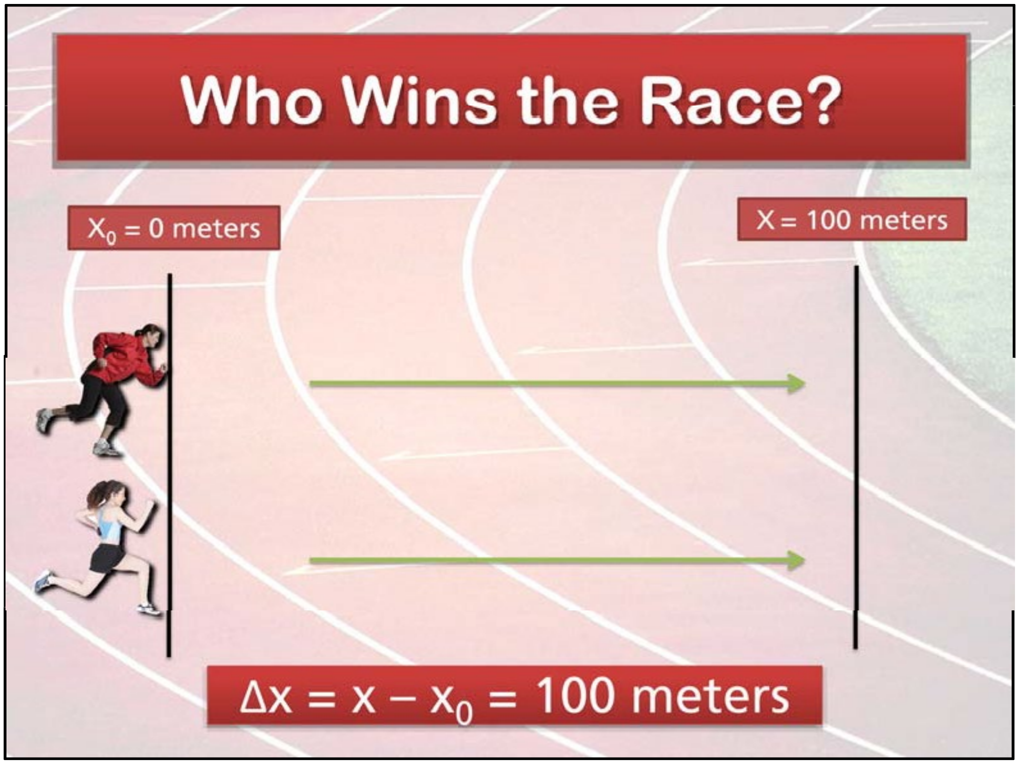
Module 1: Describing Motion
Topic Content: Speed and Velocity

Speed and Velocity

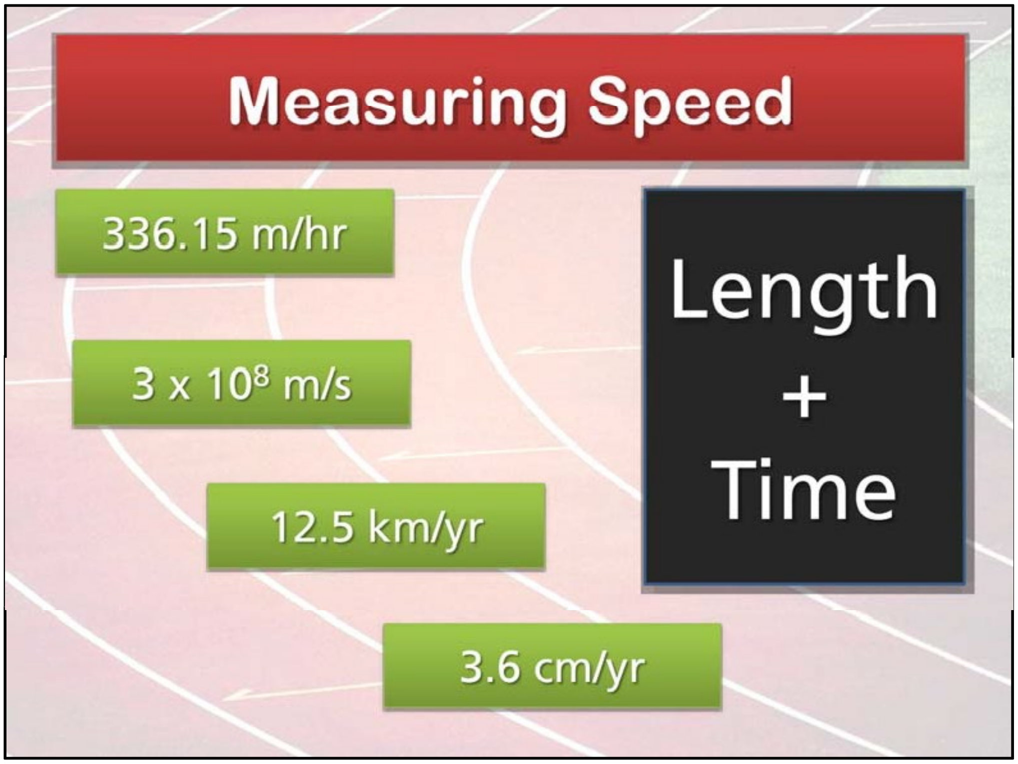
By now, we have looked at objects in motion and learned to precisely describe an object's position, and we also defined displacement as a change in position. But, if two objects have the same displacement, does that necessarily mean that their motion was identical?



Let's take a look at a race; any race will do. At the start of the race, all the runners are at the same position. Let's call this the origin, so that the initial position for each racer is x zero equals zero meters. Let's also specify that positive is the direction from the start line to the finish line. By the time the race ends, all the racers will have crossed the finish line, which is 100 meters away, so the final position for each racer at the end of the race is x equals positive 100 meters.

The displacement for each racer is delta x equals x minus x zero equals plus 100 meters. Now, how do we determine who has won the race?

The difference between racers, as you probably suspected, is the ***time*** that it takes to cover that distance or complete that displacement. When we look at distance in a period of time, the result is speed. When we look at displacement in a period of time, the result is velocity.

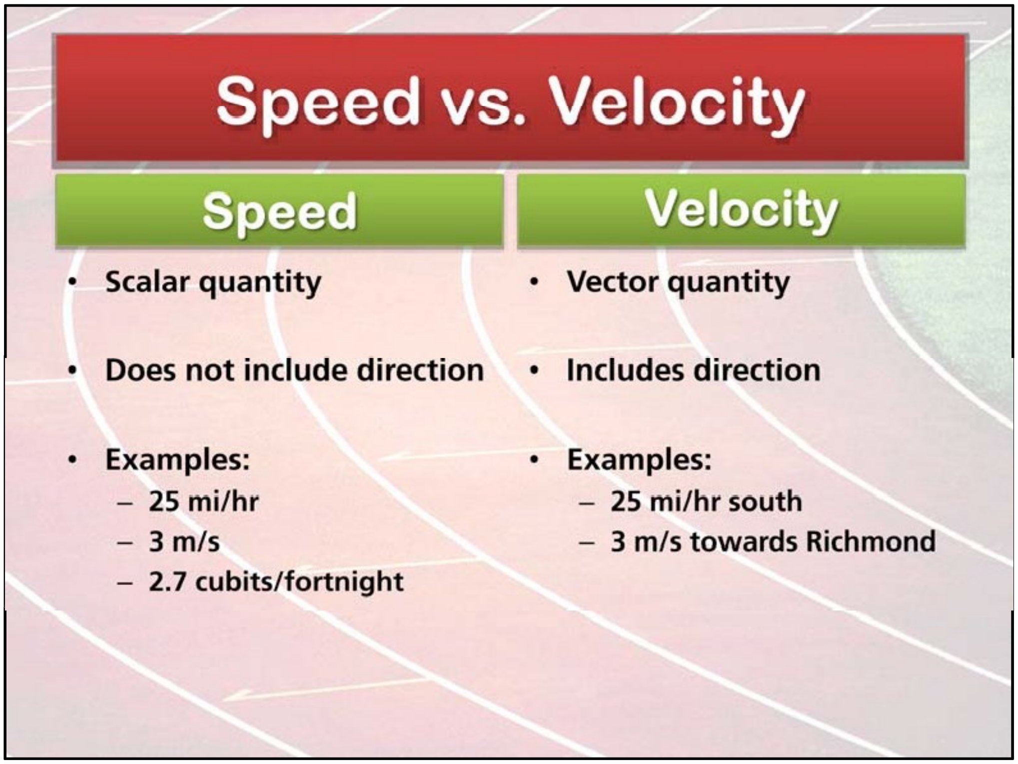


If you think about the way we measure speed, you'll see the pattern right away.

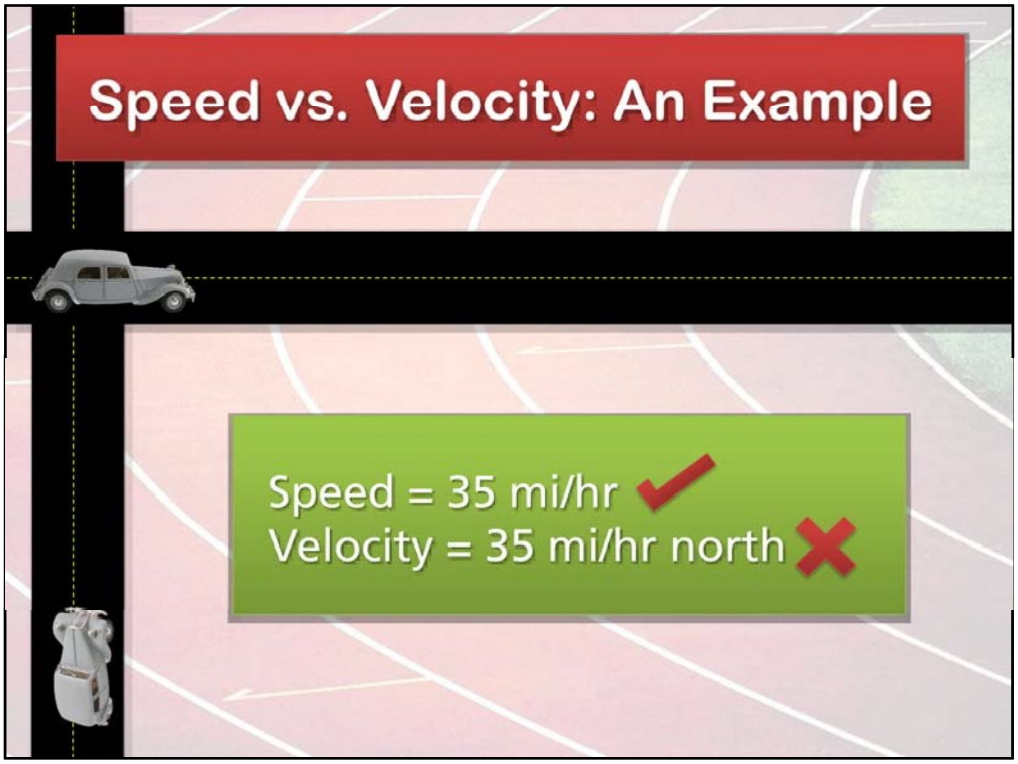
Here are several examples of speed:

- In a professional drag race, cars have been measured to travel up to 336.15 miles per hour.
- Light moves at a speed of 3×10^8 meters per second.
- The Columbia glacier in Alaska moves an average of 12.5 kilometers per year.
- The Atlantic sea floor is expanding, causing North America and Europe to separate from each other at a rate of 3.6 centimeters per year – about as fast as fingernails grow.

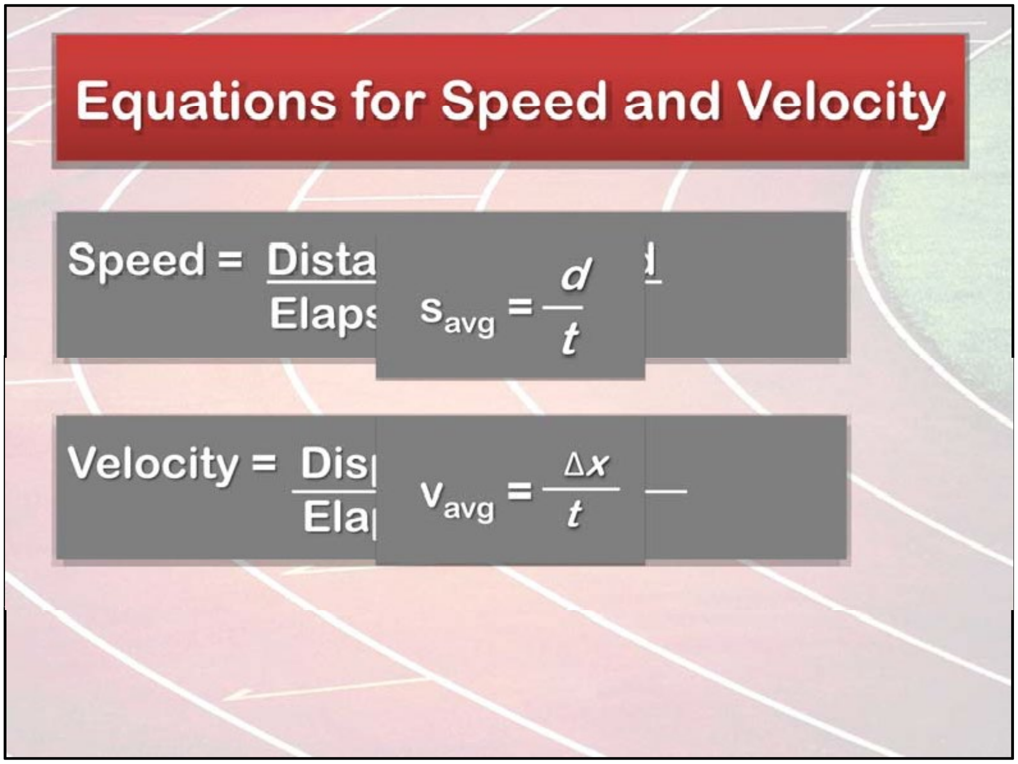
You'll notice that each of these measures of speed include some measurement of length, such as miles, meters, kilometers or centimeters, and some measurement of time, such as hours or seconds or years.



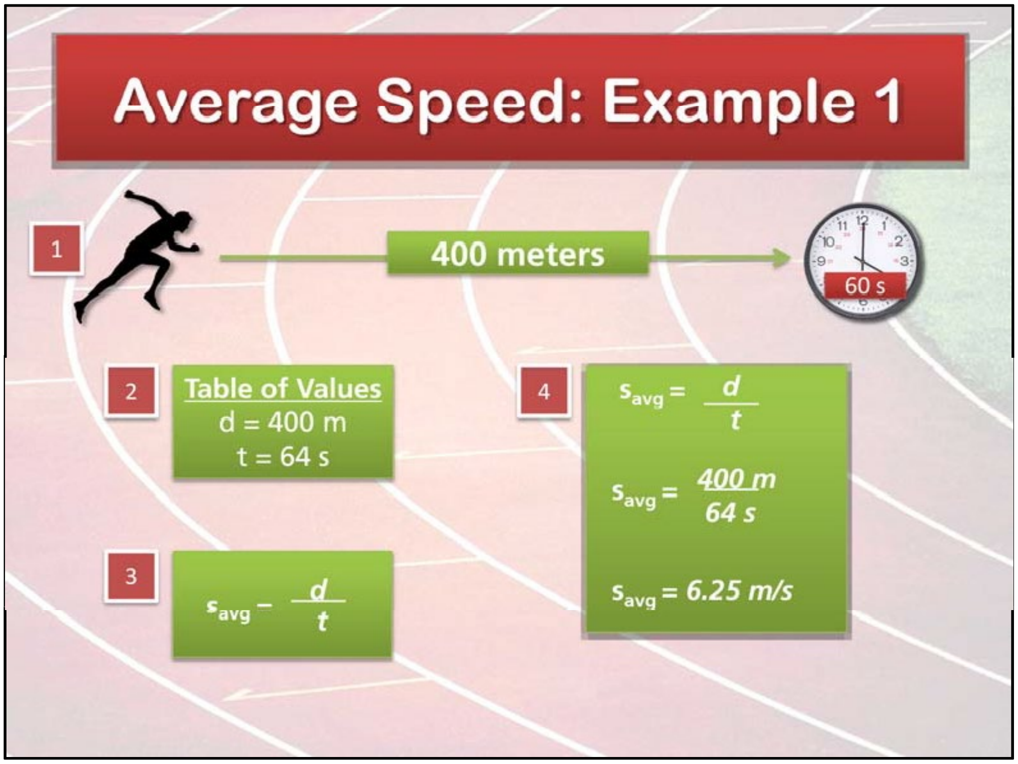
Now, just like distance and displacement, we have the two measures of speed and velocity, one of which is a scalar quantity and the other a vector quantity. Remember that vectors include direction. Speed is the scalar quantity that doesn't include direction. Examples of speeds would be twenty five miles per hour, three meters per second or even two point seven cubits per fortnight. Velocity, on the other hand, is a vector quantity, which must include direction. Twenty five miles per hour, south, and three meters per second, toward Richmond, are both examples of velocity.



Let's look at an example to show the difference between speed and velocity. A car is traveling thirty five miles per hour North on Main Street, then turns right onto Broadway, still going 35 miles per hour. Did the speed change? No. It remains at 35 miles per hour. Did the velocity change? Yes! Since the direction changed, the velocity changed as well. This concept will be very important later on in the course, especially when we get to motion in a circular path.

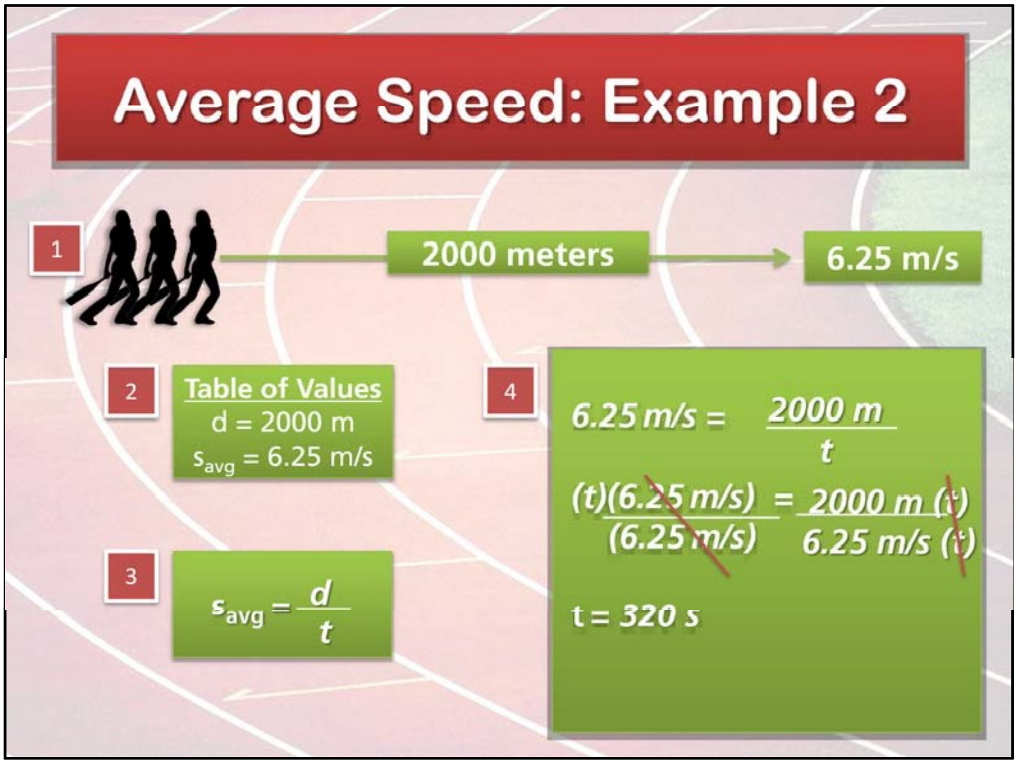


Even though speed is a scalar and velocity is a vector (which you can remember by looking at the first letter of each word!), the equations we use for speed and velocity look similar, although speed and velocity can and will often differ. At this point, we will calculate average speed and average velocity, just focusing on the starting and ending points of the motion. Later, we'll focus on what was happening in between. Average speed is equal to distance traveled divided by elapsed time. Average velocity is equal to displacement divided by elapsed time. We will use the variables v for velocity, s for speed and t for time. We will also use the subscript "avg" to represent the average. So, our equation for average velocity is v_{avg} equals Δx over t and our equation for average speed is s_{avg} equals d over t.



Let's look at an example.

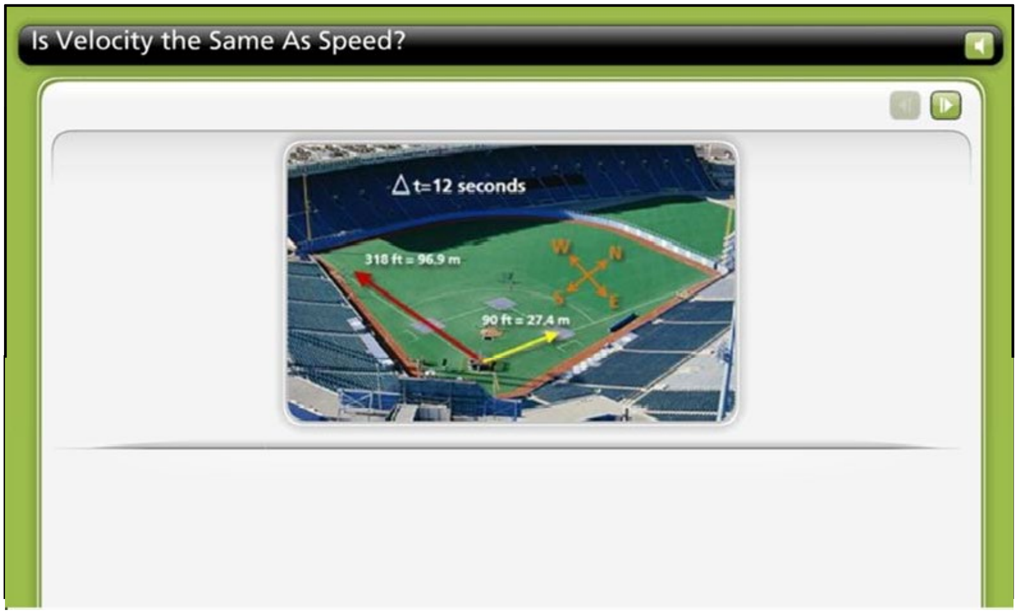
If a runner runs a 400 meter race in 64 seconds, what was his average speed? First, let's sketch a quick picture. Next, we'll create a table of variables. The distance the runner traveled in the race is 400 meters, so we write that *d* equals 400 meters. The time it took to run that distance is the elapsed time, so we write *t* equals 64 seconds. We next choose an equation, in this case the one for average speed. S_{avg} equals *d* over *t*. Now, we can substitute our values and solve the equation. We get the average speed equals 6.25 meters per second.



Let's look at another example.

In a 2000 meter rowing race, the winning team has an average speed of 6.25 meters per second. How much time did it take to complete the race? First, you need to draw a picture. Next, you'll complete a table of values. For each number given in the question, you need to determine what it is measuring and assign the proper variable. Here, you've got 2000 meters, which is your distance, so you write *d* equals 2000 meters. But in this problem, you're given the speed, not the time. So, you write s_{avg} equals 6.25 meters per second. Now, since you're looking for elapsed time and you have s_{avg} and *d*, our equation is the same as before: s_{avg} equals *d* over *t*.

Now, you're ready to substitute the values. The algebra here is slightly more complicated. To solve for *t*, you have to multiply both sides by *t* and divide both sides by 6.25 meters per second. The result is *t* equals 2000 divided by 6.25 equals 320 seconds.



Introduction
So far, we haven't focused on the difference between velocity and speed, and in the past few examples, there doesn't appear to be any difference. This is because both examples had objects moving in a straight line without change in direction, so the vector nature of velocity wasn't apparent. So, let's look at another example where the difference will be obvious.

Arrow One
A baseball player hits a pitch along the third base line, past the left fielder. As the ball continues towards the fence, 318 feet away, the batter runs around the bases. The outfielder finally retrieves the ball and throws it to third base with the ball and runner reaching the base at the same time, 12 seconds later.

318 feet is equal to 96.9 meters, and 90 feet between bases is 27.4 meters.

Arrow Two
First, let's determine the total distance traveled by the batter. You should be able to see, even without using the number line, that the batter ran to first, then second, then third base. Each leg was a distance of 27.4 meters, for a total distance of 82.2 meters.

Let's record this in our table of values. The time to run that distance was 12 seconds. Our speed equation is s_{avg} equals *d* over *t*. Substituting gives us an average speed of 6.85 meters per second.

Arrow Three
Now, let's calculate the velocity. Remember that the displacement only depends on the initial and final positions. Since the batter starts at home plate and winds up at third base, he is only 27.4 meters from where he started, so his displacement is 27.4 meters, and the time remains 12 seconds.

But, the displacement needs a direction. It turns out that for this ballpark, North is the direction you would travel from home plate to first base, so the displacement of the runner is West.

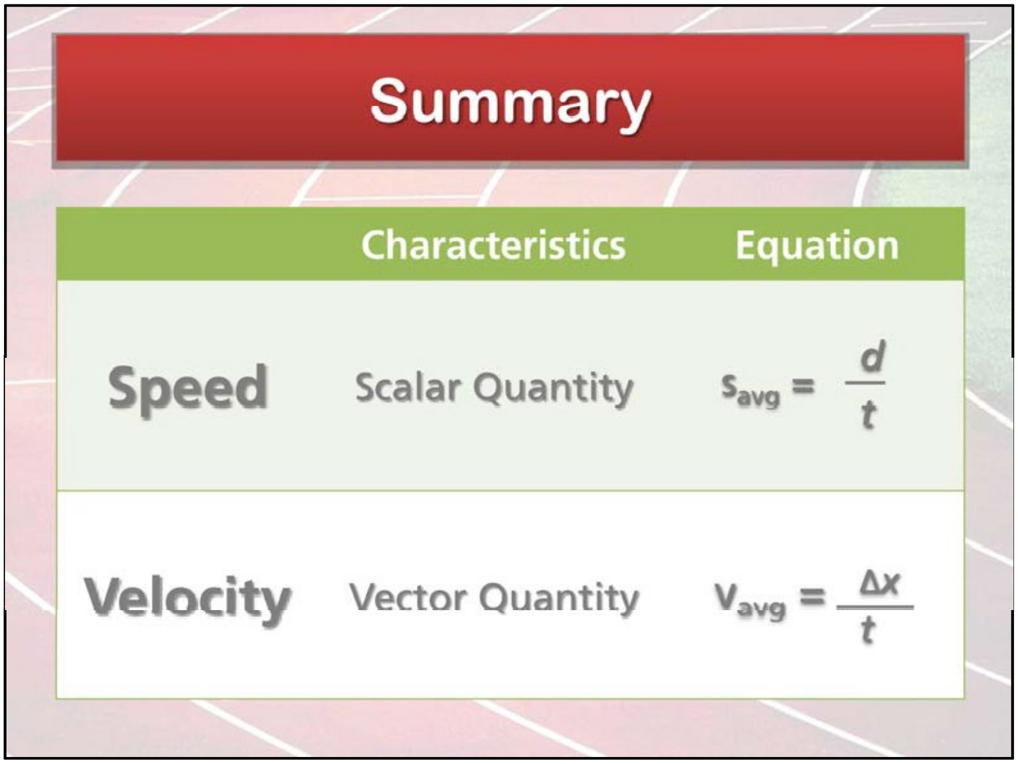
As we record these values in the table of values, pick our average velocity equation, which looks somewhat similar to the average speed equation, substitute and solve, we find that the batter's average velocity was only 2.28 meters per second West.

Arrow Four
The ball first travels a distance of 96.9 meters to reach the fence, then travels another distance of 96.9 minus 27.4 meters to get back to third base. The time remains 12 seconds. Substituting, we find that the average speed of the ball was 13.9 meters per second, which is substantially faster than the average speed of the batter which was 6.85 meters per second.

Arrow Five
Now, what about the average velocity of the ball? You should be able to anticipate the answer already. The ball travels West to the outfield fence, then back East to third base. When you calculate the displacement, you end up with a displacement of 27.4 meters West from where the batter hit the ball.

Substituting and solving, we get an average velocity of 2.28 meters per second West. Remarkably, this value is the same as that of the runner, even though it is substantially less than the average velocity.

Arrow Six
What if the batter had been able to run all the way home in a few more seconds at the same average speed? Could you guess what the average velocity would have been? If you guessed zero, you'd be correct! To run back to the starting point means that his displacement would have been zero. So, even though his average speed may have remained the same, his velocity would have been zero.



Speed and velocity both help to describe the motion of an object by comparing some measures of how far the object moved, either distance or displacement, to the time it took the object to complete that motion. Average speed is considered a scalar quantity, and is calculated by dividing the total distance an object has moved by the total elapsed time. The average velocity is a vector quantity that we calculate by dividing the displacement of the object, which compares initial position to final position, by the total elapsed time. If an object changes direction during its motion, the average velocity and average speed will not be the same.