

When people talk about "a GPS", they usually mean a GPS receiver. The Global Positioning System (GPS) is actually a constellation of 27 Earth-orbiting satellites (24 in operation and three extras in case one fails). The U.S. military developed this satellite network as a military navigation system, but soon opened it up to everybody else.

Each of these solar-powered satellites circles the globe at about 12,000 miles (19,300 km), making two complete rotations every day. The orbits are arranged so that at any time, anywhere on Earth, there are at least four satellites "visible" in the sky.

A GPS receiver's job is to locate four or more of these satellites, figure out the distance to each, and use this information to deduce its own location. This operation is based on a simple mathematical principle called trilateration. Trilateration in three-dimensional space can be a little tricky, so we'll start with an explanation of simple two-dimensional trilateration.

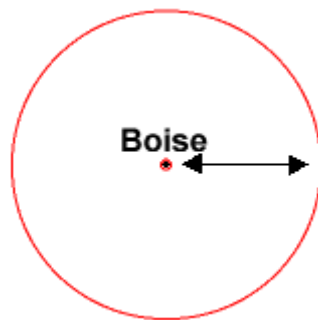
Imagine you are somewhere in the United States and you are **TOTALLY** lost -- for whatever reason, you have absolutely no clue where you are. You find a friendly local and ask, "Where am I?" He says, "You are 625 miles from Boise, Idaho".

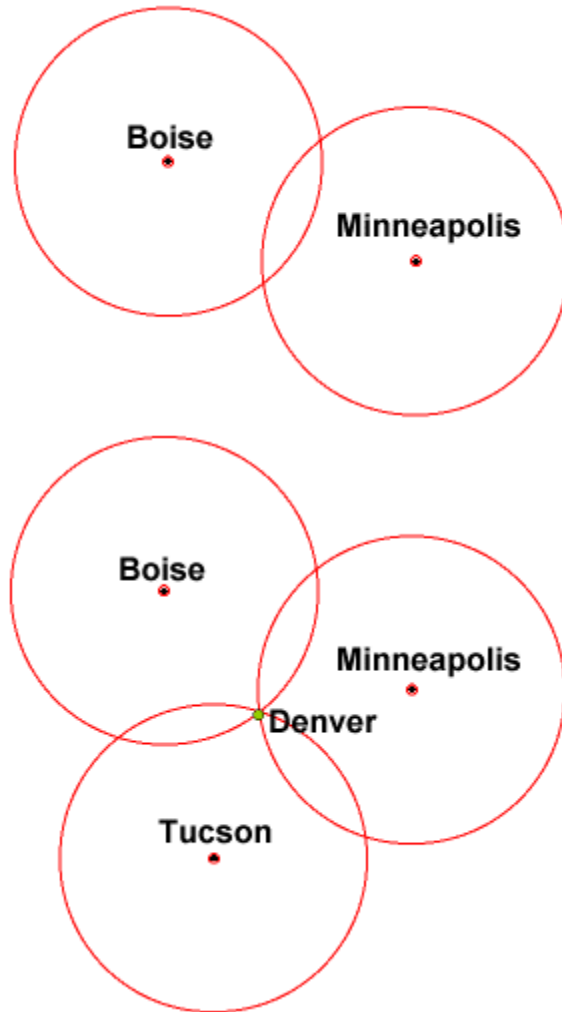
This is a nice fact, but it is not particularly useful by itself. You could be anywhere on a circle around Boise that has a radius of 625 miles, like this:

You ask somebody else where you are, and she says, "You are 690 miles from Minneapolis, Minnesota." Now you're getting somewhere. If you combine this information with the Boise information, you have two circles that intersect. You now know that you must be at one of these two intersection points, if you are 625 miles from Boise and 690 miles from Minneapolis.

If a third person tells you that you are 615 miles from Tucson, Arizona, you can eliminate one of the possibilities, because the third circle will only intersect with one of these points. You now know exactly where you are -- Denver, Colorado.

This same concept works in three-dimensional space, as well, but you're dealing with spheres instead of circles. In the next section, we'll look at this type of trilateration.





3-D Trilateration

Fundamentally, three-dimensional trilateration isn't much different from two-dimensional trilateration, but it's a little trickier to visualize. Imagine the radii from the examples in the last section going off in all directions. So instead of a series of circles, you get a series of spheres.

If you know you are 10 miles from satellite A in the sky, you could be anywhere on the surface of a huge, imaginary sphere with a 10-mile radius. If you also know you are 15 miles from satellite B, you can overlap the first sphere with another, larger sphere. The spheres intersect in a perfect circle. If you know the distance to a third satellite, you get a third sphere, which intersects with this circle at two points.

The Earth itself can act as a fourth sphere -- only one of the two possible points will actually be on the surface of the planet, so you can eliminate the one in space. Receivers generally look to four or more satellites, however, to improve accuracy and provide precise altitude information.

In order to make this simple calculation, then, the GPS receiver has to know two things:

The location of at least three satellites above you

The distance between you and each of those satellites

The GPS receiver figures both of these things out by analyzing **high-frequency, low-power radio signals from the GPS satellites.**

Radio waves are electromagnetic energy, which means they travel at the speed of light (about 186,000 miles per second, 300,000 km per second in a vacuum). The receiver can figure out how far the signal has traveled by timing how long it took the signal to arrive.

At a particular time (let's say midnight), the satellite begins transmitting a long, digital pattern called a pseudo-random code. The receiver begins running the same digital pattern also exactly at midnight. When the satellite's signal reaches the receiver, its transmission of the pattern will lag a bit behind the receiver's playing of the pattern.

The length of the delay is equal to the signal's travel time. The receiver multiplies this time by the speed of light to determine how far the signal traveled. Assuming the signal traveled in a straight line, this is the distance from receiver to satellite.

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In order to make this measurement, the receiver and satellite both need clocks that can be synchronized down to the nanosecond. **To make a satellite positioning system using only synchronized clocks, you would need to have atomic clocks not only on all the satellites, but also in the receiver itself. But atomic clocks cost somewhere between \$50,000 and \$100,000, which makes them a just a bit too expensive for everyday consumer use.**

The Global Positioning System has a clever, effective solution to this problem. Every satellite contains an expensive atomic clock, but the receiver itself uses an ordinary quartz clock, which it constantly resets. In a nutshell, the receiver looks at incoming signals from four or more satellites and gauges its own inaccuracy.

When you measure the distance to four located satellites, you can draw four spheres that all intersect at one point. Three spheres will intersect even if your numbers are way off, but four spheres will not intersect at one point if you've measured incorrectly. Since the receiver makes all its distance measurements using its own built-in clock, the distances will all be proportionally incorrect.

The receiver can easily calculate the necessary adjustment that will cause the four spheres to intersect at one point. Based on this, it resets its clock to be in sync with the satellite's atomic clock. The receiver does this constantly whenever it's on, which means it is nearly as accurate as the expensive atomic clocks in the satellites.

In order for the distance information to be of any use, the receiver also has to know where the satellites actually are. This isn't particularly difficult because the satellites travel in

very high and predictable orbits. The GPS receiver simply stores an almanac that tells it where every satellite should be at any given time. Things like the pull of the moon and the sun do change the satellites' orbits very slightly, but the Department of Defense constantly monitors their exact positions and transmits any adjustments to all GPS receivers as part of the satellites' signals.

This system works pretty well, but inaccuracies do pop up. For one thing, **this method assumes the radio signals will make their way through the atmosphere at a consistent speed (the speed of light). In fact, the Earth's atmosphere slows the electromagnetic energy down somewhat, particularly as it goes through the ionosphere and troposphere. The delay varies depending on where you are on Earth, which means it's difficult to accurately factor this into the distance calculations. Problems can also occur when radio signals bounce off large objects, such as skyscrapers, giving a receiver the impression that a satellite is farther away than it actually is.** On top of all that, satellites sometimes just send out bad almanac data, misreporting their own position.

Differential GPS (DGPS) helps correct these errors. The basic idea is to gauge GPS inaccuracy at a stationary receiver station with a known location. Since the DGPS hardware at the station already knows its own position, it can easily calculate its receiver's inaccuracy. The station then broadcasts a radio signal to all DGPS-equipped receivers in the area, providing signal correction information for that area. In general, access to this correction information makes DGPS receivers much more accurate than ordinary receivers.

Once the receiver makes its calculation, it can tell you the latitude, longitude and altitude (or some similar measurement) of its current position. To make the navigation more user-friendly, most receivers plug this raw data into map files stored in memory.

You can use maps stored in the receiver's memory, connect the receiver to a computer that can hold more detailed maps in its memory, or simply buy a detailed map of your area and find your way using the receiver's latitude and longitude readouts. Some receivers let you download detailed maps into memory or supply detailed maps with plug-in map cartridges.

A standard GPS receiver will not only place you on a map at any particular location, but will also trace your path across a map as you move. If you leave your receiver on, it can stay in constant communication with GPS satellites to see how your location is changing. With this information and its built-in clock, the receiver can give you several pieces of valuable information:

How far you've traveled (odometer)

How long you've been traveling

Your current speed (speedometer)

Your average speed

A "bread crumb" trail showing you exactly where you have traveled on the map

The estimated time of arrival at your destination if you maintain your current speed
To obtain this last piece of information, you would have to have given the receiver the coordinates of your destination, which brings us to another GPS receiver capability: inputting location data.

The basic unit of user input is the waypoint. A waypoint is simply the coordinates for a particular location. You can save this in your receiver's memory in two ways:

You can tell the receiver to record its coordinates when you are at that location.

You can find the location on a map (the internal map or another one) and enter its coordinates as a waypoint.

This capability lets you use your GPS receiver in a number of different ways. You can record any specific location that interests you so you'll be able to find it again at a later time. This might include:

Good camp sites

Favorite hiking trails

Excellent fishing spots

Scenic overlooks

Where you left your car

You can also combine a series of different waypoints to form a route. One way to use this function is to periodically record waypoints as you make a trip so that you can backtrack, or follow the same route again in the future. Route-mapping also lets you plan ahead:

When you have time to examine a map at home, you can record a series of waypoints along the roads or trails that lead to your destination. Then, when you're traveling, all you'll need to find your way is your GPS receiver.

GIS

If the receiver has a data port, you can also download your routes to a computer, which has much more storage space, and then upload them again when you plan to follow those routes. Computers can do a lot more with GPS location data than your average receiver, because computers have much more memory and much faster processing capabilities.

You can also update your computer maps easily, so you can include any surveying adjustments or changes in an area.

At its heart, a GPS receiver is just an accurate way to get raw positional data, which can then be applied to geographic information that has been accumulated over the years. This idea is incredibly simple, but it has seemingly endless applications. The considerable contributions of GPS to aviation, maritime navigation, military operation, surveying and recreation have already secured its place among the most revolutionary inventions of all time.