1. Latitude and longitude (spherical grid coordinates)
   a) Invented by ancient Greeks
   b) Equator (0° latitude) fixed by stellar observation
   c) Ptolemy (ca 100-168 CE) described how to project sphere onto a flat map. "Ptolemy's maps" made by monks in 14th and 15th centuries. Columbus would have been familiar with maps produced using Ptolemy's methods (see http://www.bl.uk/whatson/exhibitions/mapmaker.html).
   d) In 1714, the British Government offered, by Act of Parliament, £20,000 for a solution that could provide longitude to within half-a-degree (2 minutes of time). John Harrison, an English carpenter, began building clocks for use at sea (chronometers) in 1730 and was finally awarded the prize (less expenses and stipends) in 1773. See http://www.rog.nmm.ac.uk/ (search for "Harrison") and, *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time* by Dava Sobel
   e) Prime meridian (0° longitude) fixed at the Royal Observatory, Greenwich, England (http://www.rog.nmm.ac.uk/, click on Royal Observatory link)

2. Mathematical description of earth, a spheroid with grid (latitude/longitude) = DATUM
   a) North American Datum, 1927, most paper copies of current USGS topographic maps, used the Clarke sphereoid of 1866, origin at Meades Ranch, Kansas (lat 39º 12' 26.6" N, lon 98º 32' 30.5" W)
   b) NAD83 = WGS84 (for most purposes), output from most GPS receivers, datum for georeferencing many digital map products (WGS84 superceded WGS72)

3. Components
   a) Orbiting constellation of 24 satellites
      - NAVSTAR
      - Altitude approx. 12,500 mi
      - 12 hour orbital period
      - 6 orbital planes, inclined 55º to equator, 4 satellites in each plane
      - Funded and controlled by the U.S. Department of Defense
      - Broadcast on two frequencies, L1 = 1575.42 MHz and L2 = 1227.6 MHz
   b) Ground control station network
   c) GPS receivers
   d) Also Russian system called GLONASS (GLObal NAvigation Satellite System)
      - 9 orbiting (8 operational) satellites
      - http://www.rssi.ru/SFCSIC/english.html

4. A position reported by GPS should have
   a) Accuracy - minimal difference between actual location and location reported by instrument at any given time
   b) Availability - for useful navigation, position information should be available at all times
   c) Integrity - ability of a system to provide timely warnings to users or to shut itself down when it should not be used for navigation

5. Limitations
   a) Accuracy, availability, integrity (see sources error)
   b) Not a compass (compass directions can be determined when walking, driving, etc)

6. Satellites broadcast
   a) Almanac, general position info stored by receiver to help locate satellites on startup
   b) Ephemeris, satellite position data from the ground control stations used to calculate position
   c) Time signal (still using time to figure position)

7. D = RT
   a) R = speed of light
   b) T = travel time from satellite to receiver
   c) What you get is "pseudorange," the measured distance between the GPS receiver and the GPS satellite using uncorrected time comparisons (satellite transmitted time and the local receiver's reference time)
   d) 1 satellite = located on surface of sphere radius d1
   e) 2 satellites = located on circle at the intersection of two spheres radii d1 and d2
   f) 3 satellites = located at one of two points at intersection of three spheres radii d1, d2, and d3
   g) 4 satellites = BINGO
   h) 5 or more = better position

8. Expected error (12 channel parallel receiver with selective availability off)
   a) Horizontal +/- 7 to 15 meters
   b) Vertical +/- 35 meters

9. Sources of error
   a) Selective Availability is encoded error that can be built into signal to degrade accuracy. Under military control and is currently off. (see http://www.ngs.noaa.gov/FGCS/info/sans_SA/compare/ERLA.htm for comparison of positions data reported before and after selective availability from Erlanger, Kentucky)
   b) Doppler effects
   c) Atmospheric (refraction in ionosphere & stratosphere), uses model to calculate average delay
   d) Multipath signals (reflection off of nearby structures)
   e) Receiver clock errors
      - You're not carrying an atomic clock
      - Continuously reset from satellite info
   f) Orbital error (ephemeris not accurate)
   g) Number and geometry of visible satellites
   h) Interference from
      - buildings
      - terrain
      - foliage
      - weather
      - Radio frequency interference from other electronic devices (including another GPS, radios, palm devices, laptops, etc), powerlines, solar flares

10. Human error ("My GPS doesn't work!")
    a) Failure to match datum of data provided by GPS receiver with datum and projection of map being used
    b) Failure to read and understand manual
    c) Failure to keep a set of spare batteries on hand
    d) Failure to be aware of the limitations and sources of error for GPS receivers

11. Monitoring error, see the satellite status page
    a) DOP, Dilution of Precision, is a measure of the quality of the satellite geometry (number and relative positions of the satellites), 1 to 10, lower numbers are better. Not all units display this figure.
    b) EPE, Estimated Position Error (uses DOP and others to calculate), lower numbers are better

12. Minimizing error
    a) Position averaging
    b) Differential correction
        - provides cm accuracy w/ survey grade instruments and position averaging
        - requires nearby base station actively recording position data for a fixed, known, location at the same time a "rover" unit is collecting position data for a remote location; these data are post-processed to yield maximum accuracy; base station time and position records and post-processing software are usually commercial services, search for "differential gps" on the web
    c) Realtime DGPS, differential GPS radio beacons
        - Coast Guard maintaining base stations that broadcast time and position information used for differential correction (http://www.navcen.uscg.gov/dgps/Default.htm, see the coverage map)
        - Broadcast RTCM (Radio Technical Commission for Maritime Services) format information
        - Special receiver required (see http://www.edu-observatory.org/gps/gps.html for plans for building your own)
    d) WAAS, Wide Area Augmentation System, (http://gps.faa.gov/Programs/WAAS/waas.htm)
        - FAA is deploying a system for commercial aviation to correct GPS to meet accuracy, availability, and integrity requirements for critical navigation
        - Uses a network of ground reference stations to receive GPS signals. These signals are broadcast to a master station that determines corrections. Error correction information is uplinked to GEOS satellites that broadcast the data to GPS receivers on the GPS L1 frequency (1575.42MHz).
        - Not fully operational, currently available in North America only
        - Horizontal <3 meters
        - Vertical <7 meters
        - With proper receiver most DGPS-ready GPS receivers will be able to take advantage of WAAS, handheld models with WAAS capability on market now
    e) On selecting display units. Most GPS receivers can display the position in several formats. Which display units provide the best precision? In Kentucky, one minute of latitude averages 6,060 feet and one minute of longitude averages 4,850 feet. So,
        - UTM (can plot in GIS applications without conversion)
            a) Position is reported to nearest 1 meter
            b) Generally exceeds receiver accuracy limits
        - DD.ddddd (can plot in GIS applications without conversion)
            a) Position is reported to nearest 0.00001 degree
            b) Reported position is approximately +/- 0.9 to 1.1 meters
            c) Generally exceeds receiver accuracy limits
        - DD MM.mmm (usually requires conversion to decimal degrees to plot in GIS application)
            a) Position is reported to nearest 0.001 minute
            b) Reported position is approximately +/- 1.5 to 1.9 meters
            c) Generally exceeds receiver accuracy limits
        - DD MM SS.s (usually requires conversion to decimal degrees to plot in GIS application)
            a) Position is reported to nearest 0.1 second
            b) Reported position is or approximately +/- 2.5 to 3 meters
            c) Generally exceeds receiver accuracy limits

- Any display units format may be chosen and the reported position will be within the limits of accuracy of the typical hand-held receiver. Choose a format that best fits your application and the base map you are using.
- Internally, most GPS receivers maintain the position in decimal degrees to 10 to 12 decimal places, WGS 84.

f) A discussion of GPS accuracy and estimating the accuracy of your receiver is available at http://edu-observatory.org/gps/gps_accuracy.html.

g) Best practice for field measurements using handheld consumer equipment without DGPS (SA off):
- Recommend DOP<4 for most field work
- Obtain waypoint using position averaging for at least 5 minutes (if DOP is high because of skyview or satellite constellation configuration, use longer time)
- For more critical measurements: return to site multiple times over several days and obtain additional position-averaged waypoints, estimate absolute error by checking against known locations (see NGS datasheets)

13. Reference data for checking accuracy, the NGS, National Geodetic Survey
    a) Maintains a database of horizontal control points (benchmarks)
    b) Data are available on CDROM or can download from the web
    c) http://www.ngs.noaa.gov/datasheet.html
    d) Topographic quadrangle map search example
       - Scroll down, under "Retrieve NGS datasheet(s)" click USGS Quad
       - Type Lexington West them click Submit button
       - Select the KY entry in the list of quadrangles
       - Select "GPS Sites Only" to find data with skyview judged to be good for GPS
       - Submit
       - Select the data sheets you want to see, note particularly the latitude and longitude coordinates of the benchmark and its recovery information (for example, choose PID HZ2579, GPS station set by the Lexington-Fayette Urban County Government)
    e) Kentucky High Accuracy Reference Network (HARN, http://www.kytc.state.ky.us/design/survey/harn.htm)
       - Reference stations established to enable GPS surveys for Kentucky highway projects
       - Datasheets can be referenced through the HARN web site by county or through the NGS web site

14. Basic Features
    a) Waypoints - lat/lon location, label, symbol
    b) Route - a chain of waypoints to be followed in a specific order
    c) Track log - a "cookie crumb" recording of positions

15. Basic types of handheld units
    a) Track plot - shows your position, waypoints, routes, and track log.
    b) Mapping - adds a built in base map

16. Convenience features
    a) Database of waypoints for cities and other points of interest, usually has a built-in lookup facility
    b) Ability to store and display detailed area maps (highway, topo, or lake)
    c) PC interface (NMEA, National Marine Electronics Association, most common)
       - used to drive realtime navigation software
       - used to save waypoints (download) or plan routes (upload)
       - accurate speed, direction, and navigation information for automobile navigation (OnStar is a commercial system typical of this application, http://www.onstar.com/flash.html)

17. Advanced features
    a) Automatic point-to-point routing
    b) Electronic compass
    c) Barometer (altimeter)

18. Resources
    a) Don't forget orienteering (navigation using map and compass)
        - http://www.learn-orienteering.org/ has an online series of lessons
        - http://www.thecompassstore.com/howtousemapa.html simplified instructions and tips
    b) General information
        - http://gpsinformation.net/ (hardware and software reviews, extensive FAQ's, map and datum info)
        - http://www.edu-observatory.org/gps/gps.html (introduction to GPS, info on software, navigation, DGPS, build your own DGPS receiver, and others)
        - http://www.garmin.com/aboutGPS/manual.html (introductory guide to GPS)
        - http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html (GPS overview)
        - http://www.garmin.com/aboutGPS/glossary.html (glossary)
        - http://www.thalesnavigation.com/en/products/aboutgps/glossary.asp (glossary from Magellan)
        - http://tycho.usno.navy.mil/gps.html (U.S. Naval Observatory GPS page, technical information on signal characteristics, selective availability, GPS time, and others)
        - http://164.214.2.59/GandG/sathtml/ (National Imagery and Mapping Agency, NIMA, Satellite Geodesy Home Page all of the technical information you might want, ephemeris data, etc)
        - http://www.navcen.uscg.gov/gps/default.htm U.S. Coast Guard GPS navigation information pages
    c) Map server
        - http://www.topozone.com/ Search for places by name and get latitude/longitude data for creating waypoints
    d) Coordinate system conversion
        - http://crunch.tec.army.mil/software/corpscon/corpscon.html Corps of Engineers coordinate conversion utility
        - http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml National Geodetic Survey pc software resource page
    e) GPS Manufacturers
        - Garmin: http://www.garmin.com/
        - Magellan: http://www.magellangps.com/
        - Trimble: http://www.trimble.com/ (wide selection of survey-grade instruments)
        - Lowrance: http://www.lowrance.com/
        - Eagle: http://www.eaglegps.com/ (mostly gps enabled sonar/fishing units)
        - Brunton: http://www.brunton.com/ (Multi-Navigation System includes altimeter and compass)
    f) Waypoint management and other software. Remember: when downloading and installing software from the Web, you can infect your computer with a virus or other rogue software. Be sure to keep your virus protection software up to date and scan all files before executing or installing them.
        - http://www.tapr.org/~kh2z/Waypoint/ (Waypoint+ free software to exchange data between pc's and Garmin GPS units. Can make comma delimited ASCII text files for easy use with ArcView). Note that Waypoint+ doesn't support for several of the newer Garmin GPS receivers that provide elevation data like the GPS*map* 76S. Brent Hildebrant is working on a new program, Waypoint/XL. A beta-test version is available at ftp://www.tapr.org/aprssig/winstuff/aprsplus/. Waypoint/XL supports

more GPS models and provides direct export to Excel spreadsheets, ArcView shape files, and the Delorme Street Atlas software.

- http://www.oziexplorer.com/ (OziExplorer shareware for exchanging data between GPS and PC; includes support for georeferencing scanned maps; supports Garmin, Magellan, and other GPS receivers; exports to comma delimited text file)
- http://www.magellangps.com/en/products/software.asp is the link to Magellan's software page. For whatever reason, Magellan seems to have removed access to DataSave, their free utility for exchanging GPS data with a pc for Magellan receivers. Try http://www.mayabelize.ca/magellandatasave.shtml for downloading.
- http://www.easygps.com/ (Works with Garmin and Magellan. Will not export an ASCII text file; works with http://www.geocaching.com/ an outdoor adventure sport.)
- http://www.gpsu.co.uk/ GPS Utility for Garmin and Magellan (makes comma delimited text files; unregistered version limited to 50 waypoints and 500 track points; imports MapBlast, http://www.mapblast.com/, route files)

g) Palm applications (navigation and data collection)
- Delorme Solus (http://www.delorme.com, uses georeferenced bitmaps as basemaps output from Delorme web and other software applications, i.e., TopoUSA, etc.)
- Macrosoft Quo Vadis (http://www.marcosoft.com/, download street level maps from web)

h) ArcView scripts and extensions
- AVGarmin ArcView script to automatically load Waypoint+ files http://gis.esri.com/arcscripts/index.cfm?action=details&CFGRIDKEY=-962379091
- Shape to GPS ArcView script to upload shape file as a track log http://gis.esri.com/arcscripts/index.cfm?action=details&CFGRIDKEY=383915805