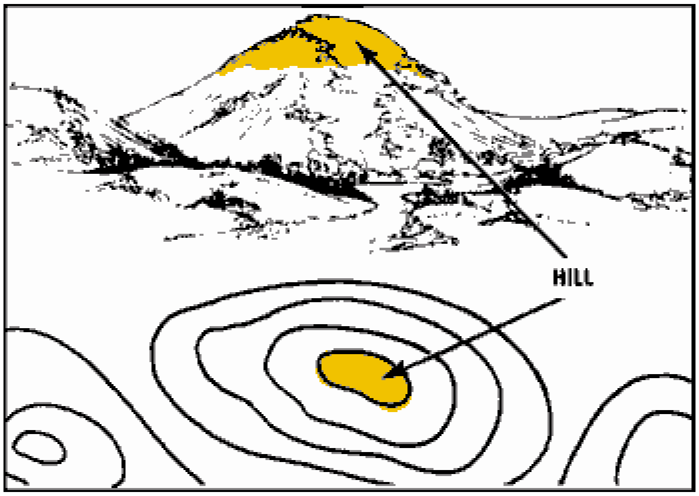
Land Navigation

- Using a topographical map for your area or the area you will be navigating in, demonstrate that you know the following map symbols:
    - A topographic map shows the shape of the Earth's surface.

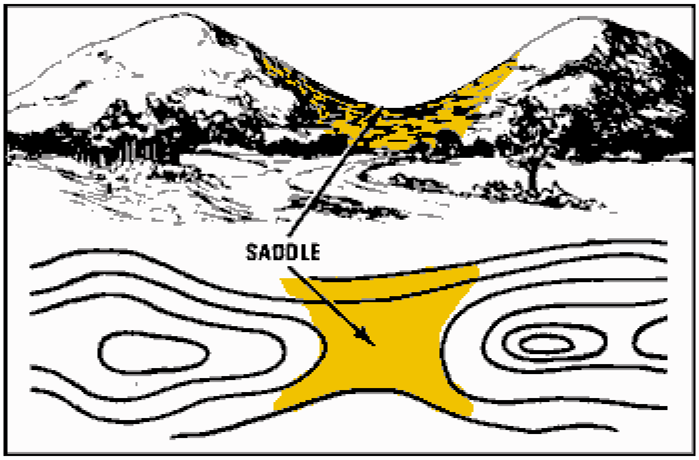
- Index contour
    - A contour line that is a bolder brown than the others and on most maps, will have a number that tells it's elevation above sea level.
    - An index contour usually occurs every fifth line.
- Contour interval
    - The vertical distance that separates each contour line on a topographic map.
    - To determine the contour interval of a map, count the number of contour lines between two adjacent index contours. Add 1 to this figure and divide by the elevation difference.
- Vertical control station
    - Control surveys present map features in correct relationship to each other and to the Earth's surface. Two kinds of control measurements are needed: ***horizontal*** and ***vertical***.
        - **Horizontal ground control** is needed to establish and maintain correct scale, position, and orientation of the map. For this purpose, latitude and longitude of selected points within the area to be mapped are determined by field surveys.
        - **Vertical control** is needed to determine the correct position of contours which show the shape or elevation of the terrain. Thus, elevations of selected points above and below the zero level must also be determined in the field.
    - Horizontal and vertical control points become the framework on which map detail is compiled. An accurate framework also permits map detail to match from one sheet to the next.
- Hard-surface, heavy-duty road
- Railroad, single track
- Power transmission line
- Building
- Checked spot elevation
- Marsh
- Map scale
    - The relationship between distance as measured on a map and the actual distance on the Earth's surface.
    - A map with a scale of 1:24,000 would mean that 1 inch on the map equals 24,000 inches on the ground, or about 2,000 feet.
    - The smaller the second number in the ratio, the smaller the area covered, and the more detail the map will show.
    - Maps will usually give you more than one way to measure distance.
- Intermittent stream
- Depression
- Ridge
- Trail
- Stream
- Hard-surface, medium-duty road
- Bridge
- Cemetery
- Campsite
- Water well or spring
- Unimproved dirt road

- Gradient
  - The rate of change in field values between two points in a field.
  - To figure the gradient on a topographic map, divide the "Difference in elevation between two points (usually in meters)" by "Distance between the same two points (usually in kilometers)"
  - Contour lines become more closely spaced when the gradient increases.
  - Contour lines become further apart when the gradient decreases.
- Explain contour lines. Be able to tell the contour interval for your map and be able to show the difference between a steep and a gentle slope.
  - Isolines connect points of equal value on a field map.
  - Isolines on a topographic map are known as *contour lines.*
  - Contour lines show points of equal elevation.
  - Contour lines do not cross each other although on a vertical cliff, they may be on top of each other.
  - Contour lines should close (even if this is somewhere off the map).
  - Closed contours appearing on a map as ellipses or circles represent hills or knolls.
  - Closed contours with hachures  represent depressions.
  - Where contour lines cross streams and rivers they have a V shape and the V points upstream.
- Use of colors on topographic maps.
  - Blue – water features, including streams, rivers, ponds, lakes, oceans, springs, and swamps. Larger patches are ponds or lakes. A thin blue band is a stream, and a broader band is a river. A broken blue line means that a stream flows only some of the time. Swamps and marshes are shown with hatched blue lines.
  - Green – vegetation. The shade of green may vary depending on the density of the ground cover under the trees. The darker the shade of green, the denser the ground vegetation. Dark green may reflect nearly impenetrable vegetation, and medium and light green shading could indicate vegetation that you could walk or slowly run through.
  - Black – anything constructed by people, including roads, trails, houses, buildings, railroads, power lines, dams, bridges, and boundaries. Paved roads and improved gravel roads are solid black lines. Unimproved roads such as jeep trails are represented by broken black lines. Trails are thinner broken lines. Solid black squares, rectangles, and varying shapes represent buildings. Ruins are outlined. Rock features also will be shown in black.
  - Yellow – open terrain, where you can easily see the sun by looking up. Dark yellow is grass that is fairly short, lighter yellow is rough open terrain, and white dots on yellow is semiopen terrain with scattered trees and bushes throughout.
  - White – open forest canopy with minimal ground vegetation. You can run fast through this terrain.
  - Brown – natural land features, such as earthbanks, gullies, depressions, dry ditches, pits, and knolls. Contour lines and form lines are also shown in brown.
  - The symbol "BM" stands for benchmark.
    - These are set in concrete and periodically checked by the USGS.
- Using a map and compass, navigate an orienteering course that has at least six legs covering at least 2.5 miles.
- Learn to use a Global Positioning System (GPS) receiver. Demonstrate that you can find a fixed coordinate at night using a GPS receiver.
- Teach the navigating skills you have learned in (a) through (d) above to your crew, another crew, a Cub or Boy Scout group, or another group.

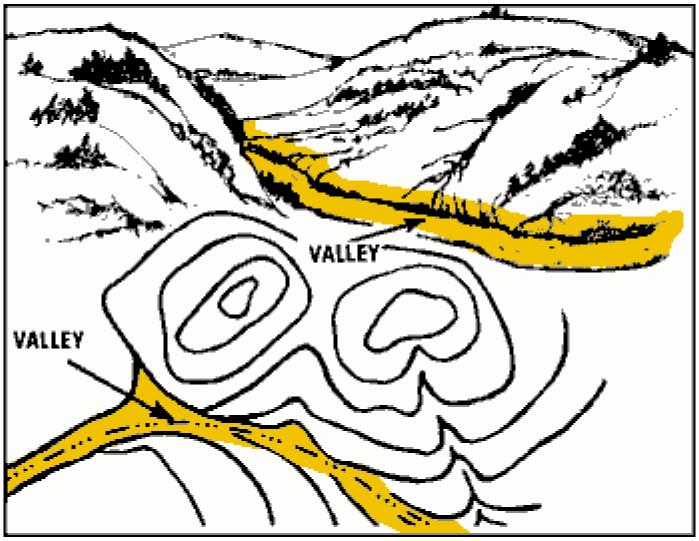
A hill is shown on a map by contour lines forming concentric circles. The inside of the smallest closed circle is the hilltop.



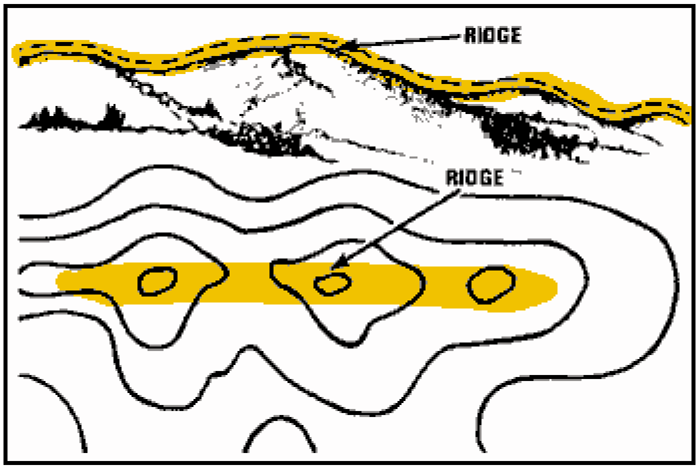
A saddle is normally represented as an hourglass



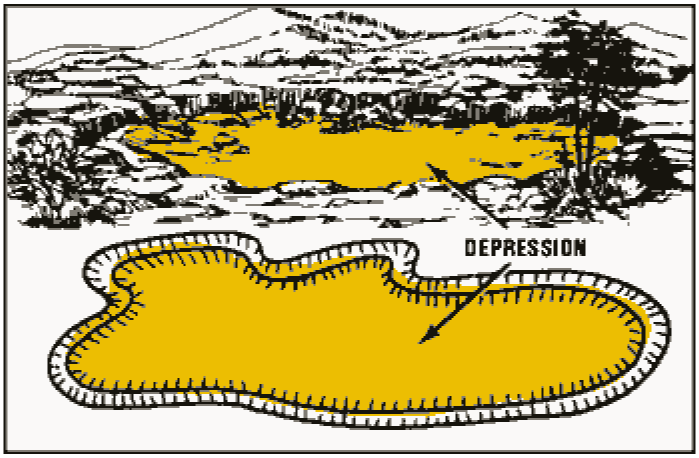
Contour lines forming a valley are either U-shaped or V-shaped.



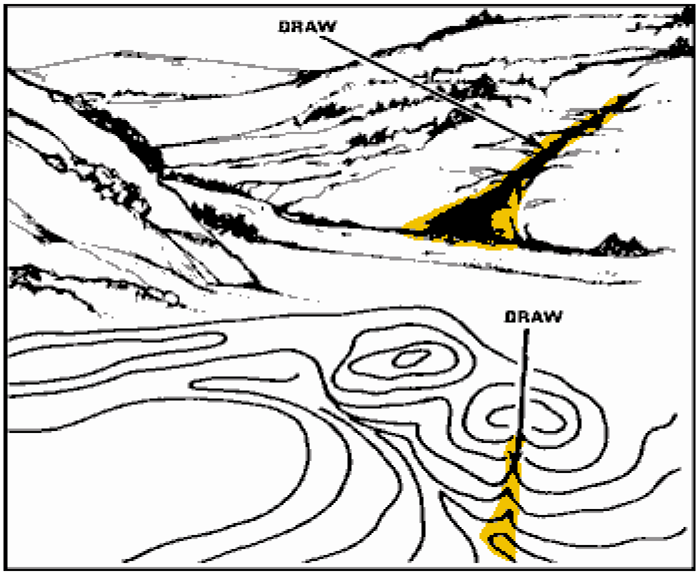
Contour lines forming a ridge tend to be U-shaped or V-shaped. The closed end of the contour line points away from high ground.



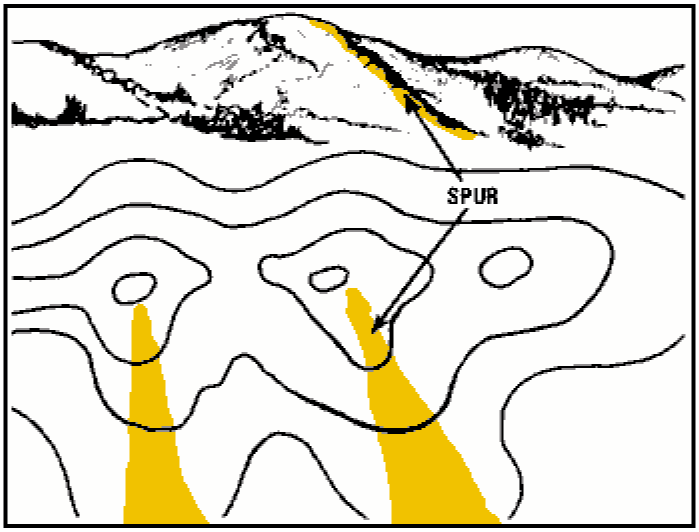
Usually only depressions that are equal to or greater than the contour interval will be shown. On maps, depressions are represented by closed contour lines that have tick marks pointing toward low ground.



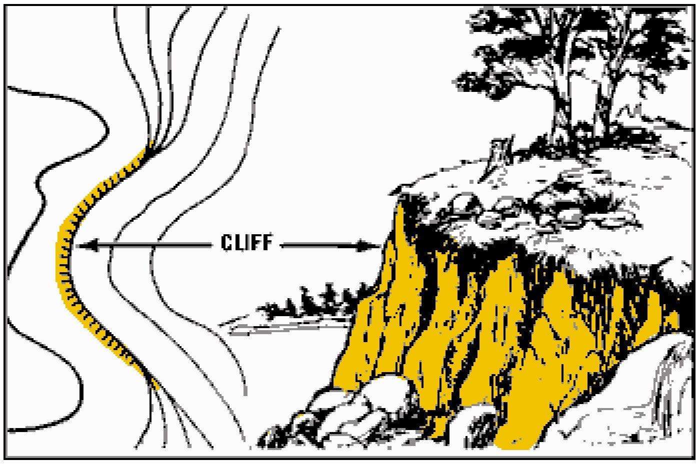
The contour lines depicting a draw are U-shaped or V-shaped, pointing toward high ground.



Contour lines on a map depict a spur with the U or V pointing away from high ground.

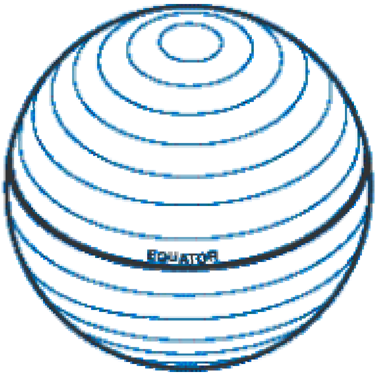


Cliffs are also shown by contour lines very close together and, in some instances, touching each other.



Latitude and Longitude

Latitude



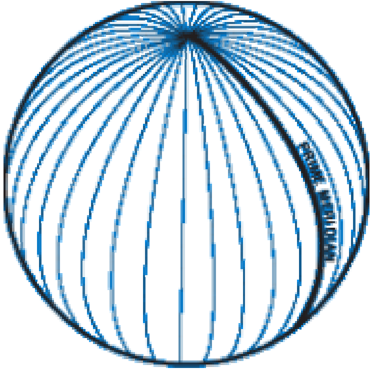
Lines of latitude measure north-south position between the poles. The equator is defined as 0 degrees, the North Pole is 90 degrees north, and the South Pole is 90 degrees south. Lines of latitude are all parallel to each other, thus they are often referred to as parallels.

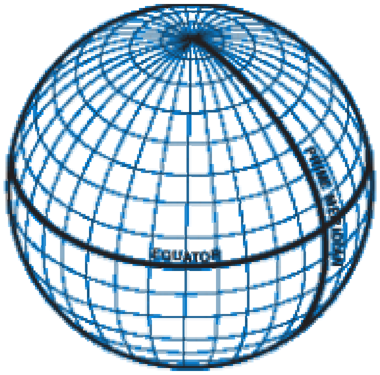
The memory rhyme I use to help remember that lines of latitude denote north-south distance is:
"Tropical latitudes improve my attitude"

One degree of latitude is
60 nautical miles, 69 statute miles or 111 km.

One minute of latitude is
1 nautical mile, 1.15 statute miles, or 1.85 km.

Longitude





Lines of longitude, or meridians, run between the North and South Poles. They measure east-west position. The prime meridian is assigned the value of 0 degrees, and runs through Greenwich, England. Meridians to the west of the prime meridian are measured in degrees west and likewise those to the east of the prime meridian are measured to by their number of degrees east.

The memory rhyme I use to help remember that lines of longitude denote east-west distance is:

> *"Lines of LONGitude are all just as*
> *LONG as one another."*

With this saying in my mind, I picture all of the longitudinal meridians meeting at the poles, each meridian the same length as the next.

Symbols for degrees, minutes and seconds:

°	**Degrees**
'	**Minutes**
"	**Seconds**

The three common formats:

DDD° MM' SS.S"	Degrees, Minutes and Seconds
DDD° MM.MMM'	Degrees and Decimal Minutes
DDD.DDDDD°	Decimal Degrees

Degrees, Minutes and Seconds

DDD° MM' SS.S"
32° 18' 23.1" N 122° 36' 52.5" W

This is the most common format used to mark maps. It's also the most cumbersome to work with. It's a lot like telling time…

There are sixty seconds in a minute (60" = 1') and
There are sixty minutes in a degree (60' = 1°).

Keeping in mind a few easy conversions between seconds and decimal minutes will help when working with maps that use degrees, minutes and seconds.

15 seconds is one quarter of a minute or 0.25 minutes
30 seconds is one half of a minute or 0.5 minutes
45 seconds is three quarters of a minute or 0.75 minutes

Degrees and Decimal Minutes

DDD° MM.MMM'
32° 18.385' N 122° 36.875' W

This is the format most commonly used when working with electronic navigation equipment.

Decimal Degrees

DDD.DDDDD°
32.30642° N 122.61458° W
or +32.30642, -122.61458

This is the format you'll find most computer based mapping systems displaying. The coordinates are stored internally in a floating point data type, and no additional work is required to print them as a floating point number.

Often the N-S and E-W designators are omitted. Positive values of latitude are north of the equator, negative values to the south. Watch the sign on the longitude, most programs use negative values for west longitude, but a few are opposite. This saves a lazy western

Guide for converting Latitude/Longitude Coordinates

DM.m = Degrees, Minutes, Decimal Minutes
D.d = Degrees, Decimal Degrees
DMS = Degrees, Minutes, Seconds

DMS to DM.m – Divide S by 60 to get .m and add .m to M to get M.m

DM.m to D.d – Divide M.m by 60 to get .d and add .d to D to get D.d

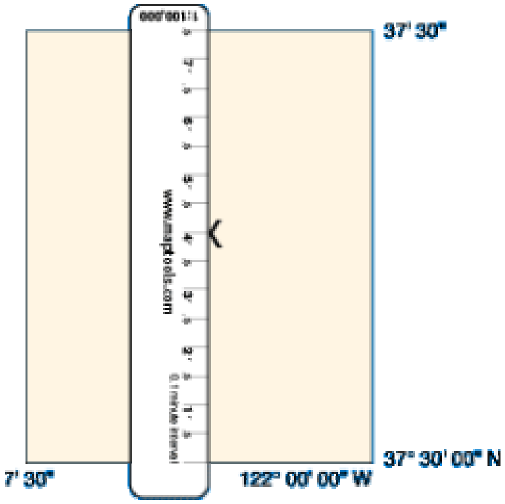
D.d to DM.m – Multiply .d by 60 to get M.m

DM.m to DMS – Multiply .m by 60 to get S

Plotting and Measuring Latitude

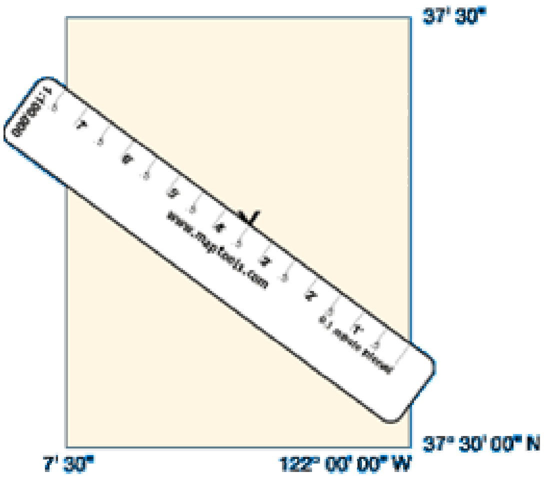
Because the lines of latitude are parallel and evenly spaced, a degree of latitude represents a constant distance on the ground. This makes plotting latitude quite straight forward.

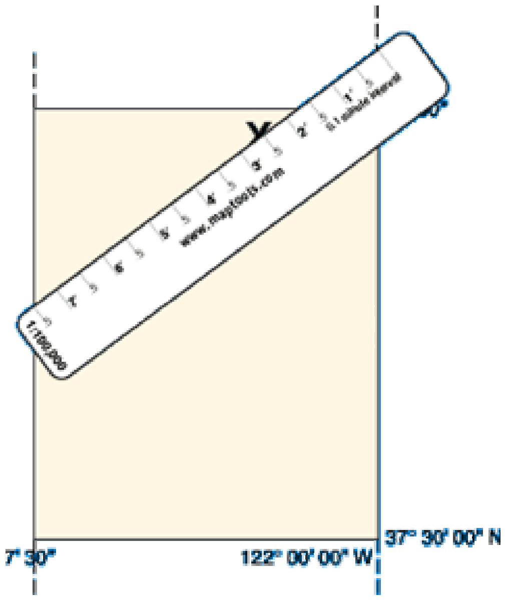
Place the ruler so that it spans the lines of latitude the point to be measured or plotted falls between. Orient the ruler north to south. The zero minute end of the ruler should be on the southern line of latitude, when you're in the northern hemisphere. To measure the latitude of a point on the map, read the value from the ruler at the point, and add it to the latitude of the line at the zero end of the ruler. On the picture to the left, the ruler indicates the X is at the 4' mark, for a resulting latitude of 37° 34' N. To plot the location of given coordinates, make a small mark on the map to indicate the line of latitude the coordinates fall on.



Plotting and Measuring Longitude

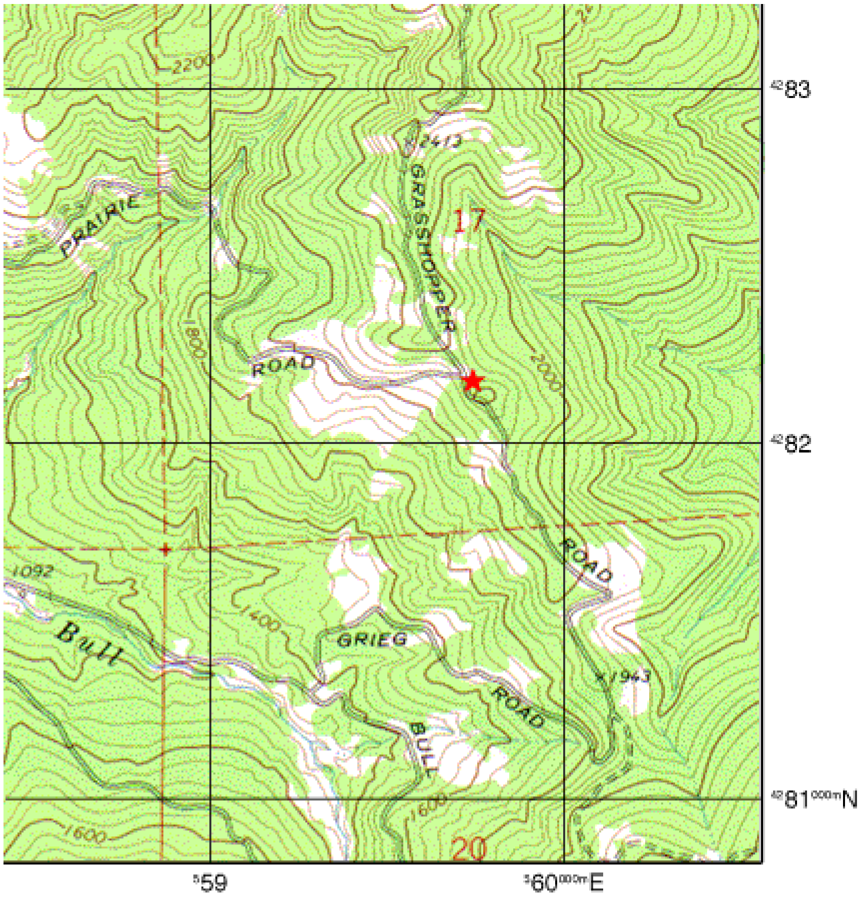
Longitude represents an east-west position on the earth. Longitude increases as you move away from the prime meridian, or 0°, in Greenwich, England. Because the lines of longitude converge at the poles, a degree of longitude represents a varying distance on the ground, depending on the latitude. Place the ruler so that it spans the lines of longitude the point to be measured or plotted falls between. The ruler will need to be on a diagonal to fit. To measure the longitude of a point on the map, slide the ruler vertically, keeping the ends on the





lines of longitude marked on the map, until the edge of the ruler touches the point to be measured. You may need to extend the lines of longitude above or below the map to properly position the ruler. On the picture to the left, the ruler indicates the X is at the 3.5' mark, for a resulting longitude of 122° 3.5' W. To plot a longitude coordinate, make a small tic on the map to indicate the line of longitude. The point of interest is located where the plotted lines of latitude and longitude cross.

A Quick Guide to Using UTM Coordinates



Standing at the road junction marked with the star on the topographic map pictured above, a GPS unit set to display position in UTM coordinates, would report a location of:

10 S 0559741
4282182

The **10 S** represents the zone you are in. The zone is necessary to make the coordinates unique over the entire globe.

The top set of numbers, **0559741**, represent a measurement of East-West position, within the zone, in meters. It's called an easting.

The bottom set of numbers, **4282182**, represent a measurement of North-South position, within the zone, in meters. It's called a northing.

The map has Universal Transverse Mercator (UTM) grid lines spaced every kilometer or 1000 meters. The vertical grid lines determine East-West position and the horizontal grid lines determine North-South position.

Look along the bottom edge of the map at the labels for the vertical grid lines.

559 and 560000 mE.

The label, 560000 mE., reads "five hundred and sixty thousand meters East." The label, 559, is an abbreviation for, 559000 mE. The two grid lines are 1000 meters apart. The horizontal grid lines are labeled in a similar manner.

Getting to Know the Metric System

If the metric system gives you heartburn, here are a few tips to help you out.

The Truth (to within 3 or 4 significant digits)		What you can remember (You'll be about 10% too short.)	
1 meter	= 3.280 feet = 1.094 yards	1 meter	~= 3 feet ~= 1 yard
100 m	= 109 yards	100 m	~= 100 yards ~= length of a football field
1000 m	= 1 kilometer = 1 km = 0.621 miles ~= 5/8 mile	1000 m	~= 1/2 mile

Shorthand for UTM Coordinates

Most land navigation activities focus on a very small portion of the globe at any one time. Typically the area of interest to an outdoorsman is less than 20 miles on a side. This focus on a small area allows us to abbreviate UTM coordinates.

The zone information and the digits representing 1,000,000m, and 100,000m are dropped. The 1m, 10m and 100m digits are used only to the extent of accuracy desired.

A GPS unit might read

10 S 0559741
4282182

Using a notation similar to the one found on a USGS topographic map, this would be written as:

Zone 10 S 559741 mE. 4282182 mN.

An abbreviated format for the same coordinates would look like:

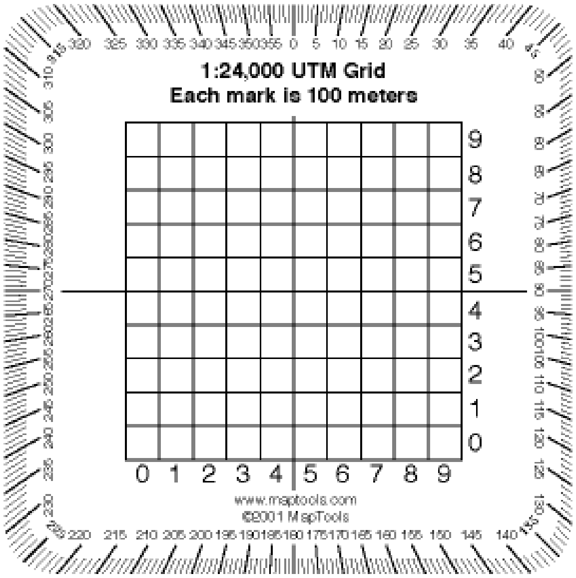
59 82	Describes a 1000m by 1000m square.
597 821	Describes a 100m by 100m square.
5974 8218	Describes a 10m by 10m square.
59741 82182	Describes a 1m by 1m square.

The 100m abbreviated format, **597 821**, and the 10m abbreviated format, **5974 8218**, are the most commonly used.

Notice that the easting is reported first, followed by the northing. Remember the phrase "read right up" to help you remember to read the easting from left to right, followed by the northing from the bottom up.

Also notice that when you abbreviate coordinates you should not do any rounding. **0559651** becomes **596** not **597**. This ensures that your position is still within the reported square. As accuracy decreases, the square gets bigger.

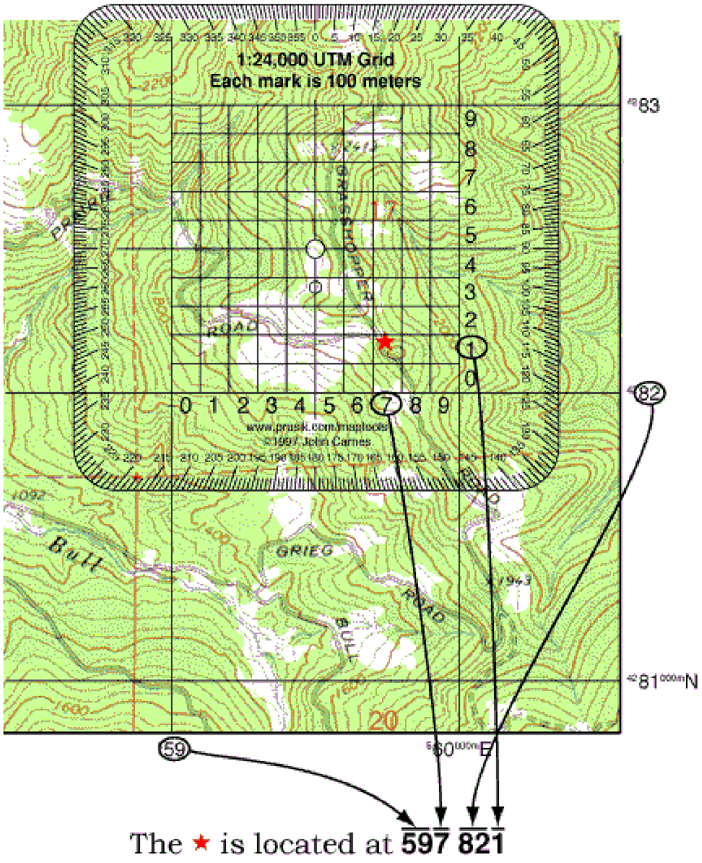
Using a UTM grid overlay tool



If you want to find your location with more precision than is available from the grid lines on the map, you will need a tool that is marked in finer divisions. One such tool is a grid overlay. The grid overlay is placed on the map with its edge aligned with the grid lines. Then the position of the mark can be determined using the tool's additional precision. Additional precision is available by either by "eyeballing" or by using a UTM Corner Ruler with finer markings. For many land navigation situations 100m precision is quite adequate. It also fits well with the 100m accuracy of civilian GPS units.

The example shown here locates the ★ to a precision of 100m. The 10,000m and 1,000m digits of the coordinate are taken from the map. Thus the coordinates **59 82** locate the 1,000 meter square containing the star. The grid overlay is placed over the grid and the 100m digit is determined. Remember to read the Easting followed by the Northing.

In 100m abbreviated format the coordinates of the ★ are **597 821**.



Why Use UTM Coordinates

The UTM coordinate system offers the following benefits:

A square grid

UTM Provides a constant distance relationship anywhere on the map. In angular coordinate systems like latitude and longitude, the distance covered by a degree of longitude differs as you move towards the poles and only equals the distance covered by a degree of latitude at the equator. Since land navigation is done in a very small part of the world at any one time using large scale maps. The UTM system allows the coordinate numbering system to be tied directly to a distance measuring system.

No negative numbers or East-West designators

Grid values increase from left to right and bottom to top

This is just like the X Y Cartesian coordinate system you learned high school math class. Simple Cartesian coordinate mathematics can be used. No spherical trigonometry is required!

Coordinates are decimal based

Ones, tens, hundreds and so on. No more minutes and seconds to convert.

Coordinates are measured in metric units

All UTM coordinates are measured in meters. Most of the world has already adopted the metric system. Now you won't need to remember how many feet are in a mile. And what's that in yards?

More details about the UTM coordinate system

The Universal Transverse Mercator projection and grid system was adopted by the U.S. Army in 1947 for designating rectangular coordinates on large scale military maps. UTM is currently used by the United States and NATO armed forces. With the advent of inexpensive GPS receivers, many other map users are adopting the UTM grid system for coordinates that are simpler to use than latitude and longitude.

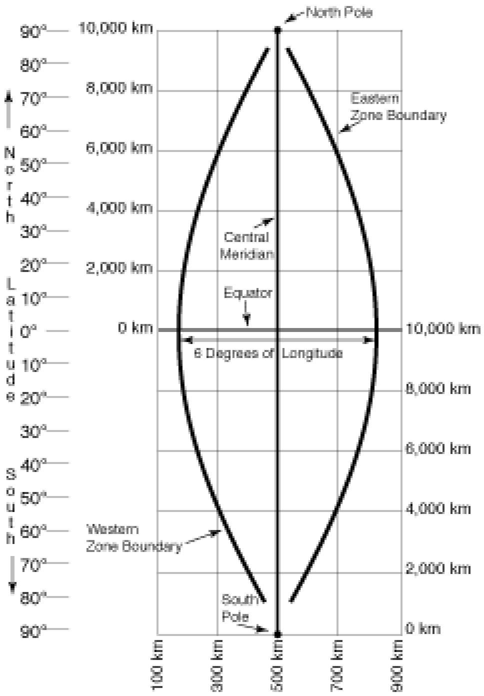
The UTM system divides the earth into 60 zones each 6 degrees of longitude wide. These zones define the reference point for UTM grid coordinates within the zone. UTM zones extend from a latitude of 80° S to 84° N. In the polar regions the Universal Polar Stereographic (UPS) grid system is used.

UTM zones are numbered 1 through 60, starting at the international date line, longitude 180°, and proceeding east. Zone 1 extends from 180° W to 174° W and is centered on 177° W.

Each zone is divided into horizontal bands spanning 8 degrees of latitude. These bands are lettered, south to north, beginning at 80° S with the letter C and ending with the letter X at 84° N. The letters I and O are skipped to avoid confusion with the numbers one and zero. The band lettered X spans 12° of latitude.

A square grid is superimposed on each zone. It's aligned so that vertical grid lines are parallel to the center of the zone, called the central meridian.

UTM grid coordinates are expressed as a distance in meters to the east, referred to as the "easting", and a distance in meters to the north, referred to as the "northing".



Eastings

UTM easting coordinates are referenced to the center line of the zone known as the central meridian. The central meridian is assigned an easting value of 500,000 meters East. Since this 500,000m value is arbitrarily assigned, eastings are sometimes referred to as "false eastings"

An easting of zero will never occur, since a 6° wide zone is never more than 674,000 meters wide.

Minimum and maximum easting values are:

160,000 mE and 834,000 mE at the equator

465,000 mE and 515,000 mE at 84° N

Northings

UTM northing coordinates are measured relative to the equator. For locations north of the equator the equator is assigned the northing value of 0 meters North. To avoid negative numbers, locations south of the equator are made with the equator assigned a value of 10,000,000 meters North.

Some UTM northing values are valid both north and south of the equator. In order to avoid confusion the full coordinate needs to specify if the location is north or south of the equator. Usually this is done by including the letter for the latitude band.

If this is your first exposure to the UTM coordinate system you may find the layout of zones to be confusing. In most land navigation situations the area of interest is much smaller than a zone. The notion of a zone falls away and we are left with a simple rectangular coordinate system to use with our large scale maps.

Frequently, in land navigation, the zone information and the digits representing 1,000,000m, and 100,000m are dropped. The 1m, 10m and 100m digits are used only to the extent of accuracy desired. Note that it's the smaller digits that are dropped in the notation used by the USGS on the edges of their maps. For example 4282000 mN. becomes 82.

Because pilots and sailors navigate over much greater distances they still favor the latitude longitude coordinate system.

UTM Coordinates on USGS Topographic Maps

All USGS topographic maps printed in the last 30 years or so include UTM grid tick marks, in blue, on the margin of the map. For a short time period after 1978 the USGS was printing a fine lined UTM grid on their topographic maps. They have since discontinued this practice.

Since most USGS 1:24,000 scale topographic maps do not have grid lines printed on them, you will need to draw them in by hand.

Start by finding a flat surface to work on. Use a straightedge that is long enough to draw a line across your map. Two to three feet long is a good length.

Line the straightedge up between two corresponding UTM tick marks along the neat line (the edge) of the map. Remember that UTM grid lines are not exactly North-South or East-West anywhere but in the center of a zone. This means that the grid lines will not be parallel to the neat lines.

Using a mechanical pencil or a fine pointed pen draw a line between the two tic marks. If you are using a pen, select one that has waterproof ink. In addition, you will want to use a straightedge that has the edges lifted off of the paper. This will help keep from leaving an ink smudge when you move the straightedge. High quality straightedges will often have a thin piece of cork stuck to the bottom. This helps keep the rule from slipping, and keeps the edge off of the paper. A piece of masking tape centered on the bottom of your straightedge will work also. Occasionally wipe of the edge of the straightedge to avoid any ink build up.

Griding maps is tedious work. We all wish the USGS would go back to printing the grid on the map. But even then, we would still need to grid our existing maps. As you can see this is not the kind of thing you want to do on the hood of a truck or using a flat rock. Grid your maps before you need them in the field! In a pinch you can fold the map over on itself and use the edge of the paper as a straightedge.

Photocopies of Maps

Frequently, you may use a photocopy of a small portion of a map rather than the entire map. This cuts down the wear and tear on the original map and allows several copies to be distributed among a group.

Make sure you transfer at least the large-print portion of the UTM grid markings onto the photocopy. It's also helpful to provide scale and contour information. Preprinted scale bars on Post-It note paper are available or just make a copy of the scale bars and "cut and paste"

Avoid the temptation to change the scale of the map with the zoom on the copier. If you use maps often you will have a good sense of distance. Alter the scale and it will be harder to judge distances. Plus your overlay tools will no longer be useful.

If you do change the scale using the copier, be sure and copy the scale bars at the same time, so they will correctly reflect the new scale.

If you are marking roads, trails or boundaries on the photocopied map, avoid obscuring the underlying feature with the mark. Pencil lines will usually allow the feature to show through as will highlighter pens.

There is nothing more frustrating than needing to know what is under a big black mark on your copy of the map.

Map Datums

A datum describes the model that was used to match the location of features on the ground to coordinates and locations on the map. Maps all start with some form of survey. Early maps and surveys were carried out by teams of surveyors on the ground using transits and distance measuring "chains". Surveyors start with a handful of locations in "known" positions and use them to locate other features. These methods did not span continents well. Frequently they also did not cross political borders either. The "known points" and their positions are the information that the map datum is based. As space based surveying came into use, a standardized datum based on the center of the earth was developed.

Every map that shows a geographic coordinate system such as UTM or Latitude and Longitude with any precision will also list the datum used on the map.

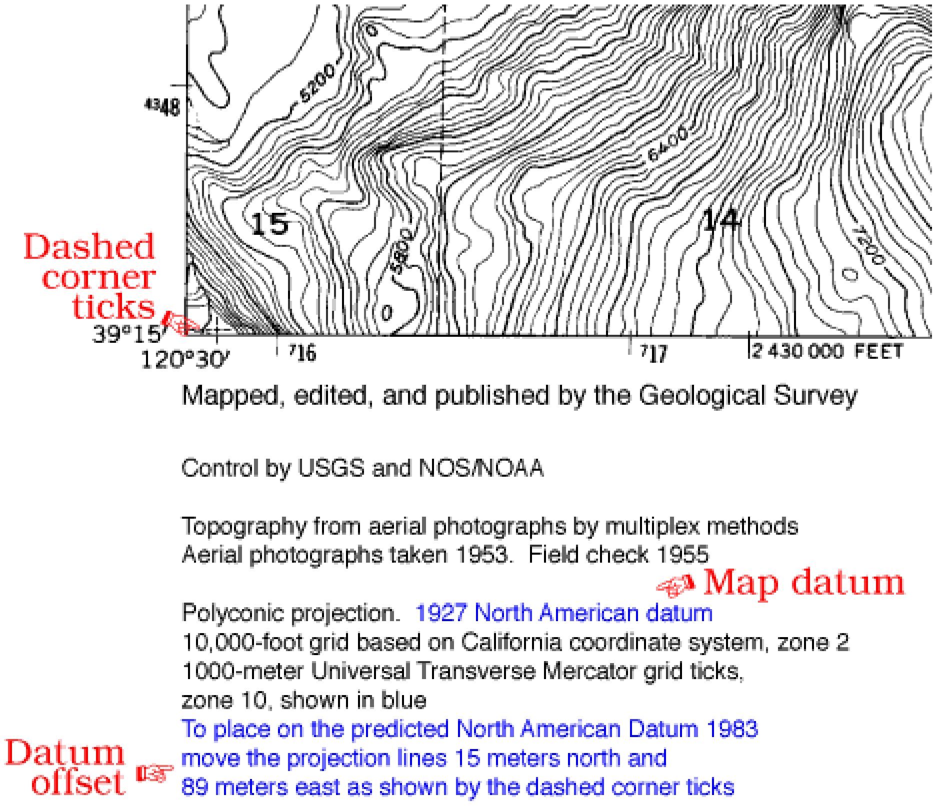
The Global Positioning System uses an earth centered datum called the World Geodetic System 1984 or WGS 84. WGS 84 was adopted as a world standard from a datum called the North American Datum of 1983 or NAD 83. For all practical purposes there is no difference between WGS 84 and NAD 83.

Most USGS topographic maps are based on an earlier datum called the North American Datum of 1927 or NAD 27. (Some GPS units subdivide this datum into several datums spread over the continent. In the Continental United States use NAD27 CONUS.)

In the Continental United States the difference between WGS 84 and NAD 27 can be as much as 200 meters.

You should always set your GPS unit's datum to match the datum of the map you are using.

On a USGS topographic map the datum information is in the fine print at the bottom left of the map. The datum will always be NAD 27. There may be information on how many meters to shift a position to convert it to NAD 83. Think of this as the error that will be introduced if you leave your GPS unit set to WGS 84. A dashed cross in the SW and NE corners of the map gives a visual indication of the difference between the two datums.



Mapped, edited, and published by the Geological Survey

Control by USGS and NOS/NOAA

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1953. Field check 1955

Polyconic projection. 1927 North American datum
10,000-foot grid based on California coordinate system, zone 2
1000-meter Universal Transverse Mercator grid ticks,
zone 10, shown in blue
To place on the predicted North American Datum 1983
move the projection lines 15 meters north and
89 meters east as shown by the dashed corner ticks

If you have somehow set your GPS to use the Borneo Datum of 1818, it's hard to say how far off you position may be. Let's just sat that this "datum thing" is something you need to pay attention to.

If you are coordinating with aircraft, they will likely have their datum set to WGS 84, as most aviation charts now use WGS 84. Should you worry about the difference in datums? Typically a pilot will not have any difficulty locating you on the ground if you can get them within several hundred meters of your location. If you are engaged in a mission that requires more precision, then your datums should match.

Global Positioning System (GPS)

Trying to figure out where you are and where you're going is probably one of man's oldest pastimes.

Navigation and positioning are crucial to so many activities and yet the process has always been quite cumbersome.

Over the years all kinds of technologies have tried to simplify the task but every one has had some disadvantage.

Finally, the U.S. Department of Defense decided that the military had to have a super precise form of worldwide positioning. And fortunately they had the kind of money ($12 billion!) it took to build something really good.

The result is the Global Positioning System, a system that's changed navigation forever.

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations.

GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. In fact, with advanced forms of GPS you can make measurements to better than a centimeter!

In a sense it's like giving every square meter on the planet a unique address.

GPS receivers have been miniaturized to just a few integrated circuits and so are becoming very economical. And that makes the technology accessible to virtually everyone.

These days GPS is finding its way into cars, boats, planes, construction equipment, movie making gear, farm machinery, even laptop computers.

Soon GPS will become almost as basic as the telephone.

Advanced Forms of GPS

The quest for greater and greater accuracy has spawned an assortment of variations on basic GPS technology. One technique, called **"Differential GPS,"** involves the use of two ground-based receivers. One monitors variations in the GPS signal and communicates those variations to the other receiver. The second receiver can then correct its calculations for better accuracy.

Another technique called **"Carrier-phase GPS"** takes advantage of the GPS signal's carrier signal to improve accuracy. The carrier frequency is much higher than the GPS signal which means it can be used for more precise timing measurements.

The aviation industry is developing a type of GPS called **"Augmented GPS"** which involves the use of a geostationary satellite as a relay station for the transmission of differential corrections and GPS satellite status information.

These corrections are necessary if GPS is to be used for instrument landings. The geostationary satellite would provide corrections across an entire continent.

Here's how GPS works in five logical steps:

1. The basis of GPS is "triangulation" from satellites.
2. To "triangulate," a GPS receiver measures distance using the travel time of radio signals.
3. To measure travel time, GPS needs very accurate timing which it achieves with some tricks.
4. Along with distance, you need to know exactly where the satellites are in space. High orbits and careful monitoring are the secret.
5. Finally you must correct for any delays the signal experiences as it travels through the atmosphere.

Improbable as it may seem, the whole idea behind GPS is to use satellites in space as reference points for locations here on earth.

By accurately measuring our distance from three satellites we can "triangulate" our position anywhere on earth.

The Big Idea Geometrically:

Suppose we measure our distance from a satellite and find it to be 11,000 miles.

Knowing that we're 11,000 miles from a particular satellite narrows down all the possible locations we could be in the whole universe to the surface of a sphere that is centered on this satellite and has a radius of 11,000 miles.

Next, say we measure our distance to a second satellite and find out that it's 12,000 miles away.

That tells us that we're not only on the first sphere but we're also on a sphere that's 12,000 miles from the second satellite. Or in other words, we're somewhere on the circle where these two spheres intersect.

If we then make a measurement from a third satellite and find that we're 13,000 miles from that one, that narrows our position down even further, to the two points where the 13,000 mile sphere cuts through the circle that's the intersection of the first two spheres.

So by ranging from three satellites we can narrow our position to just two points in space.

To decide which one is our true location we could make a fourth measurement. But usually one of the two points is a ridiculous answer (either too far from Earth or moving at an impossible velocity) and can be rejected without a measurement.

A fourth measurement does come in very handy for another reason however, but we'll tell you about that later.

Next we'll see how the system measures distances to satellites.

In Review: **Triangulating**

- Position is calculated from distance measurements (ranges) to satellites.
- Mathematically we need four satellite ranges to determine exact position.
- Three ranges are enough if we reject ridiculous answers or use other tricks.

- Another range is required for technical reasons to be discussed later.

We saw in the last section that a position is calculated from distance measurements to at least three satellites.

But how can you measure the distance to something that's floating around in space? We do it by timing how long it takes for a signal sent from the satellite to arrive at our receiver.

The Big Idea Mathematically

In a sense, the whole thing boils down to those "velocity times travel time" math problems we did in high school. Remember the old: "If a car goes 60 miles per hour for two hours, how far does it travel?"

Velocity (60 mph) x Time (2 hours) = Distance (120 miles)

In the case of GPS we're measuring a radio signal so the velocity is going to be the speed of light or roughly 186,000 miles per second.

The problem is measuring the travel time.

The timing problem is tricky. First, the times are going to be awfully short. If a satellite were right overhead the travel time would be something like 0.06 seconds. So we're going to need some really precise clocks. We'll talk about those soon.

But assuming we have precise clocks, how do we measure travel time? To explain it let's use a goofy analogy:

Suppose there was a way to get both the satellite and the receiver to start playing "The Star Spangled Banner" at precisely 12 noon. If sound could reach us from space (which, of course, is ridiculous) then standing at the receiver we'd hear two versions of the Star Spangled Banner, one from our receiver and one from the satellite.

These two versions would be out of sync. The version coming from the satellite would be a little delayed because it had to travel more than 11,000 miles.

If we wanted to see just how delayed the satellite's version was, we could start delaying the receiver's version until they fell into perfect sync.

The amount we have to shift back the receiver's version is equal to the travel time of the satellite's version. So we just multiply that time times the speed of light and BINGO! we've got our distance to the satellite.

That's basically how GPS works.

Only instead of the Star Spangled Banner the satellites and receivers use something called a "Pseudo Random Code" - which is probably easier to sing than the Star Spangled Banner.

A Random Code?

The Pseudo Random Code (PRC, shown above) is a fundamental part of GPS. Physically it's just a very complicated digital code, or in other words, a complicated sequence of "on" and "off" pulses:

The signal is so complicated that it almost looks like random electrical noise. Hence the name "Pseudo-Random."

There are several good reasons for that complexity: First, the complex pattern helps make sure that the receiver doesn't accidentally sync up to some other signal. The patterns are so complex that it's highly unlikely that a stray signal will have exactly the same shape.

Since each satellite has its own unique Pseudo-Random Code this complexity also guarantees that the receiver won't accidentally pick up another satellite's signal. So all the satellites can use the same frequency without jamming each other. And it makes it more difficult for a hostile force to jam the system. In fact the Pseudo Random Code gives the DoD a way to control access to the system.

But there's another reason for the complexity of the Pseudo Random Code, a reason that's crucial to making GPS economical. The codes make it possible to use "information theory" to "amplify" the GPS signal. And that's why GPS receivers don't need big satellite dishes to receive the GPS signals.

We glossed over one point in our goofy Star-Spangled Banner analogy. It assumes that we can guarantee that both the satellite and the receiver start generating their codes at exactly the same time. But *how* do we make sure everybody is perfectly synced?

In Review: **Measuring Distance**

1. Distance to a satellite is determined by measuring how long a radio signal takes to reach us from that satellite.

2. To make the measurement we assume that both the satellite and our receiver are generating the same pseudo-random codes at exactly the same time.

3. By comparing how late the satellite's pseudo-random code appears compared to our receiver's code, we determine how long it took to reach us.

4. Multiply that travel time by the speed of light and you've got distance.

If measuring the travel time of a radio signal is the key to GPS, then our stop watches had better be good, because if their timing is off by just a thousandth of a second, at the speed of light, that translates into almost 200 miles of error!

On the satellite side, timing is almost perfect because they have incredibly precise atomic clocks on board.

But what about our receivers here on the ground?

Remember that both the satellite and the receiver need to be able to precisely synchronize their pseudo-random codes to make the system work.

If our receivers needed atomic clocks (which cost upwards of $50K to $100K) GPS would be a lame duck technology. Nobody could afford it.

Luckily the designers of GPS came up with a brilliant little trick that lets us get by with much less accurate clocks in our receivers. This trick is one of the key elements of GPS and as an added side benefit it means that every GPS receiver is essentially an atomic-accuracy clock.

The secret to perfect timing is to make an *extra* satellite measurement.

That's right, if three perfect measurements can locate a point in 3-dimensional space, then four *imperfect* measurements can do the same thing.

Extra Measurement Cures Timing Offset

If our receiver's clocks were perfect, then all our satellite ranges would intersect at a single point (which is our position). But with imperfect clocks, a fourth measurement, done as a cross-check, will NOT intersect with the first three.

So the receiver's computer says "Uh-oh! there is a discrepancy in my measurements. I must not be perfectly synced with universal time."

Since any offset from universal time will affect all of our measurements, the receiver looks for a single correction factor that it can subtract from all its timing measurements that would cause them all to intersect at a single point.

That correction brings the receiver's clock back into sync with universal time, and bingo! - you've got atomic accuracy time right in the palm of your hand.

Once it has that correction it applies to all the rest of its measurements and now we've got precise positioning.

One consequence of this principle is that any decent GPS receiver will need to have at least four channels so that it can make the four measurements simultaneously.

With the pseudo-random code as a rock solid timing sync pulse, and this extra measurement trick to get us perfectly synced to universal time, we have got everything we need to measure our distance to a satellite in space.

But for the triangulation to work we not only need to know distance, we also need to know exactly where the satellites are.

In Review: **Getting Perfect Timing**

1. Accurate timing is the key to measuring distance to satellites.
2. Satellites are accurate because they have atomic clocks on board.
3. Receiver clocks don't have to be too accurate because an extra satellite range measurement can remove errors.

In this tutorial we've been assuming that we know where the GPS satellites are so we can use them as reference points.

But how do we know *exactly* where they are? After all they're floating around 11,000 miles up in space.

A high satellite gathers no moss

That 11,000 mile altitude is actually a benefit in this case, because something that high is well clear of the atmosphere. And that means it will orbit according to very simple mathematics.

The Air Force has injected each GPS satellite into a very precise orbit, according to the GPS master plan.

On the ground all GPS receivers have an almanac programmed into their computers that tells them where in the sky each satellite is, moment by moment.

The basic orbits are quite exact but just to make things perfect the GPS satellites are constantly monitored by the Department of Defense.

They use very precise radar to check each satellite's exact altitude, position and speed.

The errors they're checking for are called "ephemeris errors" because they affect the satellite's orbit or "ephemeris." These errors are caused by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites.

The errors are usually very slight but if you want great accuracy they must be taken into account.

Getting the message out

Once the DoD has measured a satellite's exact position, they relay that information back up to the satellite itself. The satellite then includes this new corrected position information in the timing signals it's broadcasting.

So a GPS signal is more than just pseudo-random code for timing purposes. It also contains a navigation message with ephemeris information as well.

With perfect timing and the satellite's exact position you'd think we'd be ready to make perfect position calculations. But there's trouble afoot.

In Review: **Satellite Positions**

- To use the satellites as references for range measurements we need to know exactly where they are.
- GPS satellites are so high up their orbits are very predictable.
- Minor variations in their orbits are measured by the Department of Defense.
- The error information is sent to the satellites, to be transmitted along with the timing signals.

Up to now we've been treating the calculations that go into GPS very abstractly, as if the whole thing were happening in a vacuum. But in the real world there are lots of things that can happen to a GPS signal that will make its life less than mathematically perfect.

To get the most out of the system, a good GPS receiver needs to take a wide variety of possible errors into account. Here's what they've got to deal with.

First, one of the basic assumptions we've been using throughout this tutorial is not exactly true. We've been saying that you calculate distance to a satellite by multiplying a signal's travel time by the speed of light. But the speed of light is only constant in a vacuum.

As a GPS signal passes through the charged particles of the ionosphere and then through the water vapor in the troposphere it gets slowed down a bit, and this creates the same kind of error as bad clocks.

There are a couple of ways to minimize this kind of error. For one thing we can predict what a typical delay might be on a typical day. This is called modeling and it helps but, of course, atmospheric conditions are rarely exactly typical.

Another way to get a handle on these atmosphere-induced errors is to compare the relative speeds of two different signals. This "dual frequency" measurement is very sophisticated and is only possible with advanced receivers.

Trouble for the GPS signal doesn't end when it gets down to the ground. The signal may bounce off various local obstructions before it gets to our receiver.

This is called multipath error and is similar to the ghosting you might see on a TV. Good receivers use sophisticated signal rejection techniques to minimize this problem.

Problems at the satellite

Even though the satellites are very sophisticated, they do account for some tiny errors in the system.

The atomic clocks they use are very, very precise but they're not perfect. Minute discrepancies can occur, and these translate into travel time measurement errors.

And even though the satellites positions are constantly monitored, they can't be watched every second. So slight position or "ephemeris" errors can sneak in between monitoring times.

Basic geometry itself can magnify these other errors with a principle called "Geometric Dilution of Precision" or GDOP.

It sounds complicated but the principle is quite simple.

There are usually more satellites available than a receiver needs to fix a position, so the receiver picks a few and ignores the rest.

If it picks satellites that are close together in the sky, the intersecting circles that define a position will cross at very shallow angles. That increases the gray area or error margin around a position.

If it picks satellites that are widely separated the circles intersect at almost right angles and that minimizes the error region.

Good receivers determine which satellites will give the lowest GDOP.

In Review: **Correcting Errors**

1. The earth's ionosphere and atmosphere cause delays in the GPS signal that translate into position errors.

2. Some errors can be factored out using mathematics and modeling.

3. The configuration of the satellites in the sky can magnify other errors.

4. Differential GPS can eliminate almost all error.

Basic GPS is the most accurate radio-based navigation system ever developed. And for many applications it's plenty accurate. But it's human nature to want MORE!

So some crafty engineers came up with "Differential GPS," a way to correct the various inaccuracies in the GPS system, pushing its accuracy even farther.

Differential GPS or "DGPS" can yield measurements good to a couple of meters in moving applications and even better in stationary situations.

That improved accuracy has a profound effect on the importance of GPS as a resource. With it, GPS becomes more than just a system for navigating boats and planes around the world. It becomes a universal measurement system capable of positioning things on a very precise scale.

Differential GPS involves the cooperation of two receivers, one that's stationary and another that's roving around making position measurements.

The stationary receiver is the key. It ties all the satellite measurements into a solid local reference.

Here's how it works:

The problem

Remember that GPS receivers use timing signals from at least four satellites to establish a position. Each of those timing signals is going to have some error or delay depending on what sort of perils have befallen it on its trip down to us.

Since each of the timing signals that go into a position calculation has some error, that calculation is going to be a compounding of those errors.

An extenuating circumstance

Luckily the sheer scale of the GPS system comes to our rescue. The satellites are so far out in space that the little distances we travel here on earth are insignificant.

So if two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have traveled through virtually the same slice of atmosphere, and so will have virtually the same errors.

That's the idea behind differential GPS: We have one receiver measure the timing errors and then provide correction information to the other receivers that are roving around. That way virtually all errors can be eliminated from the system, even the pesky Selective Availability error that the DoD puts in on purpose.

The idea is simple. Put the reference receiver on a point that's been very accurately surveyed and keep it there.

This reference station receives the same GPS signals as the roving receiver but instead of working like a normal GPS receiver it attacks the equations *backwards*.

Instead of using timing signals to calculate its position, it uses its known position to calculate timing. It figures out what the travel time of the GPS signals should be, and compares it with what they actually are. The difference is an "error correction" factor.

The receiver then transmits this error information to the roving receiver so it can use it to correct its measurements.

Since the reference receiver has no way of knowing which of the many available satellites a roving receiver might be using to calculate its position, the reference receiver quickly runs through all the visible satellites and computes each of their errors.

Then it encodes this information into a standard format and transmits it to the roving receivers.

It's as if the reference receiver is saying: "OK everybody, right now the signal from satellite #1 is ten nanoseconds delayed, satellite #2 is three nanoseconds delayed, satellite #3 is sixteen nanoseconds delayed..." and so on.

The roving receivers get the complete list of errors and apply the corrections for the particular satellites they're using.

In the early days of GPS, reference stations were established by private companies who had big projects demanding high accuracy - groups like surveyors or oil drilling operations. And that is still a very common approach. You buy a reference receiver and set up a communication link with your roving receivers.

But now there are enough public agencies transmitting corrections that you might be able to get them for free!

The United States Coast Guard and other international agencies are establishing reference stations all over the place, especially around popular harbors and waterways.

These stations often transmit on the radio beacons that are already in place for radio direction finding (usually in the 300kHz range).

Anyone in the area can receive these corrections and radically improve the accuracy of their GPS measurements. Most ships already have radios capable of tuning the direction finding beacons, so adding DGPS will be quite easy.

Many new GPS receivers are being designed to accept corrections, and some are even equipped with built-in radio receivers.

Post Processing DGPS

Not all DGPS applications are created equal. Some don't need the radio link because they don't need precise positioning immediately.

It's one thing if you're trying to position a drill bit over a particular spot on the ocean floor from a pitching boat, but quite another if you just want to record the track of a new road for inclusion on a map.

For applications like the later, the roving receiver just needs to record all of its measured positions and the exact time it made each measurement.

Then later, this data can be merged with corrections recorded at a reference receiver for a final clean-up of the data. So you don't need the radio link that you have to have in real-time systems.

If you don't have a reference receiver there may be alternative source for corrections in your area. Some academic institutions are experimenting with the Internet as a way of distributing corrections.

There's another permutation of DGPS, called "inverted DGPS," that can save money in certain tracking applications.

Let's say you've got a fleet of buses and you'd like to pinpoint them on street maps with very high accuracy (maybe so you can see which side of an intersection they're parked on or whatever).

Anyway, you'd like this accuracy but you don't want to buy expensive "differential-ready" receivers for every bus.

With an inverted DGPS system the buses would be equipped with standard GPS receivers and a transmitter and would transmit their standard GPS positions back to the tracking office. Then at the tracking office the corrections would be applied to the received positions.

It requires a computer to do the calculations, a transmitter to transmit the data but it gives you a fleet of very accurate positions for the cost of one reference station, a computer and a lot of standard GPS receivers. Such a deal!

If you want to know where DGPS might be headed, take a look at your hand, because soon DGPS may be able to resolve positions that are no farther apart than the width of your little finger.

Imagine the possibilities. Automatic construction equipment could translate CAD drawings into finished roads without any manual measurements. Self-guided cars could take you across town while you quietly read in the back seat.

To understand how this kind of GPS is being developed you need to understand a little about GPS signals. If two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have traveled through virtually the same slice of atmosphere, and so will have virtually the same line.

The words "Code-Phase" and "Carrier-Phase" may sound like electronic mumbo-jumbo but, in fact, they just refer to the particular signal that we use for timing measurements. Using the GPS carrier frequency can significantly improve the accuracy of GPS.

The concept is simple but to understand it let's review a few basic principles of GPS.

Remember that a GPS receiver determines the travel time of a signal from a satellite by comparing the "pseudo random code" it's generating, with an identical code in the signal from the satellite.

The receiver slides its code later and later in time until it syncs up with the satellite's code. The amount it has to slide the code is equal to the signal's travel time.

The problem is that the bits (or cycles) of the pseudo random code are so wide that even if you do get synced up there's still plenty of slop.

The problem with code-phase GPS is it's comparing pseudo random codes that have a cycle width of almost a microsecond. And at the speed of light a microsecond is almost 300 meters of error!

Code-phase GPS isn't really that bad because receiver designers have come up with ways to make sure that the signals are almost perfectly in phase. Good machines get with in a percent or two. But that's still at least 3-6 meters of error.

Survey receivers beat the system by starting with the pseudo random code and then move on to measurements based on the carrier frequency for that code. This carrier frequency is much higher so its pulses are much closer together and therefore more accurate.

If you're rusty on the subject of carrier frequencies consider your car radio. When you tune to 94.7 on the dial you're locking on to a carrier frequency that's 94.7 MHz.

Obviously we can't hear sounds at 94 million cycles a second. The music we hear is a modulation (or change) in this carrier frequency. So when you hear someone sing an "A" note on the radio you're actually hearing the 94.7 MHz carrier frequency being varied at a 440 cycle rate.

GPS works in the same way. The pseudo random code has a bit rate of about 1 MHz but its carrier frequency has a cycle rate of over a GHz (which is 1000 times faster!)

At the speed of light the 1.57 GHz GPS signal has a wavelength of roughly twenty centimeters, so the carrier signal can act as a much more accurate reference than the pseudo random code by itself. And if we can get to within one percent of perfect phase like we do with code-phase receivers we'd have 3 or 4 millimeter accuracy!

In essence this method is counting the exact number of carrier cycles between the satellite and the receiver.

The problem is that the carrier frequency is hard to count because it's so uniform. Every cycle looks like every other. The pseudo random code on the other hand is intentionally complex to make it easier to know which cycle you're looking at.

So the trick with "carrier-phase GPS" is to use code-phase techniques to get close. If the code measurement can be made accurate to say, a meter, then we only have a few wavelengths of carrier to consider as we try to determine which cycle really marks the edge of our timing pulse.

Resolving this "carrier phase ambiguity" for just a few cycles is a much more tractable problem and as the computers inside the receivers get smarter and smarter it's becoming possible to make this kind of measurement without all the ritual that surveyors go through.

You've got to hand it to the FAA. They think big!

They realized the great benefits GPS could bring to aviation, but they wanted *more*. They wanted the accuracy of Differential GPS and they wanted it across the whole continent. Maybe the whole world.

Their plan is called the "Wide Area Augmentation System" or "WAAS," and it's basically a continental DGPS system.

The idea grew out of some very specific requirements that basic GPS just couldn't handle by itself. It began with "system integrity." GPS is very reliable but every once in a while a GPS satellite malfunctions and gives inaccurate data.

The GPS monitoring stations detect this sort of thing and transmit a system status message that tells receivers to disregard the broken satellite until further notice. Unfortunately this process can take many minutes which could be too late for an airplane in the middle of a landing.

So the FAA got the idea that they could set up their own monitoring system that would respond much quicker. In fact, they figured they could park a geosynchronous satellite somewhere over the U.S. that would instantly alert aircraft when there was a problem.

Then they reasoned that they could transmit this information right on a GPS channel so aircraft could receive it on their GPS receivers and wouldn't need any additional radios.

But wait a second! If we've got the geosynchronous satellite already transmitting on the GPS frequency, why not use it for positioning purposes too? Adding another satellite helps with positioning accuracy and it ensures that plenty of satellites are always visible around the country.

But wait another second! Why not use that satellite to relay differential corrections too?

Oh, this is sounding good!

The FAA figured that with about 24 reference receivers scattered across the U.S. they could gather pretty good correction data for most of the country. That data would make GPS accurate enough for "Category 1" landings (i.e. very close to the runway but not zero visibility)

The ramifications of this go well beyond aviation, because the system guarantees that DGPS corrections will be raining out of the sky for everyone to use.

To complete the system the FAA wants to eventually establish "Local Area Augmentation Systems" near runways.

These would work like the WAAS but on a smaller scale. The reference receivers would be near the runways and so would be able to give much more accurate correction data to the incoming planes.

With a LAAS aircraft would be able to use GPS to make Category 3 landings (zero visibility).

GPS technology has matured into a resource that goes far beyond its original design goals. These days scientists, sportsmen, farmers, soldiers, pilots, surveyors, hikers, delivery drivers, sailors, dispatchers, lumberjacks, fire-fighters, and people from many other walks of life are using GPS in ways that make their work more productive, safer, and sometimes even easier.

"Where am I?"

The first and most obvious application of GPS is the simple determination of a "position" or location. GPS is the first positioning system to offer highly precise location data for any point on the planet, in any weather. That alone would be enough to qualify it as a major utility, but the accuracy of GPS and the creativity of its users is pushing it into some surprising realms.

Knowing the precise location of something, or someone, is especially critical when the consequences of inaccurate data are measured in human terms. For example, when a stranded motorist was lost in a South Dakota blizzard for 2 days, GPS helped rescuers find her.

GPS is also being applied in Italy to create exact location points for their nationwide geodetic network which will be used for surveying projects. Once in place it will support the first implementation of a nationally created location survey linked to the WGS-84 global grid.

Sometimes an exact reference locator is needed for extremely precise scientific work. Just getting to the world's tallest mountain was tricky, but GPS made measuring the growth of Mt. Everest easy. The data collected strengthened past work, but also revealed that as the Khumbu glacier moves toward Everest's Base Camp, the mountain itself is getting taller.

Where am I going?"

GPS helps you determine exactly where you are, but sometimes important to know how to get somewhere else. GPS was originally designed to provide navigation information for ships and planes. So it's no surprise that while this technology is appropriate for navigating on water, it's also very useful in the air and on the land.

On the Water

It's interesting that the sea, one of our oldest channels of transportation, has been revolutionized by GPS, the newest navigation technology. Trimble introduced the world's first GPS receiver for marine navigation in 1985. And as you would expect, navigating the world's oceans and waterways is more precise than ever.

Today you will find Trimble receivers on vessels the world over, from hardworking fishing boats and long-haul container ships, to elegant luxury cruise ships and recreational boaters. A New Zealand commercial fishing company uses GPS so they can return to their best fishing holes without wandering into the wrong waters in the process.

But GPS navigation doesn't end at the shore.

Flying a single-engine Piper Cub or a commercial jumbo jet requires the same precise navigation information, and GPS puts it all at the pilot's fingertips as safely as possible.

By providing more precise navigation tools and accurate landing systems, GPS not only makes flying safer, but also more efficient. With precise point-to-point navigation, GPS saves fuel and extends an aircraft's range by ensuring pilots don't stray from the most direct routes to their destinations.

GPS accuracy will also allow closer aircraft separations on more direct routes, which in turn means more planes can occupy our limited airspace. This is especially helpful when you're landing a plane in the middle of mountains. And small medical evac helicopters benefit from the extra minutes saved by the accuracy of GPS navigation.

But you don't need your head in the clouds to use GPS for navigation.

Finding your way across the land is an ancient art and science. The stars, the compass, and good memory for landmarks helped you get from here to there. Even advice from someone along the way came into play. But, landmarks change, stars shift position, and compasses are affected by magnets and weather. And if you've ever sought directions from a local, you know it can just add to the confusion. The situation has never been perfect.

Today hikers, bikers, skiers, and drivers apply GPS to the age-old challenge of finding their way. Borge Ousland used Trimble GPS to navigate the snow and ice to ski his way to the top of the world and into the record books. And two wilderness rangers employed GPS to establish a route across the Continental Divide for horse riders and packers.

If navigation is the process of getting something from one location to another, then tracking is the process of monitoring it as it moves along.

Commerce relies on fleets of vehicles to deliver goods and services either across a crowded city or through nationwide corridors. So, effective fleet management has direct bottom-line implications, such as telling a customer when a package will arrive, spacing buses for the best scheduled service, directing the nearest ambulance to an accident, or helping tankers avoid hazards.

GPS used in conjunction with communication links and computers can provide the backbone for systems tailored to applications in agriculture, mass transit, urban delivery, public safety, and vessel and vehicle tracking. So it's no surprise that police, ambulance, and fire departments are adopting systems like Trimble's GPS-based AVL (Automatic Vehicle Location) Manager to pinpoint both the location of the emergency and the location of the nearest response vehicle on a computer map. With this kind of clear visual picture of the situation, dispatchers can react immediately and confidently.

Chicago developed a GPS tracking system to monitor emergency vehicles through their streets, saving precious time responding to 911 calls. And on the commercial front, two taxi companies in Australia track their cabs for better profit and improved safety.

Where is everything else?"

It's a big world out there, and using GPS to survey and map it precisely saves time and money in this most stringent of all applications. Today, Trimble GPS makes it possible for a single surveyor to accomplish in a day what used to take weeks with an entire team. And they can do their work with a higher level of accuracy than ever before.

Trimble pioneered the technology which is now the method of choice for performing control surveys, and the effect on surveying in general has been considerable. You've seen how GPS pinpoints a position, a route, and a fleet of vehicles. Mapping is the art and science of using GPS to locate items, then create maps and models of everything in the world. And we do mean everything. Mountains, rivers, forests and other landforms. Roads, routes, and city streets. Endangered animals, precious minerals and all sorts of resources. Damage and disasters, trash and archeological treasures. GPS is mapping the world.

For example, Trimble GPS helped fire fighters respond with speed and efficiency during the 1991 Oakland/Berkeley fire to plot the extent of the blaze and to evaluate damage. In a less urgent yet equally important situation, the city of Modesto, California improved their efficiency and job performance by using GPS and mountain bikes to create a precise map of its network of water resources and utilities.

Bringing precise time to the world

"When will it all happen?"

Although GPS is well-known for navigation, tracking, and mapping, it's also used to disseminate precise time, time intervals, and frequency. Time is a powerful commodity, and exact time is more powerful still. Knowing that a group of timed events is perfectly synchronized is often very important. GPS makes the job of "synchronizing our watches" easy and reliable.

There are three fundamental ways we use time. As a universal marker, time tells us when things happened or when they will. As a way to synchronize people, events, even other types of signals, time helps keep the world on schedule. And as a way to tell how long things last, time provides and accurate, unambiguous sense of duration.

GPS satellites carry highly accurate atomic clocks. And in order for the system to work, our GPS receivers here on the ground synchronize themselves to these clocks. That means that every GPS receiver is, in essence, an atomic accuracy clock.

Astronomers, power companies, computer networks, communications systems, banks, and radio and television stations can benefit from this precise timing. One investment banking firm uses GPS to guarantee their transactions are recorded simultaneously at all offices around the world. And a major Pacific Northwest utility company makes sure their power is distributed at just the right time along their 14,797 miles of transmission lines.

Map coordinate systems and grids

USGS quad maps all contain grids of one sort or another. Perhaps the most well-known outside SAR circles is the Latitude/Longitude grid (Lat/Lon), but more often we use the Universal Transverse Mercator system (UTM) in SAR work.

The Lat/Long system

In the Lat/Long system, the features on the surface of the earth are mapped onto a sphere, and a pair of angles is used to identify the points on the earth. The **meridians of longitude** are 360 equally spaced *great circle arcs* connecting the north and south poles. The meridian which passes through Greenwich, England is arbitrarily called "0" longitude, and meridians to the east or west of this meridian are measured in degrees east or west. **Parallels of latitude** start at the equator, which is 0 degrees latitude, and are basically slices parallel to the equator; they are also measured in degrees, and the angle referred to is the one between a line connecting the center of the earth to the surface of the earth at the equator and another line connecting the center of the earth to the surface of the earth at the point in question.

The lat/long system is cumbersome to use. There are 360 degrees used for latitude (0-180 East and 0-180 West), and there are 180 degrees used for longitude (0-90 North and 0-90 South). Each degree is divided into 60 "minutes" and each minute into 60 "seconds." The biggest problem for the map user is that lines of longitude converge at the poles and also a difference of "3 minutes" between two points cannot readily be converted to a distance, since this distance depends crucially on the distance from the equator.

The UTM system

The UTM system is a rectangular coordinate system. The globe is divided up into "zones" of 6 degrees longitude with the first zone running from 180 degrees west longitude to 174 degrees west longitude. The central meridian in each zone is assigned the arbitrary "Easting" coordinate of 500 kilometers, and all points within the zone are assigned coordinates based on their distance from the equator ("Northing") and from the hypothetical 0 point of Easting coordinate; so at the equator and at the central meridian the coordinate is (500.0,0). Since zones are less than 1000 kilometers wide there is no point which is actually given the coordinate 0,0, and all UTM coordinates are positive. Zones are also divided into sections designated by a letter.

Different ways of reporting UTM coordinates

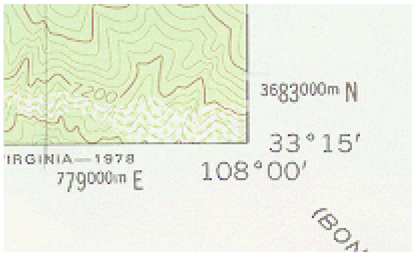
Most GPS units report UTMs in meters rather than kilometers, and it is common to see on your GPS display something like this:

13S 0360639
    3885020

This is to be read as a location in UTM zone 13, section S, with easting coordinate of 360369 meters and a northing coordinate of 3885020 meters; that means that the given position is 139631 meters west of the central meridian (which has coordinate 500000) of zone 13, and 3885020 meters north of the equator. In kilometers this would be 360.369 easting and 3885.020 northing.

Even though only the digits down to 100 meters are significant, when reading UTM coordinates from a GPS display to base camp, rattle off every digit that is displayed, regardless of precision. This is to ensure that no errors are introduced into the coordinates by teams who interpret their own coordinates and round them off. Leave issues of precision to base camp, and instead concern yourself with getting information to them without introducing error into it yourself. This [easting followed by northing] is the preferred method for reporting UTMs to basecamp, even though some other organizations, notably the military, use a different, abbreviated method, the Military Grid Reference System (MGRS), described below.

A quick glance at a map shows that *[even the xxx.x kilometer format]* is sending more information than is typically necessary. In general, on a 7.5 minute quad map only the kilometer and tens of kilometer digits change, and so one *could* abbreviate the reported figure even further by leaving off the hundred and thousand kilometer digits. This is a technique routinely used in the military, and in this (MGRS) reporting system one would report the location above as "606850" --- the first three digits being the ten kilometer, one kilometer and one hundred meter digits of easting, and the second three digits being the same figures for the northing coordinate. Figuring out what digits to use is fairly easy when you look at a topo map: the UTM coordinates are printed along the edge of the map like this:



The UTM coordinates shown are 779.0km easting and 3683.0km northing. As you can see, the leading digits, which would be dropped in this format, are printed smaller than the digits you would report. Unfortunately, if you use the six digit format in reporting to base camp you might find yourself having to explain why you're only reporting one number instead of two; this format is not widely used on missions, and you're not saving any time if you use a format that requires you to explain yourself. Stick to the easting/northing format, add verbiage to make it clear what you're reporting ("easting zero-three-six-zero-six-three-niner, northing three-eight-eight-five-zero-two-zero").

One last point: when reporting UTM coordinates, one reports the easting first, then the northing. This is easy to remember when reading them off GPS units, because the format displayed is the correct format to read off to base camp for most GPS units (I have seen some low-end units do it backwards, though). To remember this when using a map, just *Read Right Up* (i.e. *Read* left to *Right* along the horizontal edge to get easting, then *Up* along a vertical edge to get northing).

Geodetic Data

The Earth is not actually spherical, and this creates a problem in mapmaking. The Lat/lon and UTM coordinates of a point on the surface of the earth are actually dependent upon the way that the Earth differs from a sphere. This is only a problem when there are multiple measurements for how the Earth is shaped, and naturally there *are* mutiple measurements.

Until very recently, all USGS maps were made with coordinates based on some measurements of the shape of the Earth made in 1866. This resulted in what was known as the North American Datum of 1927, or NAD27. But recently the USGS has updated their data, and now uses the North American Datum of 1983 (NAD83) on its maps. **It is not possible to "mix-and-match" UTM coordinates taken off of maps with different data.** An NAD27 map might show a particular pair of coordinates corresponding to a point on the earth some 200 yards away from where the same coordinates would be on a map of the same area with NAD83. This point was hammered home to us last year when we tried to work in an area which straddled two USGS quads and we used quads that had been made with different data --- and we were puzzled about why UTM coordinates read from the maps were not working out the way we expected them to. Always check your map datum when comparing coordinates obtained from two different sources (GPS/Map, Map/Map, Map/team-in-the-field-reporting-position, etc.).

The mixing-and-matching of map datum is most often a problem when using maps along with GPS receivers. Most GPS receivers use the WGS84 datum (neither NAD27 nor NAD83!) out of the box, and have to be reset through the menu system to use a different datum. BEFORE YOU LEAVE BASE CAMP, you should make sure that you are using the same datum that is used on incident base's maps! This has been a problem in recent missions, and you must absolutely be aware of it.

One last thought: while it could be considered unnecessary radio chatter, you might consider reporting your geodetic datum along with your UTM coordinates when calling in a position to base camp. This reduces the possibility that they not be aware of the difference between your datum and the one on their map; it doesn't eliminate it, of course, but it makes sure that the mistake of transcribing an NAD27 UTM coordinate onto a map with NAD83 grid lines without a conversion isn't *your* mistake.

Using a Compass

Parts of a compass

There are several different kinds of compasses, but they have many common features. The *base* of an orienteering compass is a rectangular piece of transparent plastic. On the ends and sides there are often scales of inches, miles, etc. that relate to the common scales on maps. A certain distance on the map is equivalent to an actual distance on land as determined by the scales. On the base is an arrow, called the "direction of travel" arrow or DOT. The DOT is used to depict where you are going or where you are pointing the compass.

The *bezel* is a raised circular transparent mechanism having marks on the edge representing the number of degrees. Inside its perimeter are a set of parallel lines. The middle line among these usually has some sort of arrow, pointing to the north mark on the edge. Let's call the middle arrow the "northward" arrow.

Inside the bezel is the magnetic *needle*, with one end which will point to magnetic north. It is suspended at the center and is usually balanced so it doesn't rub against the bezel. The bezel is also usually filled with a liquid to damp the motion of the needle, so that it settles quickly after some disturbance. The needle is usually colored red and white or red and black. The important point is that the red part of the needle always points toward the north pole of the local magnetic field. Note that this is **not** the same as saying that the needle always points toward the Earth's magnetic north pole. The difference is that due to perturbations in the Earth's magnetic field, it does not look like a simple dipole or bar magnet, with North at one end and South at the other. The Earth's magnetic field has curvature. We'll talk more about this when we discuss declination.

Determining the bearing to a landmark

The proper technique for holding a compass depends upon what type of compass you have. For an orienteering compass without fold-up mirror or any other sort of sighting mechanism, the best method is to place your elbows comfortably at your sides, and keep them against your sides. To obtain a bearing to a landmark, face the landmark squarely with your feet comfortably apart. Hold the compass in front of you with your elbows close to your sides, with the compass level and the direction of travel arrow pointing directly away from you, perpendicular to the plane of your shoulders. In order to get consistent readings from the compass, it is important to re-create this position faithfully. Turn your whole body to modify the direction you are pointing, rather than moving your hands or arms. Holding the compass in this manner will result in more repeatable measurements and help to decrease errors in your bearings. Now rotate the bezel of your compass until the "north" (red or luminous) part of the needle is within the orienting marks. You can now read the magnetic bearing to the landmark off of the bezel at the direction of travel arrow.

A sighting compass must be held up to your eye so that you may look through it. Some of these have a folding cover with a mirror on the inside. When used, the cover is opened to tilt above the bezel, and there is a notch on the cover for sighting. The idea is to look at your target through the sighting notch and use the mirror to see when the magnetic needle is properly in place. Make sure to hold it as level as possible so the needle doesn't drag, and that any alignment marks such as lines on the mirror or notches on the bezel are properly lined up.

To obtain the bearing to a landmark, simply sight toward the landmark and rotate the bezel until the north-pointing end of the needle lines up with the alignment marks in the bezel. Then read the bearing to the landmark off the edge of the bezel.

Sometimes it is useful to know the "back bearing" from a landmark to your current location. The easiest way to do this is to find the bearing of the landmark, then turn the compass around and read the back bearing off of the bezel at the tail end of the direction of travel arrow. The back bearing is also easily determined from your bearing by simply adding or subtracting 180 degrees. Depending on what's comfortable for you, another way to determine back bearing is to simply use the bezel. Twist the bezel until the *southward* -pointing end of the magnetic needle (usually black or white) is lined up with the *northward* arrow of the bezel. The reading which is now indicated by the arrow or tick-mark on the bezel is the back bearing.

Exercise: finding bearings to local landmarks

Once we get to the practice area you'll see that we have laid out markers pointing at prominent features nearby. Go to each one in turn and determine the bearing from the marker to the landmark.

Walking a bearing

It sounds simple, but there are some practical considerations when you decide to walk toward a landmark you have chosen. For example, how can you make sure that you stay on course? What if there are some obstacles in the way? You could walk with your compass out in front of you set to the desired direction of travel, and keep looking down at it to stay on course. A better way is to pick some distant object that you can see that is in the direction that you want to go, and walk toward it. Keep looking at the object frequently, since its appearance may change as you get closer, or you may lose sight of it if you drop into a low area. When you get to the object, repeat this exercise until you get where you want to go. If there are obstacles (streams, cliffs, rocks, etc.) in the way, you can walk around them to get to the object you picked out from your last point. Then go to the other side of the object and repeat this process.

Exercise: The Three-Point Compass Walk

This is a simple field exercise we will do to practice walking bearings. We'll find an area that's open enough to work in, but wooded enough for it to be a challenge. Mark your starting position by dropping a coin (the value of the coin should be proportional to your confidence that you can find it again). Pick a random bearing, set your compass to that bearing, and walk it for a random distance, say 100 feet. Remember that distance. Stopping after this distance, add 120 to the bearing you've been walking, then set your compass to the new bearing and walk for the same distance as before. Stop, add 120 to the bearing again, and walk the same distance once more. You should be no more than a few paces away from the spot where you dropped your coin.

Magnetic anomalies

Since compass needles are really just lightweight magnets, compass measurements can be thrown off by nearby metal objects. Be sure to keep the compass well away from things like your radio, your car, that barbed-wire fence you're standing next to, railroad tracks, the power lines nearby, etc. You also need to keep metal objects such as belt buckles, knives, and pens away from the compass.

There are other phenomena associated with terrain that can affect compass readings, too. Tailings from mines where iron or other magnetic ores were gathered can affect compass readings. There are also geological features that are magnetic, such as the Malpais volcanic deposits south of Grants and northwest of Ruidoso, New Mexico.

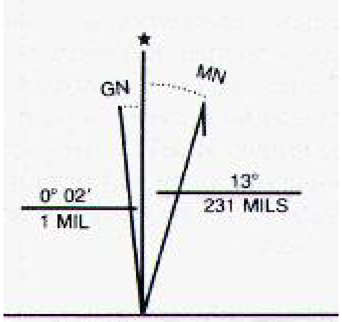
Navigation with a map and a compass

Magnetic declination

The map and compass can be used together to tell you precisely where you are and how to get where you want to be. But without keeping a few things in mind you might as well not have either.

As we mentioned earlier, the compass needle does not actually point at the northern end of the Earth's axis, that is "true north," but rather at the north pole of the local magnetic field. Most maps, however, are drawn in a projection which puts meridians of longitude parallel to the sides of the map --- that is, the vertical edges of the map point to true north. The angle between a line drawn from any point on the map to the north pole, and a line drawn from that same point to the local magnetic north is known as the *magnetic declination*, and is currently about 10.5 degrees East in our area. In other words, when your compass is reading zero degrees along your direction of travel, you're actually traveling on a true heading of 10.5 degrees true. Similarly, if you measure on your map that you have to follow a true heading of 10.5 degrees, you must know that when you use your compass to follow that path you have to set it for a heading of zero degrees!

Many people have come up with mnemonics to help remember whether to add or subtract declination to convert from magnetic to true bearings. One reliable tool that you can't forget is the declination diagram printed on the map. Here's an example of one, taken from a USGS training website (**NOT** a map of our area!):



What this diagram tells you is that true north (the line with the star) lies at the top of the page. Magnetic north (the line with the half-arrowhead) is 13 degrees to the right of true north, and the UTM grid ("GN") north is two minutes to the left of true north. So, when your compass is reading 0, it is pointing thirteen degrees to the right of true north, so 0 magnetic = 13 true. In the case of this declination ("east declination"), MAG+DEC=TRUE. If you memorize formulas better than you can read declination diagrams, remember that formula, because it's the one that's appropriate for areas with east declination such as ours.

One approach for dealing with declination is to draw magnetic north lines onto your map. To do this, set your compass to the declination --- thirteen degrees in the case above, and set it on the map with the north line of the bezel parallel to a true north line on the map (ignore the needle for this, just use the markings on the case). Now your direction of travel arrow points along magnetic north. Using the edge of your compass as a straightedge, draw a magnetic north line. It is best to draw several of these lines, across the entire map. Now you can read magnetic bearings directly off of the map by making measurements relative to your magnetic north lines instead of the true north lines, obviating the need for any formulas at all. But be mindful of one thing: magnetic declinations change over time, and the declination printed on the map might not be the declination which is actually affecting your compass today; the change is small over a year, but some maps were printed 10 years ago or more. The declination you must take into account is today's declination, because that's the one your compass sees. So if you draw in magnetic north lines, make sure you're doing so with the right declination.

Another caution which can be important in other parts of the country: the declination diagram is not always to scale, especially if it is depicting small angles. In the case of small angles the figure might be exaggerated, but the numbers printed nearby will be correct. Sometimes map users are told to extend the magnetic north line on the declination diagram to obtain magnetic north lines on the map, and most of the time that's OK, but watch out for printed statements nearby that the diagram is "for obtaining numerical values only." And remember, too, that the declination diagram might be outdated. For these two reasons it's probably better not to use the diagram directly to draw your magnetic north lines.

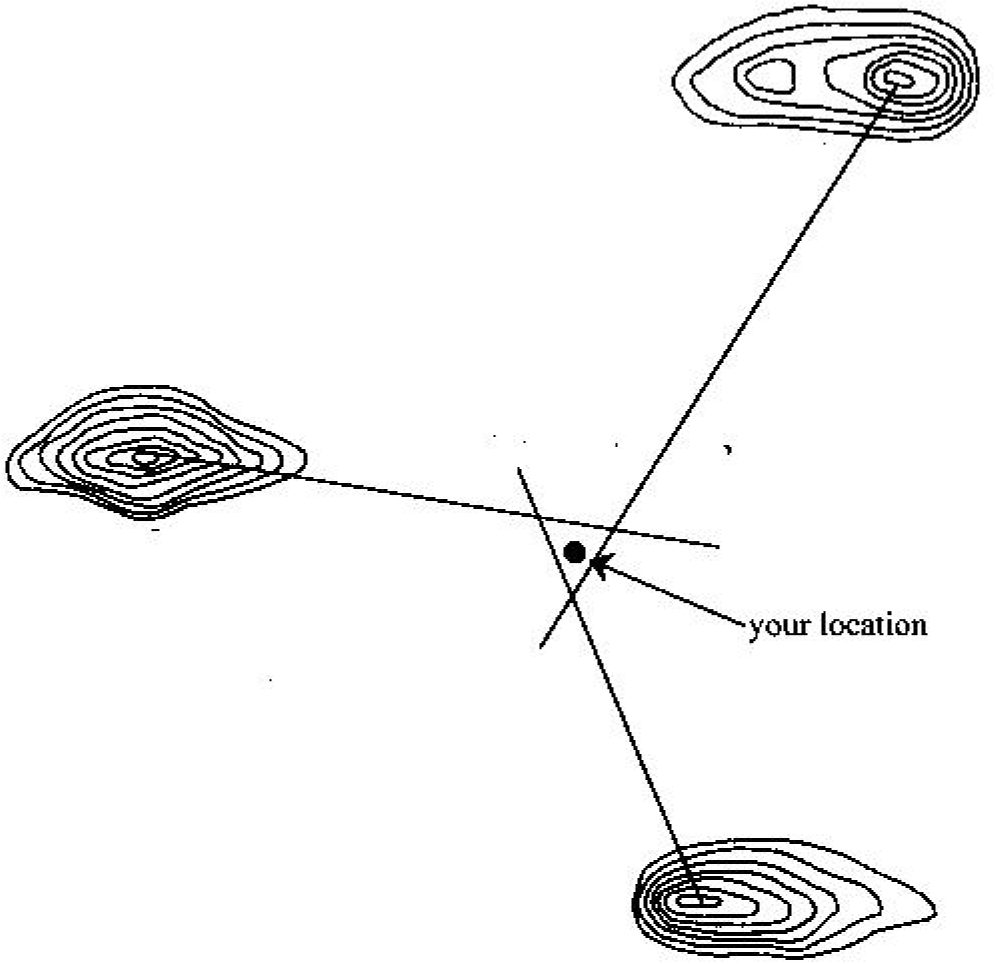
Exercise: finding true bearings

With each of the magnetic bearings you obtained in the bearing exercise above, determine the true bearing by applying declination.

Resection to locate position on the map

In order to determine what direction to go in order to get where you want to be, you must first know where you are. Sometimes this is easy, such as when you can unambiguously identify a feature on the map, and you *know* that you are standing right next to it. In other cases the map and compass can be used together to locate your current position on the map. This process is sometimes referred to as "triangulation" but is more precisely called "resection."

In order to locate yourself on the map by performing resection, the basic idea is to compare your topographic map to what you are looking at, and identify terrain features that you are sure you can both see and associate with a feature on the map. Just by looking at the map and the terrain, you should have a general idea of your location. Terrain recognition is important to pinpoint your location more accurately. Now you determine bearings to these features, and draw lines on the map corresponding to the bearing to those features. The use of at least three lines is recommended, and they should cross in a small triangle. It is ideal to choose landmarks all around you, but sometimes this is not practical, as when on one side of a mountain range, with nothing distinguishable in the other direction. Choose landmarks as far apart as possible. Your best guess at your position will be in the center of the triangle that you draw. This process is illustrated schematically below:



A few points should be made about resectioning. First and most obvious, the more points you use, the more accurate you will be able to determine your position. Using more points will also tell if you have a "flyer," i.e. one bearing that you did wrong or terrain feature you misidentified. This line will be way off where the others meet. For these reasons it is preferable to look at as many features as possible. Second, be very careful when using man-made objects. Keep in mind that maps are updated infrequently, and that man-made features usually change more frequently than the terrain features do!

Exercise: Terrain identification and resection

Now that you have true bearings to all the landmarks we pointed out for you in the two exercises above, it's time to figure out where we are. The first step is to identify each of those features on your map; this is probably the hard part, and we'll probably be spending a good bit of time on this. The next step is to draw lines from the feature on the map which make the same angle with the true north lines the bearing you determined dictates they should. Where the lines intersect is where we are. Congratulations, you've done a resection!

Estimating distance

It is easy enough to use pacing to estimate short distances in the field. However, another very useful skill is the ability to estimate longer distances in the field, and how these compare to distances on the map. This comes with practice. Mastery of this skill will help enormously in terrain recognition, since in addition to the shape of the object, some clues about how to uniquely identify the feature can be gained from estimating about how far away it is, and seeing if this is consistent with the map. The best way to practice is to carry a topographical map of the area while you are hiking. Pick out objects that you will be hiking to, and see how long it takes you to get there. Stop and look around while hiking, and see if you can pick out near and far objects on your topographical map.

Walking a bearing taken from a map

Ok, you've marked two points on your map, one representing your starting point and the other representing the place you want to be. What now?

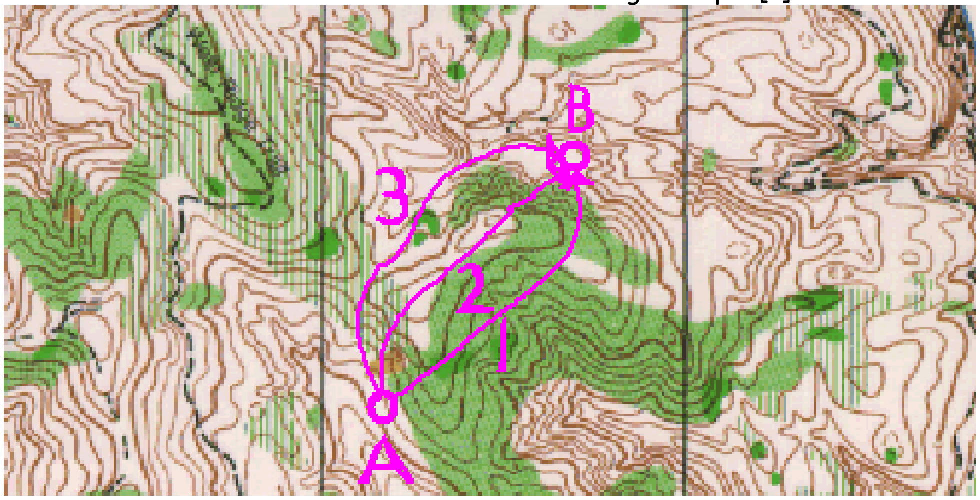
The easiest way to set yourself up to walk to your destination is to set your compass to the right bearing. Draw a straight line between starting point and destination, set your compass so that the DOT arrow points from starting point to destination. Now rotate the bezel of your compass so that the parallel lines inside are lined up with the magnetic north lines you've drawn onto your map. Your compass is now set so that if you turn yourself until the north-pointing part of the compass needle is lined up with the alignment marks on the bezel, then you will be walking the correct magnetic bearing to your destination.

Once you have set your compass to the correct bearing, you can forget the map again and just follow the bearing as we discussed above: pick out a landmark that lies along your intended direction of travel and walk towards it.

Route-finding strategies

The High Road or the Low Road?

After determining where you are and where you want to go, you must then consider how to get there. You could walk in a straight line, following a bearing until you get to your landmark. The shortest distance between two points is a straight line, but only on a perfectly flat surface or if you can fly there! Even in real terrain, the direct route is not always the fastest or the safest. Let's consider an orienteering example [1].



Sample Routes for hypothetical leg

In the picture above, assume that we want to go from point A to point B. We could go by route 1, 2, or 3. Route 1 is the straightest, but goes through heavy vegetation and you might have trouble navigating once in there. Route 2 is also fairly straight and less tree-covered, but goes over two hills that might take a lot of time and energy to climb. Route 3 is the longest, but has little vegetation and a gradual slope. You must consider tradeoffs such as distance, navigation ability, and how strong you feel in order to decide the best route for you. There is no right or wrong answer.

Locating a nearby "handrail"

Finally, it is most efficient to make maximum use of available terrain features or man-made objects to help you get from one place to another. For example, you may determine a bearing to a distant point and decide that it is easy enough to walk straight to that location. But what if you were looking for something small, like a mine entrance or a spring to use as an emergency water source? You might get lucky and walk straight to the object, but if you make a small error in sighting, or walk off of the bearing a little, you could walk right past the object you are looking for. Most orienteering experts follow terrain features that are hard to miss but take you nearby the object you are looking for. For example, a spring, even an intermittent one, will usually have a drainage flowing downhill from it. Instead of trying to walk right to the spring, you might choose to navigate conservatively a little down the drainage from the spring. The drainage will be harder to miss than a small spring, and when you get there, you can turn uphill and walk right to the spring. Spend the time to think about where you want to go, and what terrain features you might take advantage of in this way to help you get there.

BATHYMETRIC FEATURES

Area exposed at mean low tide; sounding datum line***	
Channel***	=====
Sunken rock***	+

BOUNDARIES

National	
State or territorial	
County or equivalent	
Civil township or equivalent	
Incorporated city or equivalent	
Federally administered park, reservation, or monument (external)	
Federally administered park, reservation, or monument (internal)	
State forest, park, reservation, or monument and large county park	
Forest Service administrative area*	
Forest Service ranger district*	
National Forest System land status, Forest Service lands*	
National Forest System land status, non-Forest Service lands*	
Small park (county or city)	

BUILDINGS AND RELATED FEATURES

Building	
School; house of worship	
Athletic field	
Built-up area	
Forest headquarters*	
Ranger district office*	
Guard station or work center*	
Racetrack or raceway	
Airport, paved landing strip, runway, taxiway, or apron	
Unpaved landing strip	
Well (other than water), windmill or wind generator	
Tanks	●
Covered reservoir	
Gaging station	
Located or landmark object (feature as labeled)	
Boat ramp or boat access*	
Roadside park or rest area	
Picnic area	
Campground	
Winter recreation area*	
Cemetery	Cem

COASTAL FEATURES

Foreshore flat	Mud
Coral or rock reef	Reef
Rock, bare or awash; dangerous to navigation	
Group of rocks, bare or awash	
Exposed wreck	
Depth curve; sounding	18 23
Breakwater, pier, jetty, or wharf	
Seawall	
Oil or gas well; platform	○ ■

CONTOURS

Topographic

Index	6000
Approximate or indefinite	
Intermediate	
Approximate or indefinite	
Supplementary	
Depression	
Cut	
Fill	
Continental divide	

Bathymetric

Index***	
Intermediate***	
Index primary***	
Primary***	
Supplementary***	

CONTROL DATA AND MONUMENTS

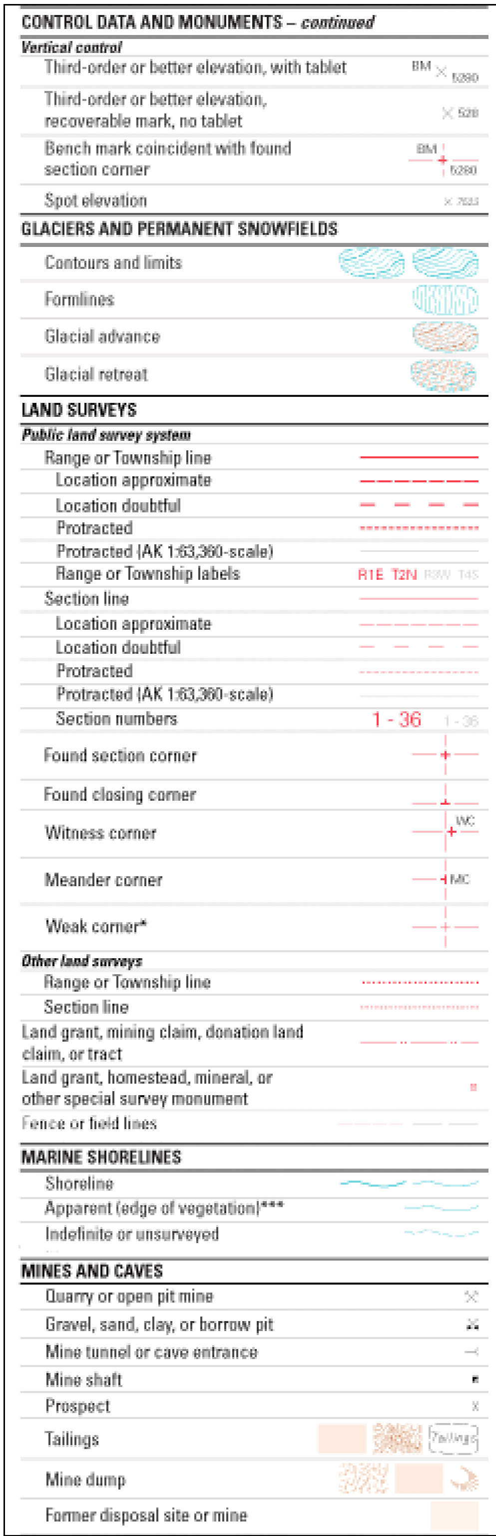
Principal point**	3-20
U.S. mineral or location monument	▲ USMM 438
River mileage marker	+ Mile 69

Boundary monument

Third-order or better elevation, with tablet	BM 9134 BM 277
Third-order or better elevation, recoverable mark, no tablet	5628
With number and elevation	67 4567

Horizontal control

Third-order or better, permanent mark	△ Neace Neace
With third-order or better elevation	BM △ 52 Pike BM393
With checked spot elevation	△ 1012
Coincident with found section corner	Cactus Cactus
Unmonumented**	+



CONTROL DATA AND MONUMENTS – *continued*

Vertical control	
Third-order or better elevation, with tablet	BM × 5280
Third-order or better elevation, recoverable mark, no tablet	× 528
Bench mark coincident with found section corner	BM 5280
Spot elevation	× 7523

GLACIERS AND PERMANENT SNOWFIELDS

Contours and limits	
Formlines	
Glacial advance	
Glacial retreat	

LAND SURVEYS

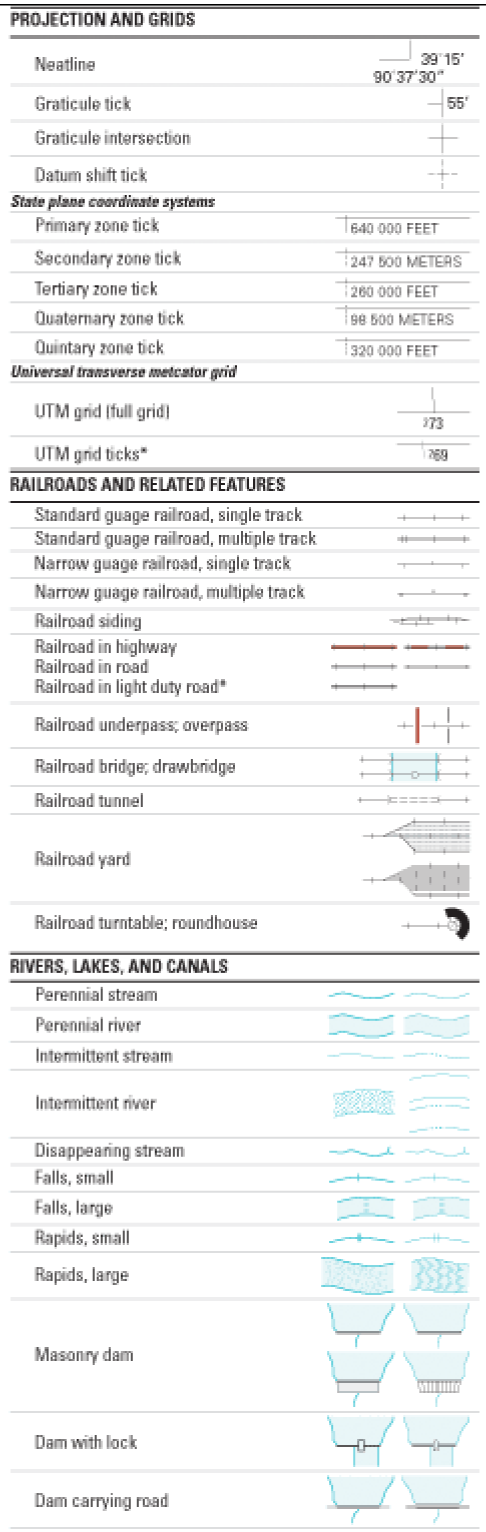
Public land survey system	
Range or Township line	
Location approximate	
Location doubtful	
Protracted	
Protracted (AK 1:63,360-scale)	
Range or Township labels	R1E T2N R3W T4S
Section line	
Location approximate	
Location doubtful	
Protracted	
Protracted (AK 1:63,360-scale)	
Section numbers	1 - 36 1 - 36
Found section corner	
Found closing corner	
Witness corner	WC
Meander corner	MC
Weak corner*	
Other land surveys	
Range or Township line	
Section line	
Land grant, mining claim, donation land claim, or tract	
Land grant, homestead, mineral, or other special survey monument	
Fence or field lines	

MARINE SHORELINES

Shoreline	
Apparent (edge of vegetation)***	
Indefinite or unsurveyed	

MINES AND CAVES

Quarry or open pit mine	⚒
Gravel, sand, clay, or borrow pit	⚒
Mine tunnel or cave entrance	≺
Mine shaft	■
Prospect	X
Tailings	Tailings
Mine dump	
Former disposal site or mine	



PROJECTION AND GRIDS

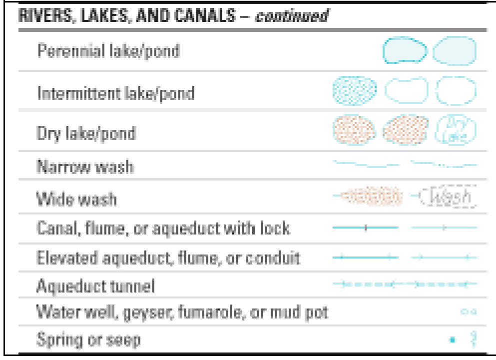
Neatline	39°15′ 90°37′30″
Graticule tick	55′
Graticule intersection	
Datum shift tick	
State plane coordinate systems	
Primary zone tick	640 000 FEET
Secondary zone tick	247 500 METERS
Tertiary zone tick	260 000 FEET
Quaternary zone tick	98 500 METERS
Quintary zone tick	320 000 FEET
Universal transverse metcator grid	
UTM grid (full grid)	273
UTM grid ticks*	269

RAILROADS AND RELATED FEATURES

Standard guage railroad, single track	
Standard guage railroad, multiple track	
Narrow guage railroad, single track	
Narrow guage railroad, multiple track	
Railroad siding	
Railroad in highway Railroad in road Railroad in light duty road*	
Railroad underpass; overpass	
Railroad bridge; drawbridge	
Railroad tunnel	
Railroad yard	
Railroad turntable; roundhouse	

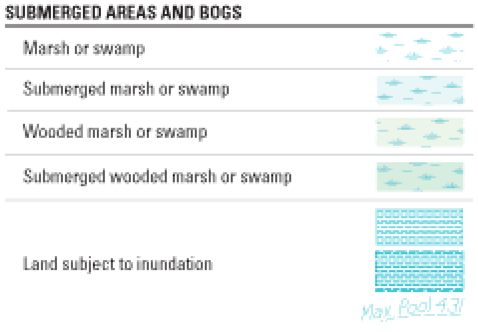
RIVERS, LAKES, AND CANALS

Perennial stream	
Perennial river	
Intermittent stream	
Intermittent river	
Disappearing stream	
Falls, small	
Falls, large	
Rapids, small	
Rapids, large	
Masonry dam	
Dam with lock	
Dam carrying road	



RIVERS, LAKES, AND CANALS – *continued*

Perennial lake/pond	
Intermittent lake/pond	
Dry lake/pond	Dry Lake
Narrow wash	
Wide wash	Wash
Canal, flume, or aqueduct with lock	
Elevated aqueduct, flume, or conduit	
Aqueduct tunnel	
Water well, geyser, fumarole, or mud pot	
Spring or seep	



SUBMERGED AREAS AND BOGS

Marsh or swamp	
Submerged marsh or swamp	
Wooded marsh or swamp	
Submerged wooded marsh or swamp	
Land subject to inundation	Max Pool 431

ROADS AND RELATED FEATURES

Please note: Roads on Provisional-edition maps are not classified as primary, secondary, or light duty. These roads are all classified as improved roads and are symbolized the same as light duty roads.

Primary highway	
Secondary highway	
Light duty road Light duty road, paved* Light duty road, gravel* Light duty road, dirt* Light duty road, unspecified*	
Unimproved road Unimproved road*	
4WD road 4WD road*	
Trail	
Highway or road with median strip	
Highway or road under construction	Under Const
Highway or road underpass; overpass	
Highway or road bridge; drawbridge	
Highway or road tunnel	
Road block, berm, or barrier*	
Gate on road*	
Trailhead*	

SURFACE FEATURES

Levee	Levee
Sand or mud	Sand
Disturbed surface	
Gravel beach or glacial moraine	Gravel
Tailings pond	Tailings Pond

TRANSMISSION LINES AND PIPELINES

Power transmission line; pole; tower	
Telephone line	Telephone
Aboveground pipeline	
Underground pipeline	Pipeline

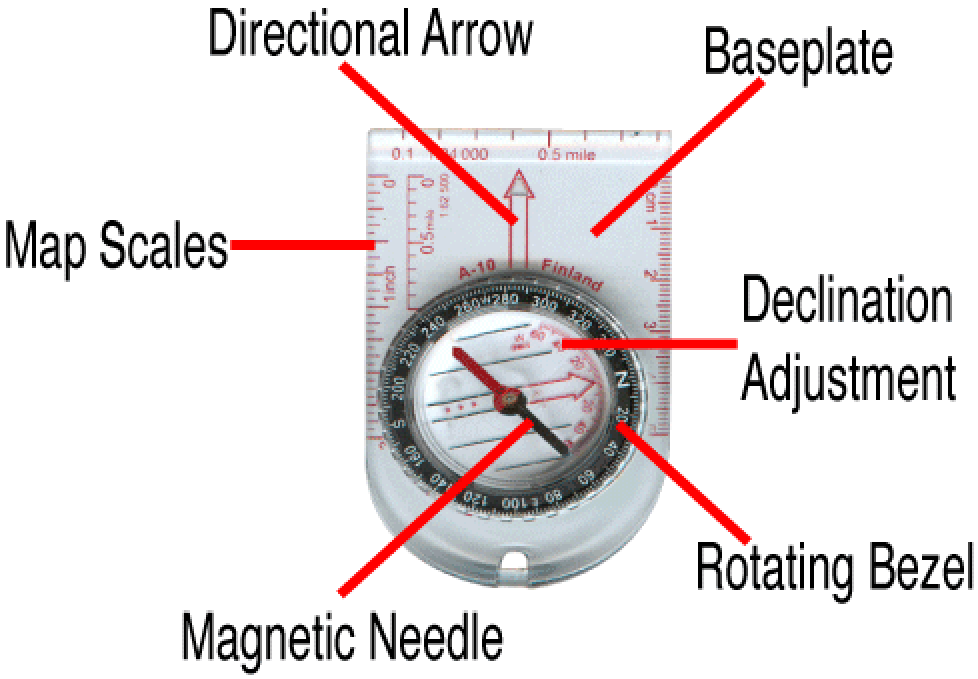
VEGETATION

Woodland	
Shrubland	
Orchard	
Vineyard	
Mangrove	Mangrove

Using a Map and Compass

In orienteering, you use the map and compass together as a unit, but the map is most important. You can navigate to a point on the earth without a compass but not without a map.

Parts of an Orienteering Compass



Base Plate -The plastic "base" that the compass mechanism or "housing" is mounted to. The base plate is often inscribed with the various scales found on maps.

Declination Adjustment - Allows you to correct for the error between Magnetic North (measured by the compass needle) and True North (as depicted on most maps).

Rotating Bezel - a rotating dial that allows you to adjust the compass to the orientation of your map. The markings are sometimes called the compass rose.

Magnetic Needle - The working part of the compass. The needle rotates with the Earth's magnetic fields. The red end of the needle always points to magnetic north.

Map Scales - Inscribed on the Base Plate. Allows easy measurement of various map scales. Usually 1:24,000 on topograhical maps.

Directional Arrow - Provides a sight line to travel after calculating a bearing from a map.

Declination

Most maps you are most likely to use are drawn with their tops aimed at true north, the north pole. However, compass needles do not point to true north. They are pulled toward magnetic north, an area in Canada more than a thousand miles away from the north pole. Arrows drawn in the bottom margin of many maps show the difference between true north and magnetic north. The difference between true north and magnetic north, measured in degrees, is called declination. If you do not compensate for declination, you will not be able to find the actual direction between two points as related to the north and south of the landscape. The simplest solution is to convert the language of the map into the language of the compass. Do this by drawing magnetic north-south lines on the map by lining up a ruler against the magnetic north arrow and extending this line with a pencil to the top of the map. Draw parallel lines to this one, a ruler's width apart. On most orienteering maps, this has already been done because they are drawn with the tops aimed at magnetic north.

You can take a bearing from a map with magnetic north-south lines drawn on by aligning the edge of the compass baseplate along the route of travel, making sure that the direction-of-travel arrow is pointing in the direction you intend to go. Rotate the bezel until the orienting arrow or north-south lines lie parallel to and in the same direction as the magnetic north-south lines on the map. Read the bearing directly opposite of the bearing index.

If the magnetic north-south lines are not drawn on the map, convert the language of the compass to that of the map. When you take a bearing from the map or apply it to the map, you must add or subtract the declination to the compass reading depending on whether the declination is easterly or westerly. Always add the number of degrees of error for west declination and subtract for east declination.

Orienting a map means aligning it with the terrain. You can do this visually, but it is easier to make errors that way. A more accurate way of aligning the map and terrain is to use a compass. First, rotate the compass bezel until N or 360 degrees is lined up with the direction-of-travel arrow. Next, set the compass down on the map, with the compass edge along one of the north-south magnetic lines and the direction-of-travel arrow pointing north. Rotate the map and the compass until the compass needle matches the direction-of-travel arrow. The map is not oriented.

A quick field method of orienting the map is to hold the compass on the map and turn the map and compass so that the compass needle parallels or lines up with the north-south magnetic lines, with the north end of the needle toward the top of the map. Check the terrain around you to ensure that it matches what you see on the map. You can do this almost constantly while on a course and even when moving.

Measuring Distance on a Map

You can measure distance on a map by using a compass scale, a ruled compass edge, or any straight edge.

Using a Compass

Depending on the type of compass, a variety of scales may be marked along the edge of the baseplate. Ideally, one scale on the compass is the same as that on your map. For example, if your map has a scale of 1:24,000 and your compass has that scale on its baseplate, measuring distance is simple. Take the edge of the compass with the proper scale on it and connect the points for which the distance is desired. Simply read the distance directly from the scale.

Identifying Landmarks

With a compass and a map, you can identify a landmark that you can see from the ground if you know where you are on the map. Take bearing to the object. Set the compass on the map with one edge of the baseplate touching your location. Point the N end of the housing toward the top of the map. Pivot the entire compass around your location until either the north-south lines in the compass housing or the orienting arrow parallels the north-south magnetic lines of the map. Extend a line from your location up into the map using the baseplate edge of the compass as a guide. Somewhere along that line is the landmark you wish to identify. Compare map, bearing, and actual terrain to located and identify the feature in question.

Questions???

Use the topographic map to answer the following questions:

What is the Index Contour to the east of the Southern Pacific railroad?

What is the Contour Interval between Index Contour 250 and Index Contour 300?

What does the symbol "x346" represent?

What is the altitude of the hill to the east of the Southern Pacific railroad?

Is the gradient sloping or steep?

What does the dashed line running through the "x346" symbol represent?

Looking at the hill to the east of the Southern Pacific railroad, where would you most likely NOT attempt to climb and why?

What does the acronym "USGS" stand for?