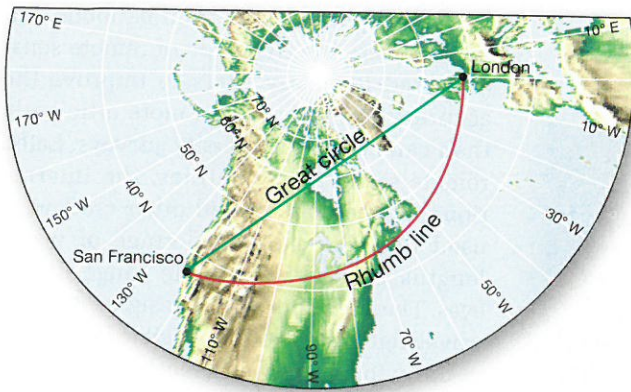
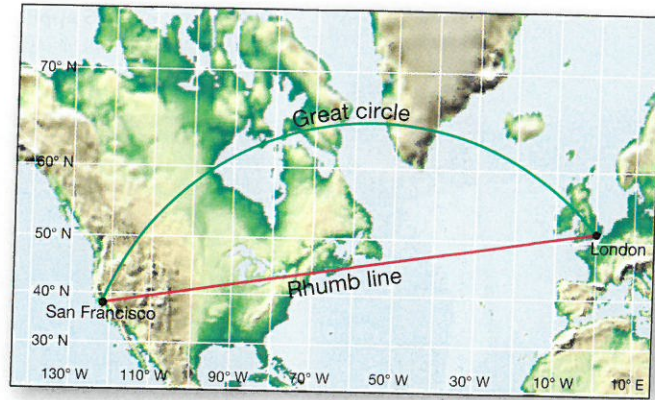




(a) The gnomonic projection is used to determine the shortest distance (great circle route) between San Francisco and London because on this projection the arc of a great circle is a straight line.

▲Figure 1.20 Determining great circle routes.



(b) The great circle route is then plotted on a Mercator projection, which has true compass direction. Note that straight lines or bearings on a Mercator projection (rhumb lines) are not the shortest route.

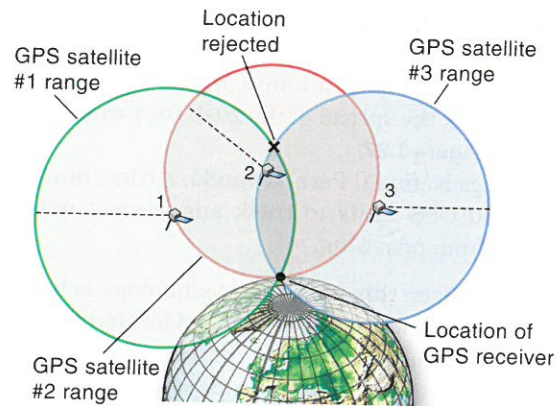
sensing, and geographic information systems (GIS). GPS relies on satellites in orbit to provide precise location and elevation. Remote sensing utilizes spacecraft, aircraft, and ground-based sensors to provide visual data that enhance our understanding of Earth. GIS is a means for storing and processing large amounts of spatial data as separate layers of geographic information; geographic information science is the geographic subfield that uses this technique.

Global Positioning System

The **Global Positioning System (GPS)** uses radio signals from satellites to accurately determine latitude, longitude, and elevation anywhere on or near the surface of Earth. The system comprises at least 27 orbiting satellites, in six orbital planes, that transmit navigational signals to Earth-bound receivers (backup GPS satellites are in orbital storage as replacements). Think of the satellites as a constellation of navigational beacons with which you can interact to determine your unique location. As we know, every possible square meter of Earth's surface has its own address relative to the latitude–longitude grid.

A GPS receiver senses signals from at least four satellites—a minimum of three satellites for location and a fourth to determine accurate elevation. The distance between each satellite and the GPS receiver is calculated using clocks built into each instrument that time radio signals traveling at the speed of light between them (Figure 1.21). The receiver calculates its true position—latitude, longitude, and elevation—using trilateration (determining a position using the distance from three known points). GPS units also report accurate time to within 100 billionths of a second. This allows GPS base stations to have perfectly synchronized timing, essential to worldwide communication, finance, and many industries.

GPS receivers are built into many smartphones, wristwatches, and motor vehicles and can be bought as



▲Figure 1.21 Using satellites to determine location through GPS. Imagine a ranging sphere around each of three GPS satellites. These spheres intersect at two points, one easily rejected because it is some distance above Earth and the other at the true location of the GPS receiver. In this way, signals from three satellites can reveal the receiver's location; adding a fourth satellite determines elevation.

handheld units. Standard cell phones not equipped with a GPS receiver determine location based on the position of cell phone towers—a process not as accurate as GPS measurement.

The GPS is useful for diverse applications. For example, commercial airlines use the GPS to improve accuracy of routes flown and thus increase fuel efficiency. Scientific applications of GPS technology are extensive. Consider these examples:

- In geodesy, GPS helps refine knowledge of Earth's exact shape and how this shape is changing.
- Scientists used GPS technology in 1998 to accurately determine the height of Mount Everest in the Himalayan Mountains, raising its elevation by 2 m (6 ft).
- On Mount St. Helens in Washington, a network of GPS stations measure ground deformation associated with earthquake activity. In southern California, a similar