Torque

- So far in our discussion of forces, we have shown that forces can cause linear motion of objects.

- We described the motion of these objects in terms of the motion of the center of mass of the object.

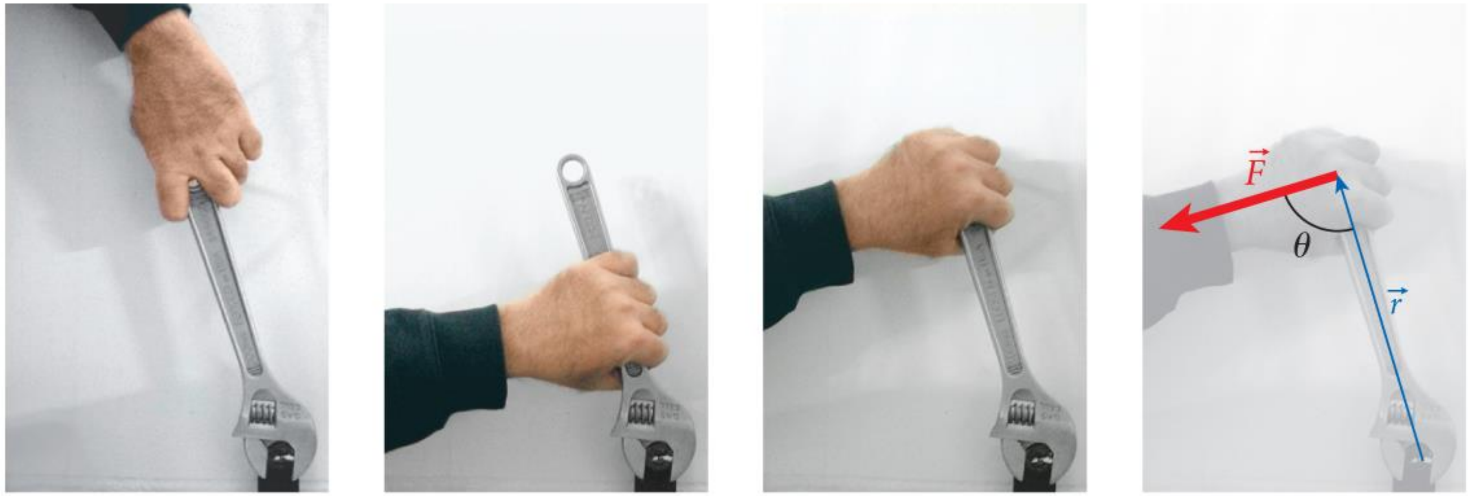
- However, we have not addressed one general question:
  - Where do we attach the force vectors acting on an extended object in a free-body diagram?

- You can exert a force on an extended object at a point away from its center of mass, which can cause the extended object to rotate as well as move linearly.

Torque

- Consider the hand pulling on the wrench to loosen the bolt shown below:

Impossible Not So Easy Easy



(a) (b) (c) (d)

- Force, direction, and moment arm are important.
- Define torque as the vector cross product of the force and the moment arm:

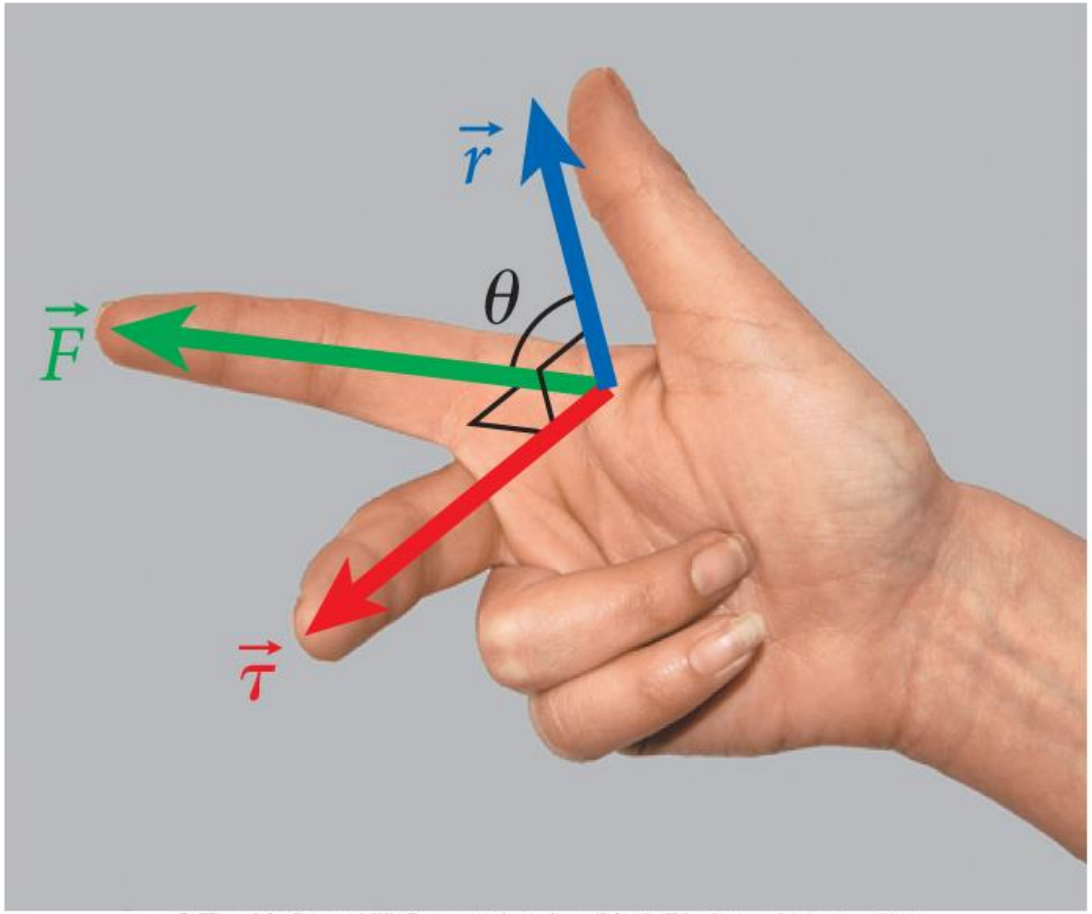
$$\vec{\tau} = \vec{r} \times \vec{F}$$

Torque

- The SI units of torque are N·m:
  - The English units are foot-pounds.
- The magnitude of the torque is:

$$\tau = rF\sin\theta$$

- Torque is an axial vector.
- The direction of the torque is given by the right hand rule.



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Torque

- Torques around any fixed axis of rotation can be clockwise or counter-clockwise.
- A clockwise torque tends to make an object rotate in a clockwise direction.
- We define the **net torque** as the difference between the sum of all clockwise torques and the sum of all counter-clockwise torques:

$$\tau_{\text{net}} = \sum_i \tau_{\text{counter-clockwise},i} - \sum_j \tau_{\text{clockwise},j}$$

Torque

- Choose the combination of the position vector and the force vector that produces the highest magnitude of torque around the point indicated by the black circle.

$$\vec{\tau} = \vec{r} \times \vec{F}$$

$$\tau = rF \sin\theta$$