Part I: Newton’s Laws
Chapter 4: Kinematics in Two Dimensions

4.3 Relative Motion
reference frames: The three players Amy, Carlos, and Bill, each carries their coordinate system.¹

The middle-player game:

- $v_{CA} = v_{CB} + v_{BA}$
- $v_{AB} = v_{AC} + v_{CB}$
- $v_{BC} = v_{BA} + v_{AC}$

$v_{AB}$ is A relative to B.

The flipping game: $v_{AB} = -v_{BA}$

- $v_{CA} = v_{CB} - v_{AB}$

1) Start with the middle-player version. 2) Flip wherever to make it feel more natural.

¹Steadfast Amy, steady Carlos, steady Bill: we say inertial reference frames. In all inertial reference frames, everyone gets “$\vec{F}_{net} = m\vec{a}$” as a ready-to-go law of physics.
Where do these games come from?

$\vec{r}_{\text{CB}}$ is C relative to B:

- $\vec{r}_{\text{CB}} = \vec{r}_{\text{AB}} + \vec{r}_{\text{CA}}$

Vector addition is commutative:

- $\vec{r}_{\text{CB}} = \vec{r}_{\text{CA}} + \vec{r}_{\text{AB}}$

Take the time derivative:

- $\vec{v}_{\text{CB}} = \vec{v}_{\text{CA}} + \vec{v}_{\text{AB}}$

What about vector subtraction?

- $\Delta \vec{r} = \vec{r}_{\text{finish}} - \vec{r}_{\text{start}}$
- $\vec{r}_{\text{CA}} = \vec{r}_{\text{CB}} - \vec{r}_{\text{AB}}$
- $\vec{r}_{\text{CA}} + \vec{r}_{\text{AB}} = \vec{r}_{\text{CB}}$ ✓
For you to do: Describe the velocity of the plane relative to the ground in two ways:

▸ (1) Using a coordinate axes and unit vectors.
▸ (2) As a magnitude and an angle (make sure I can interpret your angle).

▸ The plane’s air speed is 300 mph.
▸ The wind is blowing 60 mph.
For you to do: What is the plane’s ground speed?

- The plane’s air speed is 300 mph.
- The wind is blowing 60 mph.