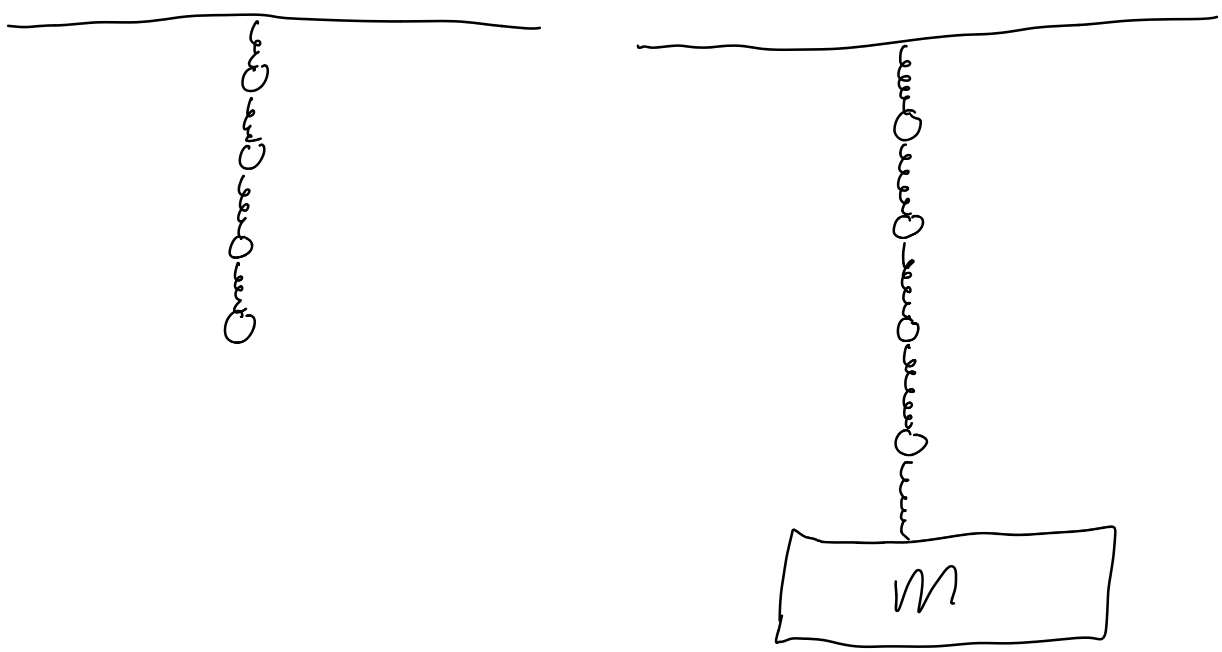


$\Delta\vec{p} = 0 \implies \vec{F}_{net} = 0$

$$\vec{F}_{net} = \vec{F}_{grav} + \vec{F}_{tension}$$

$$\vec{F}_{tension} = -\vec{F}_{grav} = \langle 0, mg, 0 \rangle$$

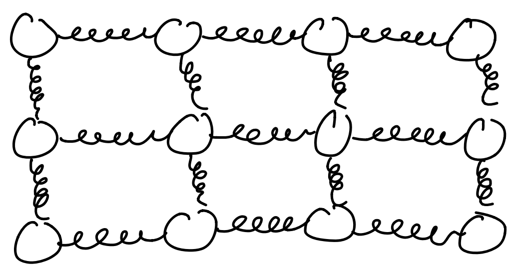
Think of the string like a bunch of atoms



Result: the string stretches
(only slightly)

Even a thin string is ~millions of atoms across

- Real solids arrange into a crystal "latice" structure

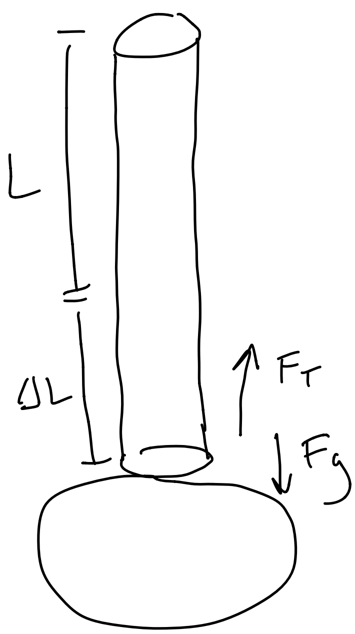


Each bond has a characteristic length and spring stiffness

System of springs like this is complicated on large scales, use a quantity called "Young's modulus" to describe the behavior of the system we have a string or wire

A: cross sectional area

L: Length of wire w/ no force



F_T: "Tensile force"

ΔL: Length of stretch (like s of the spring)

$$\boxed{\frac{F_T}{A} = Y \frac{\Delta L}{L}}$$

Y: Young's modulus units: $\frac{N}{m^2}$

Property of material

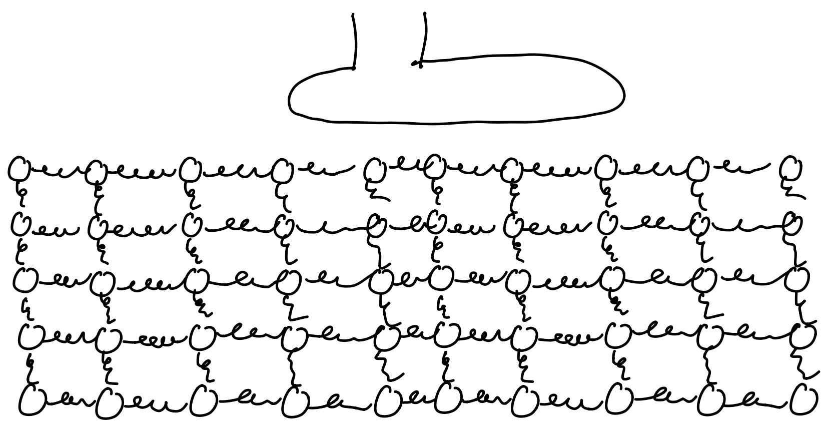
Ignore 4.4 - 4.6

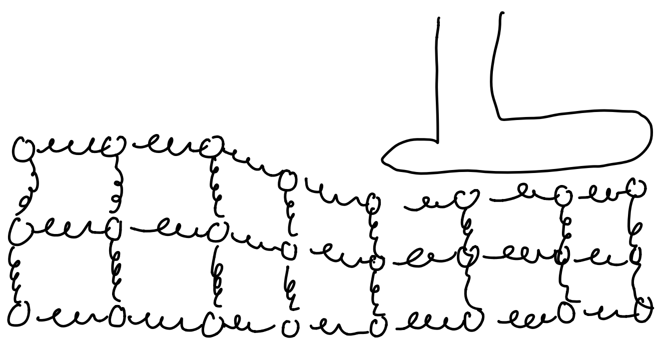
won't be held responsible

Back to our initial question

When I stand on the floor, how does it "know" what force to use?

Floor is a solid:





We call this "normal force" simply because it is perpendicular

Two carts collide