GPS

Global Positioning System (GPS)

- Why GPS?
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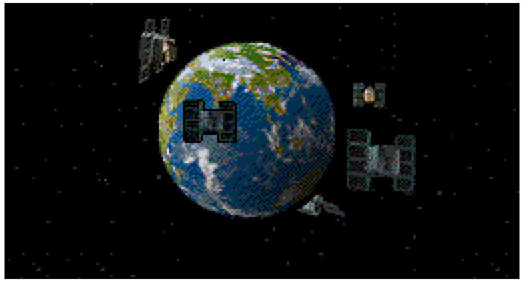
Why GPS?

- Trying to figure out where you are and where you're going is probably one of man's oldest tasks
- Navigation and positioning are crucial to so many activities and yet the process has always been quite cumbersome
- The U.S. Department of Defense decided that the military had to have a super precise form of worldwide positioning
- The result is the Global Positioning System (GPS).

What is GPS? (1)

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



  - Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs
- 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!

What is GPS? (2)

- 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

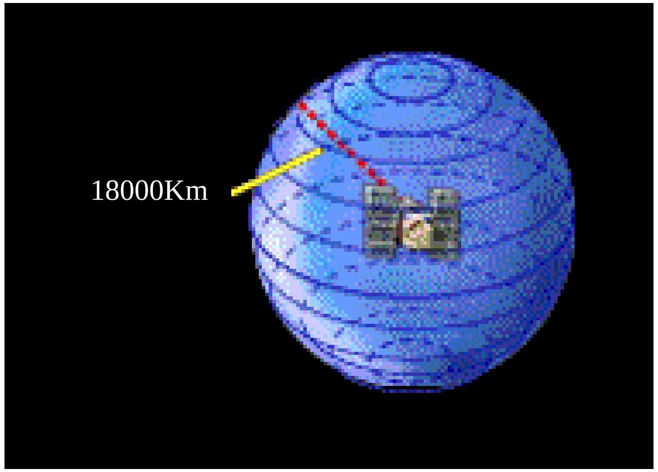
- These days GPS is finding its way into cars, boats, planes, construction equipment, movie making gear, farm machinery, laptop computers …

How GPS works?

- The basis of GPS is "triangulation" from satellites
  - triangulation is a method of determining the relative positions of objects using the geometry of triangles
- To "triangulate", a GPS receiver measures distance using the travel time of radio signals
- To measure travel time, GPS and GPS receivers need very accurate timing
- Along with distance, GPS receivers need to know exactly where the satellites are in space
- Finally, it is necessary to correct for any delays the signal experiences as it travels through the atmosphere

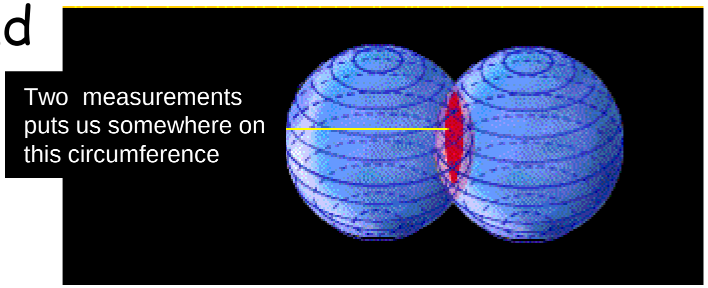
Triangulation (1)

- The whole idea behind GPS is to use satellites in space as reference points for locations here on earth
  - by very, very accurately measuring our distance from three satellites it is possible to "triangulate" our position anywhere on earth
- Step 1: Suppose we measure our distance from a satellite and find it to be 18,000Km; knowing that we are 18,000Km 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 18,000Km



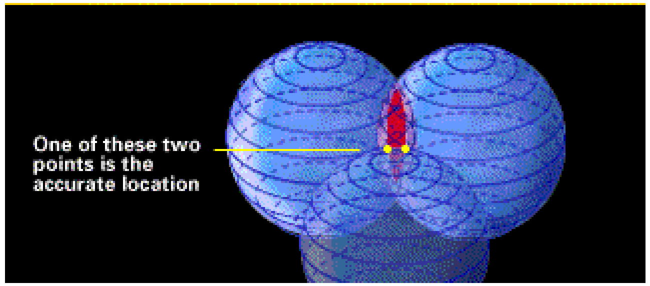
Triangulation (2)

- Step 2: Next, say we measure our distance to a second satellite and find out that it is 16,000Km away; that tells us that we are not only on the first sphere but we are also on the surface of a sphere that is centered on this satellite and has a radius of 16,000Km
- Or in other words, we are somewhere on the circumference where these two spherical surfaces intersect



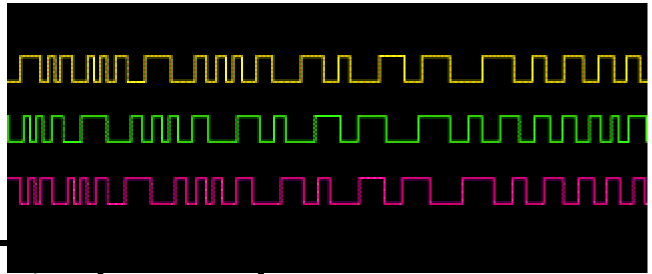
Triangulation (3)

- Step 3: If we then make a measurement from a third satellite and find that we are 17,000Km from that one, that narrows our position down even further, to the two points where the 17,000Km surface of the sphere cuts through the circumference that is the intersection of the first two spheres.



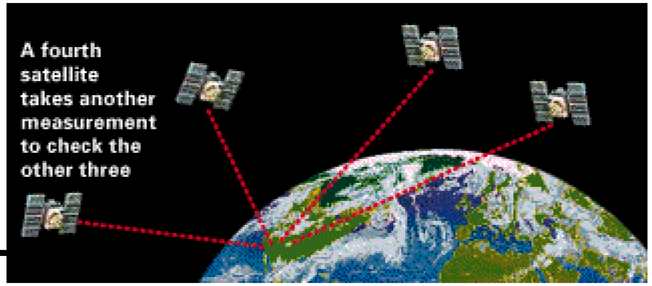
- To decide which one is our true location we could make a fourth measurement but, usually, one of the two points is a ridiculous answer (either too far from Earth or moving at an impossible velocity) and can be rejected without a measurement
- A fourth measurement does come in very handy for another reason however, but this will be explained later …

Measuring distance



- Measuring distance from a satellite is based on measuring the travel time that a radio signal coming from a satellite takes to be received by a GPS receiver
  - and on the basic formula: distance = velocity × *time*
  - the velocity of a radio signal is the speed of light (in vacuum) or roughly 299 792 458m per second
  - therefore, the problem is measuring this travel time - the times are going to be awfully short (around 0.06s)
- Assuming we have precise clocks, to measure the travel time
  - satellites and receivers generate simultaneously a "Pseudo Random Code" - a sequence of random "on" and "off" pulses
  - the amount GPS receiver have to shift back its own sequence in order to match the satellite's version is equal to the travel time

Synchronization



- On the satellite side, timing is almost perfect because they use incredibly precise atomic clocks
  - atomic clocks use the oscillations of a particular atom; this form of timing is the most stable and accurate reference man has ever developed
  - atomic clocks are too expensive to be used by GPS receivers
- If GPS receiver's clocks were perfect, then all our satellite centered spheres would intersect at a single point (which is our position)
  - with imperfect clocks, a fourth measurement, done as a cross-check, will NOT intersect with the first three
  - the GPS 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 – this is called "the synchronization process"

Satellite positions

- Each GPS satellite was injected into a very precise orbit, according to the GPS master plan
  - around 18,000Km up in space
  - these satellite orbits are arranged so that a minimum of five satellites are in view from every point on the globe
- All GPS receivers have an almanac programmed into their computers that tells them where in the sky each satellite is, moment by moment

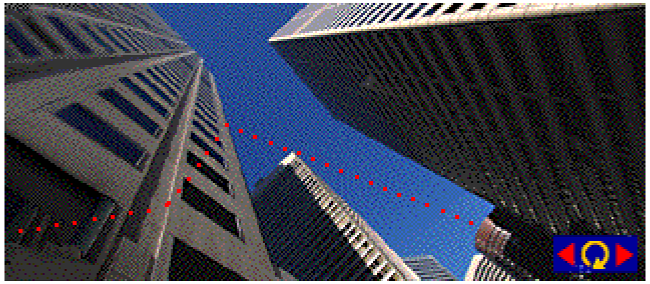
Ephemeris errors

- The satellite basic orbits are quite exact and the GPS satellites are constantly monitored
  - very precise radars are used to check each satellite's exact altitude, position and speed
  - the errors they are 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.
- Once a satellite's exact position is measured, this information is sent back up to the satellite itself
- The satellite then includes this new corrected position information in the timing signals it is broadcasting
  - so a GPS signal is more than just pseudo-random code, it also contains ephemeris information as well

Other sources of errors (1)

- The atmosphere is not 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
  - the speed of a satellite radio signal is not constant
- Mathematical models of the atmosphere can predict much of these delays
  - the satellites constantly transmit updates to the basic ionospheric model
  - a GPS receiver must factor in the angle each signal is taking as it enters the atmosphere because that angle determines the length of the trip through the perturbing medium
- Advanced GPS receivers - "dual frequency" - compare the relative speeds of two different signals to handle on these atmosphere-induced errors

Other sources of errors (2)



- Multipath errors
  - due to obstructions on earth causing signal reflection and dispersion – signal noise
- Atomic clocks are not perfect!
- Slight position or ephemeris errors can sneak in between monitoring times
- Intentional errors
  - policy called "Selective Availability" or "SA" to make sure that no hostile force can use GPS to make accurate weapons; military receivers used a decryption key to remove the SA errors; other people could get the list of SA errors, for each satellite and moment by moment, 24h later
  - turned off since May 1, 2000

Differential GPS (DGPS)

- Differential GPS involves the cooperation of two receivers, one that is stationary and another that is roving around making position measurements
  - if two receivers are fairly close to each other, say within a few hundred kilometers, the signals that reach both of them will have virtually the same errors
  - the reference receiver is kept on a point that has been very accurately surveyed
  - the reference receiver 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 for each visible satellite
  - the reference receiver transmits this error information to the roving receiver
  - both GPS receivers are linked to separate radio transmitters for differential errors correction purposes

Differential corrections

- Applications requiring very accurate coordinates but not in real-time, may use the differential corrections published by public and private organizations
  - with a delay of few hours
  - by Internet
  - avoiding DGPS
- In Portugal
  - SERVIR **Sistema de Estações de GNSS de Referência Virtuais – Instituto Geográfico do Exército (http://www.igeoe.pt/index.php?id=45)**

Bibliography

- **Trimble GPS Tutorial** (from which most of this presentation was copied) http://www.trimble.com/gps_tutorial/whygps.aspx

- **Dana, Peter H., Department of Geography, University of Texas, 1994** http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html