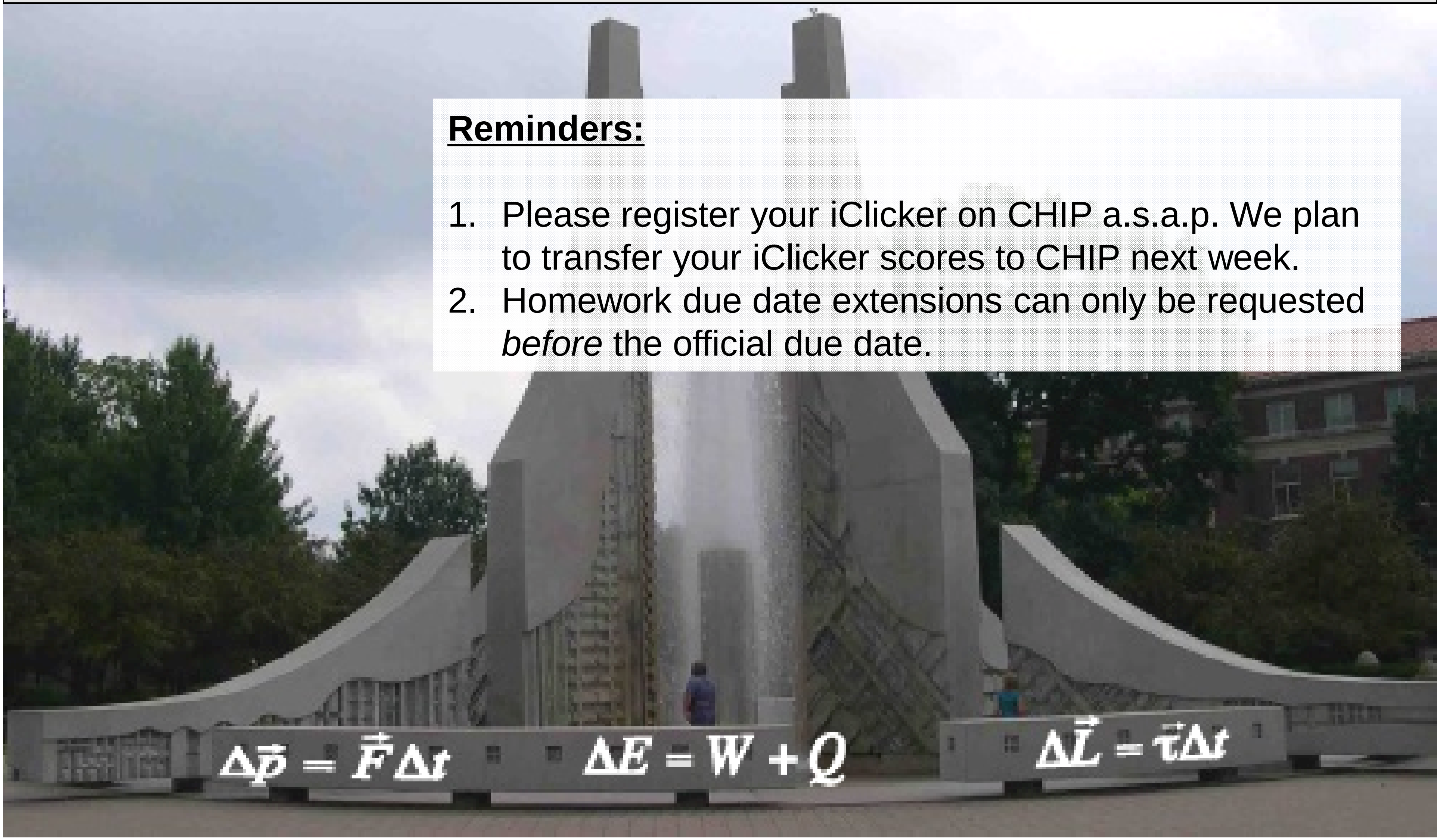
PHYS 172: Modern Mechanics — Spring 2012



Reminders:

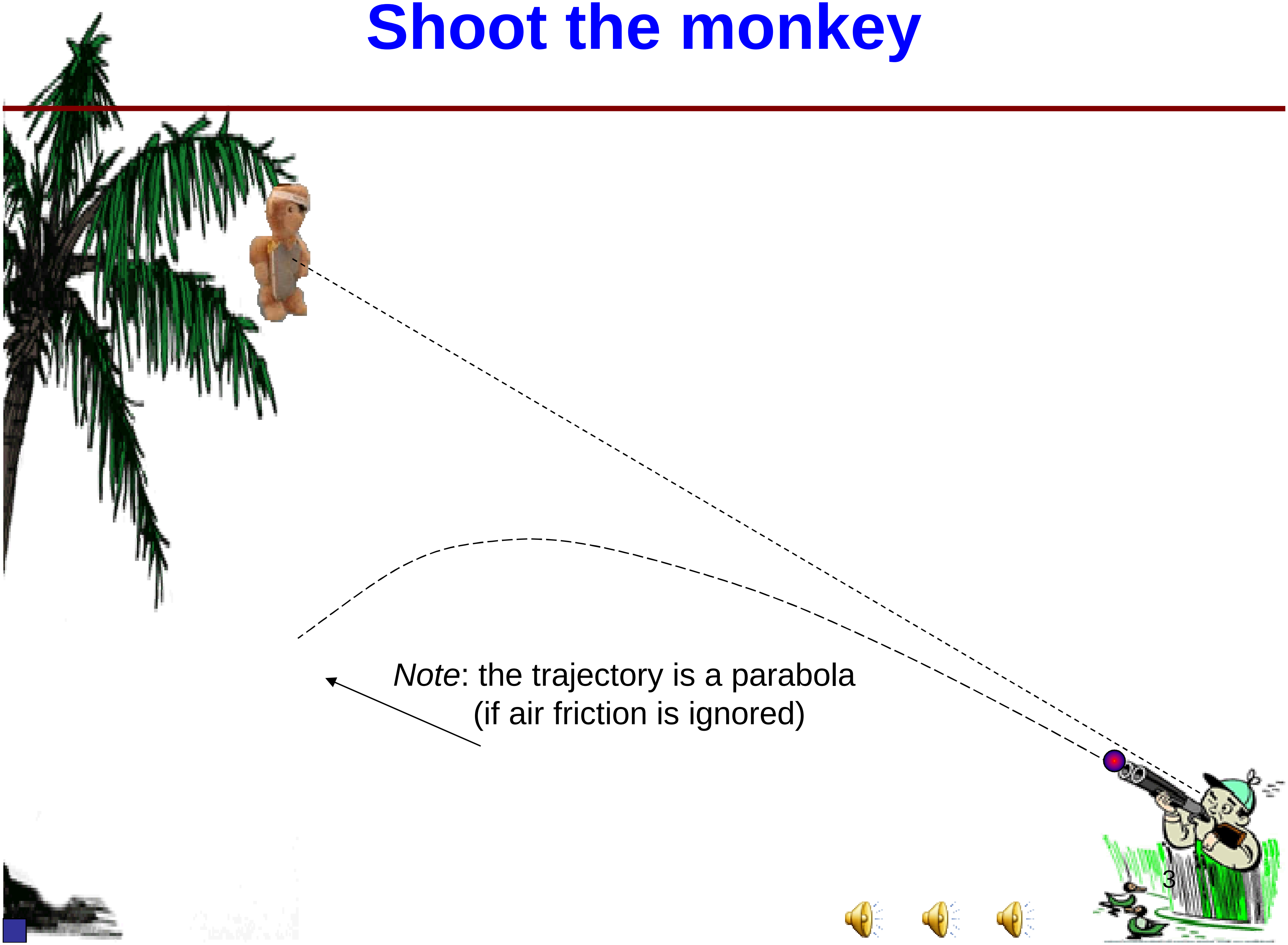
1. Please register your iClicker on CHIP a.s.a.p. We plan to transfer your iClicker scores to CHIP next week.
2. Homework due date extensions can only be requested *before* the official due date.

Lecture 4 – **Physical Models, Fundamental Interactions** Read 2.7–2.8, 3.1-3.4

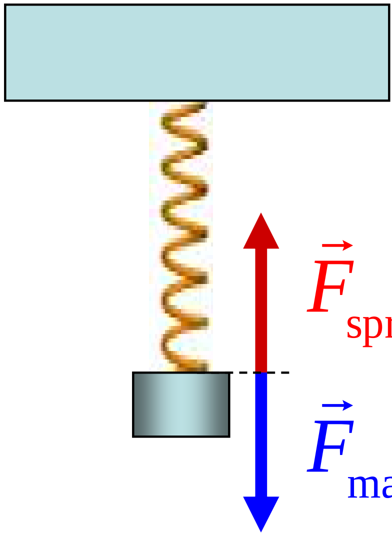
Today

- Poor Monkey
- Reciprocity (Equal and Opposite Forces)
- Example: Colliding Students
- Four Fundamental Forces
- Gravity… Lots of Gravity

Shoot the monkey



Reciprocity: Newton's 3d law



$$\vec{F}_{\text{spring on mass}}$$

$$\vec{F}_{\text{mass on spring}}$$

Force magnitudes are the same
Directions are opposite
They act on *different* objects

$$\vec{F}_{\text{spring on mass}} = -\vec{F}_{\text{mass on spring}}$$

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

Reciprocity (Newton's 3rd law):

The forces of two objects on each other are always equal and are directed in opposite directions

NOTE: Velocity-dependent forces (e.g., magnetic forces) do not obey Newton's 3rd law!

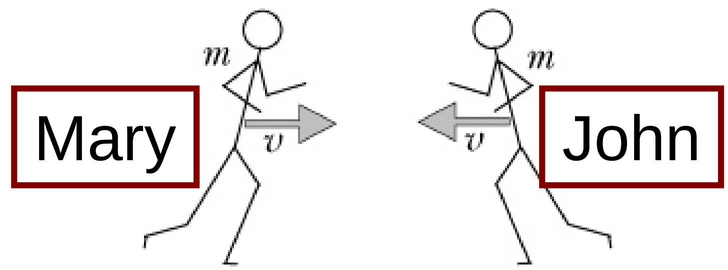
Physical models

“Spherical cow”

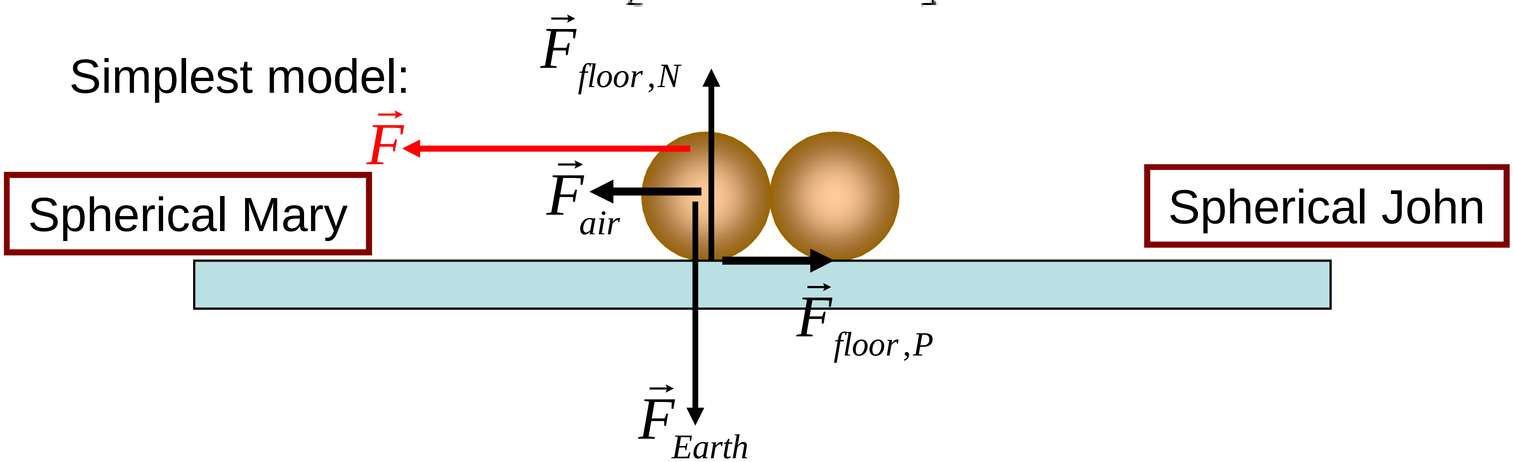
Ideal model: ignore factors that have no significant effect on the outcome

Example: colliding students

Mary and John are late for class and run into each other head-on.
Q: Estimate the force that one student exerts on the other during collision



Simplest model:

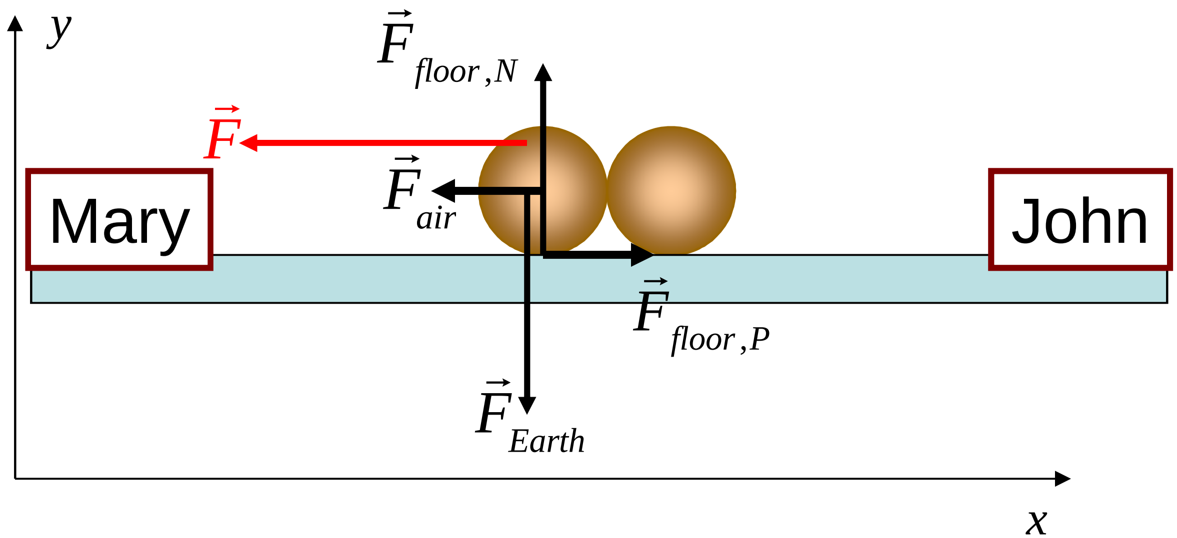


System: Spherical Mary

Surroundings: Earth, floor, air, Spherical John

Forces acting on Mary: Earth, floor, air, John

Example: colliding students



Strategy:

$$\vec{p}_f - \vec{p}_i = \vec{F}_{net}\Delta t$$

$$\vec{p} = \gamma m\vec{v}$$

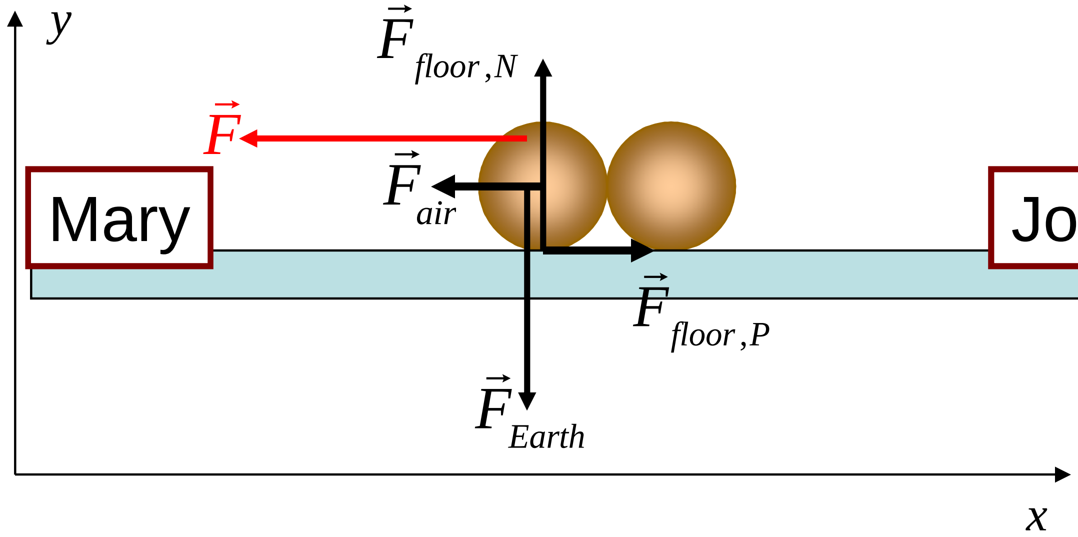
$$\vec{r}_f = \vec{r}_i + \vec{v}_{avg}\Delta t$$

$$\vec{p}_f - \vec{p}_i = \vec{F}_{net}\Delta t$$

$$<0,0> - <p_{ix},0> = <\underbrace{F_{floor,P} - F_{air}}_{\text{Small}} - F, \underbrace{F_{floor,N} - F_{Earth}}_{\text{These cancel}}> \Delta t$$

$$<-p_{ix},0> = <-F,0> \Delta t \quad \rightarrow\rightarrow \quad \boxed{p_{ix} = F\Delta t}$$

Example: colliding students



Strategy:

$$\vec{p}_f - \vec{p}_i = \vec{F}_{net}\Delta t$$

$$\vec{p} = \gamma m\vec{v}$$

$$\vec{r}_f = \vec{r}_i + \vec{v}_{avg}\Delta t$$

$$p_{ix} = F\Delta t$$

What is collision time? → *Assume: v_i =5 m/s, Δx=0.05m*

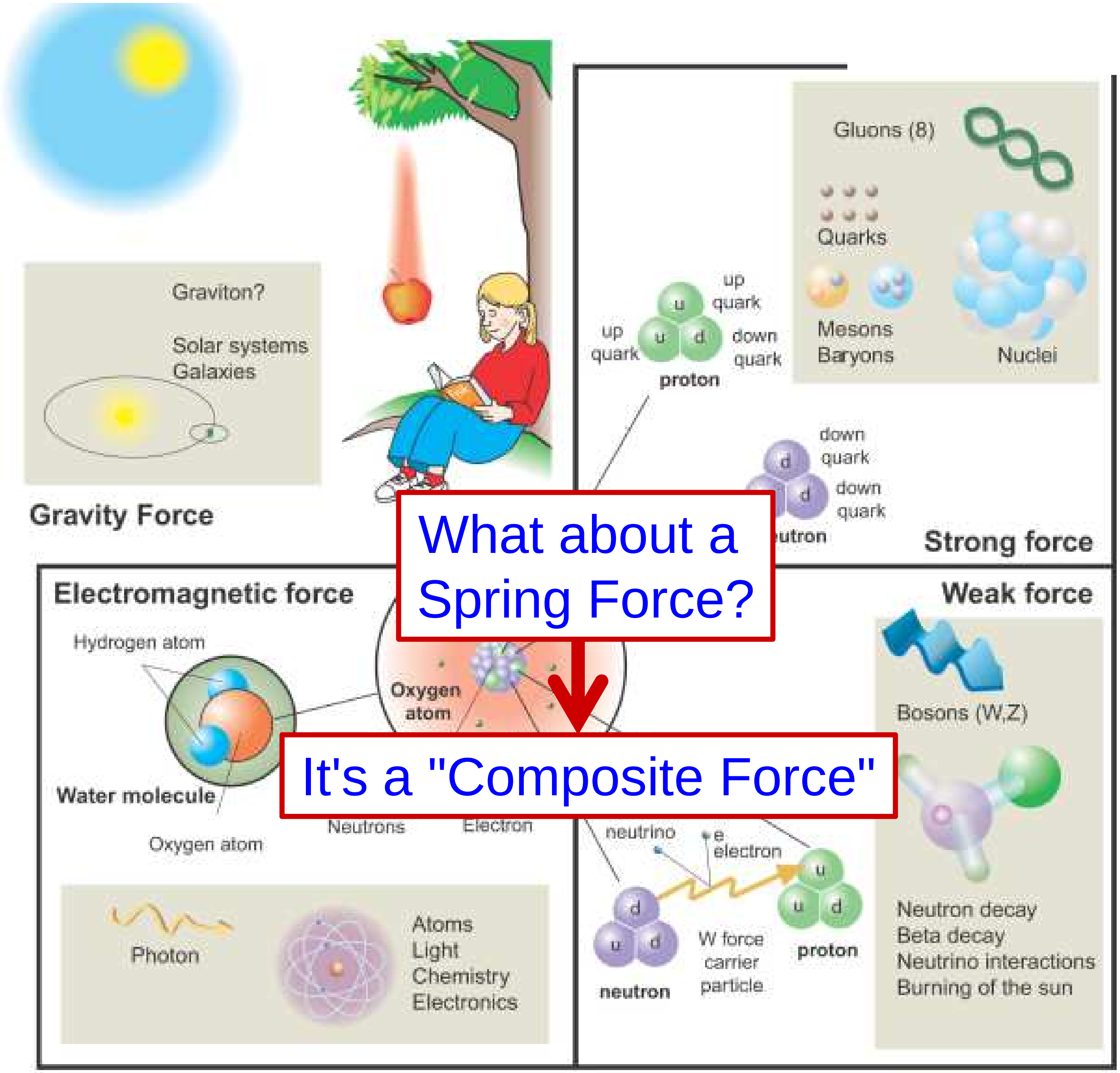
$$v_{avg} = \frac{\Delta x}{\Delta t} \rightarrow \Delta t = \frac{\Delta x}{v_{avg}} \rightarrow \Delta t = \frac{\Delta x}{\left(v_i + v_f\right)/2} \qquad \boxed{\Delta t = 0.02\ \text{s}}$$

What is initial momentum? → *Assume: m=60 kg* → $p_{ix} = mv_{ix} = 300\ \text{kg}\cdot\text{m/s}$

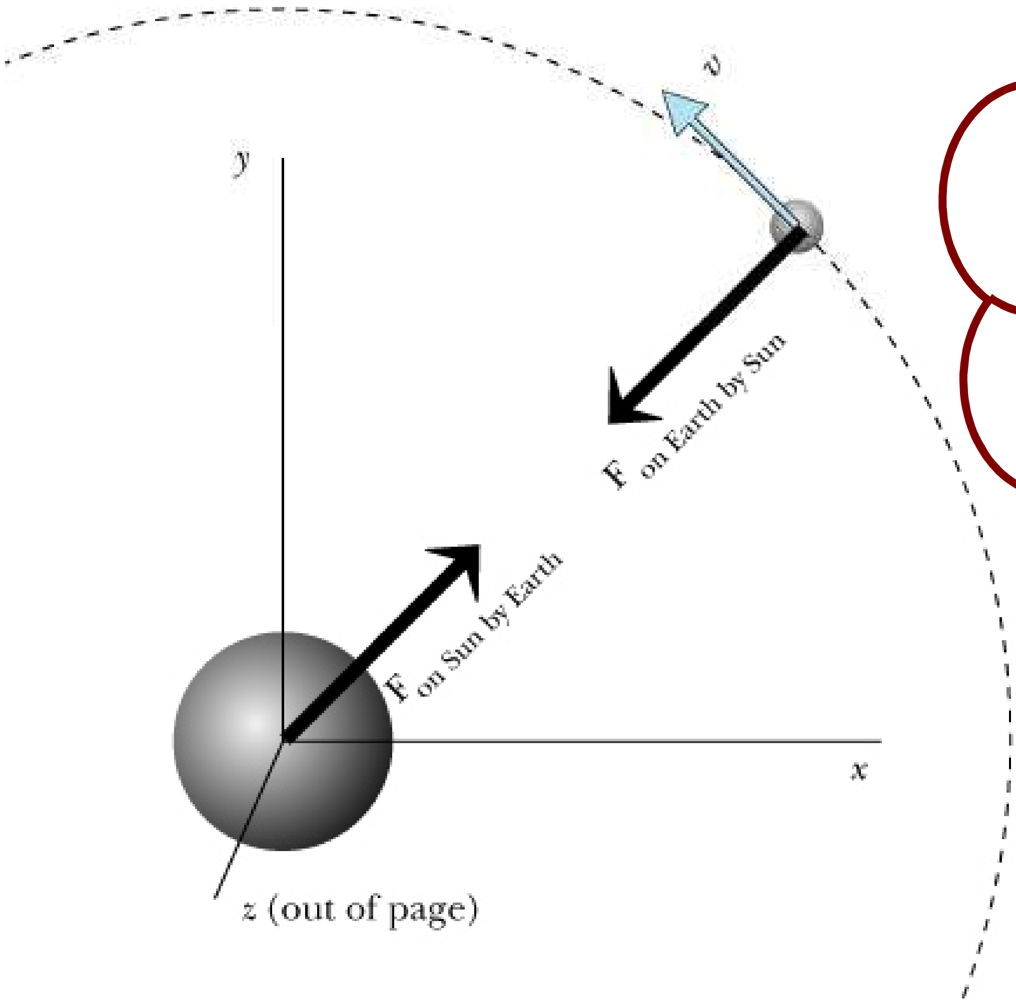
Find F: $$F = \frac{p_{ix}}{\Delta t} = \frac{300\ \text{kg}\cdot\text{m/s}}{0.02\ \text{s}} = 15000\ \text{N}$$

John hits Mary with 15,000 N!

The Four Fundamental Forces



Newton's Great Insight:



The same force

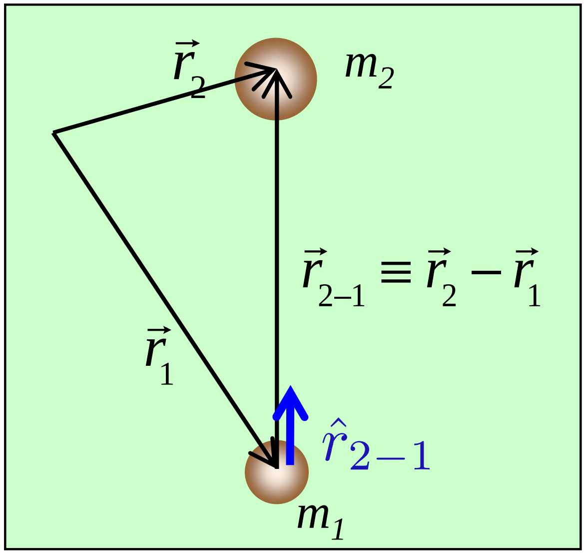
that attracts things

toward the earth

also keeps planets

orbiting about the sun

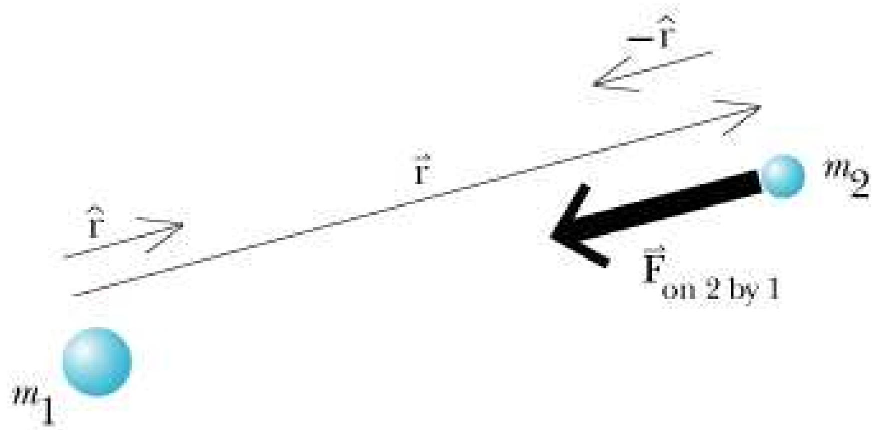
Force of Gravity



$$\vec{F}_{\text{on 2 by 1}} = -G\frac{m_1 m_2}{\left|\vec{r}_{2-1}\right|^2}\hat{r}_{2-1}$$

$$G = 6.7 \times 10^{-11}\frac{N \cdot m^2}{kg^2}$$

Force of Gravity



Depends on

Product of Masses

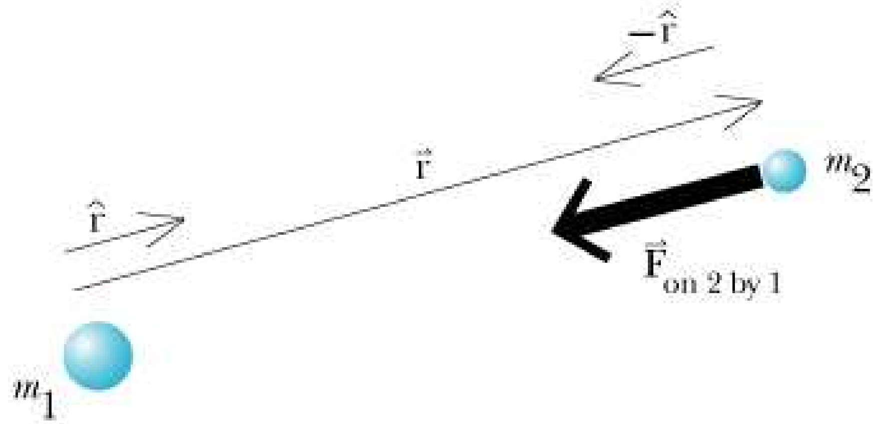
$$\vec{F}_{\text{on 2 by 1}} = -G\frac{m_1 m_2}{|\vec{r}_{2-1}|^2}\hat{r}_{2-1}$$

Attractive

Inverse-Square Law

Features of gravitational force

$$\vec{F}_{grav\text{ on }2\,\text{by}1} = -G\frac{m_2 m_1}{\left|\vec{r}_{2-1}\right|^2}\hat{r}_{2-1}$$



gravity is always <u>attractive</u>

$$\vec{F}_{grav\text{ on }2\,\text{by}1} = -G\frac{m_2 m_1}{\left|\vec{r}_{2-1}\right|^2}\hat{r}_{2-1}$$

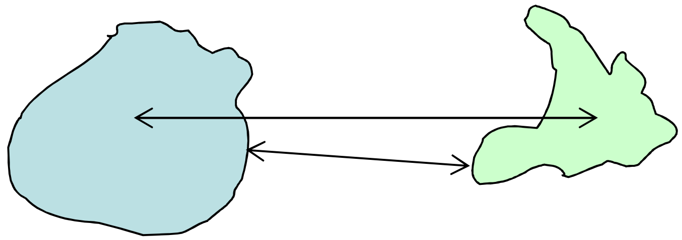
gravity is an <u>inverse square law</u>

$$\vec{F}_{grav\text{ on }2\,\text{by}1} = -G\frac{m_2 m_1}{\left|\vec{r}_{2-1}\right|^2}\hat{r}_{2-1}$$

the force depends upon
the <u>product</u> of the masses

Distance between two objects

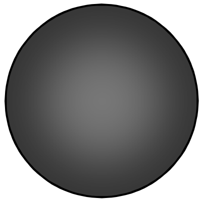
Real objects have size & shape



Point object: idealized object which has no size, all mass is in one point

If distance between the two objects is >> than their size, can model the objects as point-masses

Special case: spherical objects (spherical symmetry)



Uniform-density spheres interact gravitationally in exactly the same way as if all their mass were concentrated at the center of the sphere.

Spheres act like a point mass!

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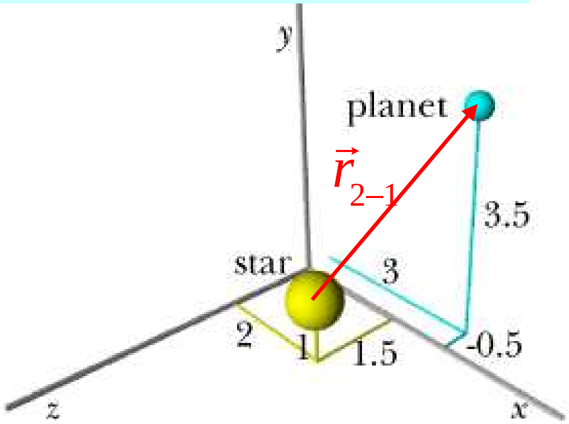
Gravitational force on a planet

$$\vec{F}_{grav\ \text{on}\,2\,\text{by}\,1} = -G\frac{m_2 m_1}{\left|\vec{r}_{2-1}\right|^2}\hat{r}_{2-1}$$



G = 6.7 x 10^{-11} N•m/kg^2

STAR	PLANET
$m_1 = 4\times10^{30}\ \text{kg}$	$m_2 = 3\times10^{24}\ \text{kg}$
$\vec{r}_1 = \langle 2,1,1.5\rangle\times10^{11}\ \text{m}$	$\vec{r}_2 = \langle 3,3.5,-0.5\rangle\times10^{11}\ \text{m}$

1. Calculate $\vec{r}_{2-1} \equiv \vec{r}_2 - \vec{r}_1$

$$\vec{r}_{2-1} = \langle 1,2.5,-2\rangle\times10^{11}\ \text{m}$$

2. Distance $\left|\vec{r}_{2-1}\right| = \sqrt{\left(1\times10^{11}\ \text{m}\right)^2 + \left(2.5\times10^{11}\ \text{m}\right)^2 + \left(-2\times10^{11}\ \text{m}\right)^2} = 3.35\times10^{11}\ \text{m}$

3. Unit vector: $\hat{r}_{2-1} = \dfrac{\vec{r}_{2-1}}{\left|\vec{r}_{2-1}\right|} = \dfrac{\langle 1,2.5,-2\rangle\times10^{11}\ \text{m}}{3.35\times10^{11}\ \text{m}} = \langle 0.299,0.746,-0.597\rangle$

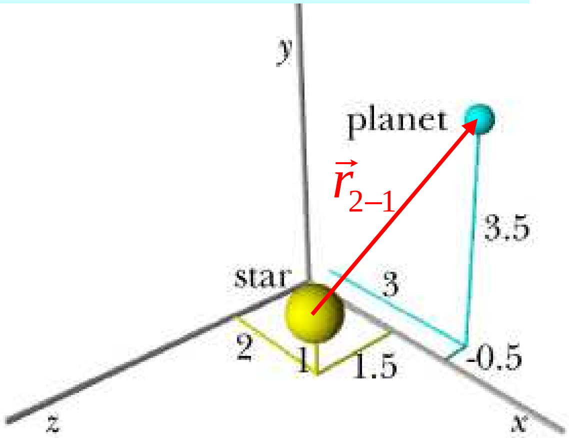
3. Force: $\vec{F}_{grav\ \text{on}\,2\,\text{by}\,1} = -G\dfrac{m_2 m_1}{\left|\vec{r}_{2-1}\right|^2}\hat{r}_{2-1} = -7.16\times10^{21}\langle 0.299,0.746,\text{-}0.597\rangle\ \text{N}$

$$\vec{F}_{grav\ \text{on planet by star}} = 7.16\times10^{21}\langle \text{-}0.299,\text{-}0.746,0.597\rangle\ \text{N}$$

magnitude *direction*

Gravitational force on a planet

$$\vec{F}_{grav\ \text{on}\,2\,\text{by}\,1} = -G\frac{m_2 m_1}{\left|\vec{r}_{2-1}\right|^2}\hat{r}_{2-1}$$



G = 6.7 x 10^{-11} N•m/kg^2

star	planet
$m_1 = 4\times10^{30}\ \text{kg}$	$m_2 = 3\times10^{24}\ \text{kg}$
$\vec{r}_1 = \langle 2,1,1.5\rangle\times10^{11}\ \text{m}$	$\vec{r}_2 = \langle 3,3.5,-0.5\rangle\times10^{11}\ \text{m}$

$$\vec{F}_{grav\ \text{on planet by star}} = 7.16\times10^{21}\langle -0.299,-0.746,0.597\rangle\ \text{N}$$

Checking results:

1. Diagram
2. Order of magnitude
3. Units
4. Unit vector

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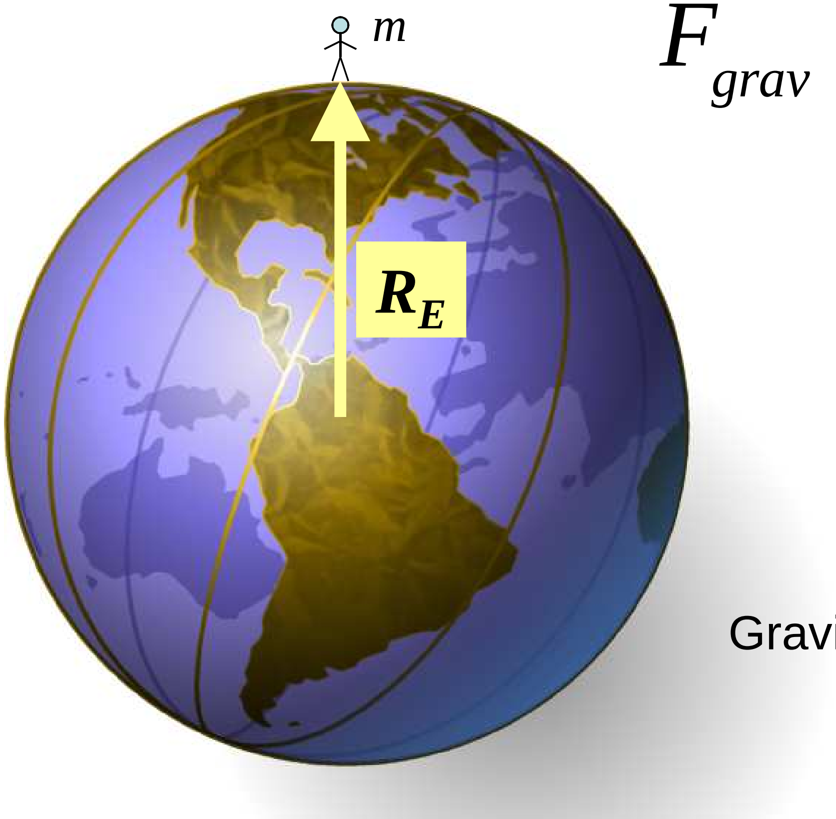
Gravitational force near the Earth's surface



$M_E = 5.976 \times 10^{24}$ kg
$R_E = 6.37 \times 10^{6}$ m

$$\vec{F}_{grav\ \text{on}\ m\ \text{by}\ M_E} = -G\frac{M_E m}{|R_E|^2}\hat{r}$$

~ The same for all objects on surface

$$\boxed{\vec{F}_{grav\ \text{on}\ m\ \text{by}\ M_E} = \vec{g}m}$$

Gravitational field

$$\boxed{\vec{g} = -G\frac{M_E}{|R_E|^2}\hat{r}}$$

The magnitude: $\boxed{g = 9.8 \text{ N/kg} = 9.8 \text{ m/s}^2}$

$$\boxed{F_g = mg}$$

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What We Did Today

- Poor Monkey
- Reciprocity (Equal and Opposite Forces)
- Example: Colliding Students
- Four Fundamental Forces
- Gravity… Lots of Gravity