Theme Music: Movin’ Out  
Billy Joel

Cartoon: Bill Amend  
FoxTrot

EQUICK  
SOMEAK  
SLOWNEAK

I sometimes wish Newton had stopped at two laws.
Next Week

- Quiz Monday on acceleration.
- Lab 3: The second week of the pendulum lab. You will analyze your data and defend your results to the rest of your class.
- Tutorial 3: Newton’s third law. You will try to make sense of N3 and see how it can be true – and test it experimentally as well!
- For HW this week you will need to use Logger Pro to analyze a video. Download it at [http://www.vernier.com/downloads/lp3demo.html](http://www.vernier.com/downloads/lp3demo.html)
Summary of Newton’s Laws

■ Newton 0:
  – Objects only feel forces when something touches them.
    An object responds to the forces it feels when it feels them.

■ Newton 1:
  – An object that feels a net force of 0 keeps moving with the same velocity (which may = 0).

■ Newton 2:
  – An object that is acted upon by other objects changes its velocity according to the rule
    \[ \vec{a} = \frac{\vec{F}_{\text{net}}}{m} \]
Free-Body Diagrams: Motivation

- We will be considering many cases that include many objects.
- In order not to get confused about which forces go where we introduce a free-body diagram.
- This allows us to keep careful track of both N0 and N2.
  - each object only feels forces acting on itself (N0)
  - each object satisfies its own N2 response equation, \( a = \frac{F_{\text{net}}}{m} \)
Free-Body Diagrams: Procedure

- For each object in the system being considered, we
  - draw a dot representing the object
  - find all the objects touching it
  - draw arrows starting at the dot in the direction of the forces, with lengths indicating the approximate relative size of the forces
  - label each force according to our convention
We're only considering horizontal motions and pForces!
One more icon:  
The Implications Game

- Once we have established foothold ideas, we work with them to see what they imply for a variety of situations.
- This “implications game” is the core of scientific reasoning.
See what it implies!
Working out the implications

- Consider the example above. If we assume no friction, how does the pair of blocks speed up?
- Consider them first as a single system. The problem is much simpler then.
- Afterwards, let’s consider it as two separate blocks. What does the result of treating it as a single system tell us?
Assuming no friction!

\[ \vec{a}_{A+B} = \frac{1}{m_{A+B}} \vec{N}_{\text{hand} \rightarrow A+B} \]
Now consider each box separately

\[ \vec{a}_A = \frac{1}{m_A} \left( \vec{N}_{\text{hand} \to A} + \vec{N}_{B \to A} \right) \]

\[ \vec{a}_B = \frac{1}{m_B} \vec{N}_{A \to B} \]
Compare the equations!

- All the accelerations must be the same.

\[(m_A + m_B)\ddot{a} = \vec{N}_{hand \rightarrow A}\]

\[m_A \ddot{a} = \vec{N}_{hand \rightarrow A} + \vec{N}_{B \rightarrow A}\]

\[m_B \ddot{a} = \vec{N}_{A \rightarrow B}\]

\[(m_A + m_B)\ddot{a} = \vec{N}_{hand \rightarrow A} + \vec{N}_{B \rightarrow A} + \vec{N}_{A \rightarrow B}\]

Why is this \(N\) “on A” and not “on A+B”?
A serious implication

- In order for our treatment of the two objects as a system and as separate parts to be the same we must conclude:

\[ \vec{\mathcal{N}}_{B \rightarrow A} + \vec{\mathcal{N}}_{A \rightarrow B} = 0 \]

or

\[ \vec{\mathcal{N}}_{B \rightarrow A} = -\vec{\mathcal{N}}_{A \rightarrow B} \]
Newton’s 3\textsuperscript{rd} Law

- When two objects touch each other, each exerts a force on the other.
- pForces are interactions between objects.
- In order for our analysis to be consistent, when two objects interact, the pForces they exert on each must be equal and opposite.
- This must be tested experimentally.
- Strangely enough, it works!

\[ \vec{F}_{A \rightarrow B} = -\vec{F}_{B \rightarrow A} \]
Does N3 always hold?

- You will be checking N3 for some cases of normal forces in tutorial next week and it will always work.
- For tension and friction forces we could also do the experiment and see that it works.

It will work for every case until we get into systems where more than two-bodies interact at the same time- for example when radiation (e.g., light) is emitted.
Footholds 2.0
Revised summary of Newton’s Laws

- Newton 0:
  - Objects only feel forces when something touches them. An object responds to the forces it feels when it feels them.

- Newton 1:
  - An object that feels a net force of 0 keeps moving with the same velocity (which may = 0).

- Newton 2:
  - An object that is acted upon by other objects changes its velocity according to the rule

\[ \vec{a} = \frac{\vec{F}_{\text{net}}}{m} \]

- Newton 3:
  - When two objects interact the forces they exert on each other are equal and opposite.

\[ \vec{F}_{A \rightarrow B} = -\vec{F}_{B \rightarrow A} \]