ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Localization

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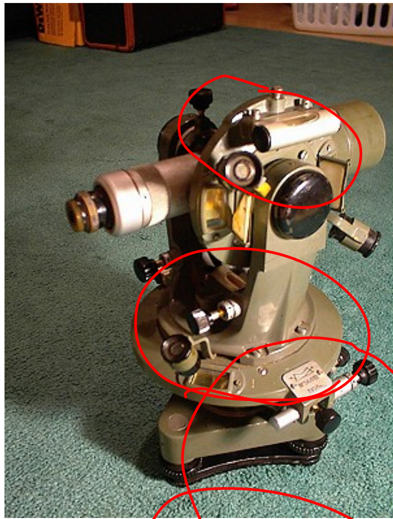
Determination of Angles

- Optical angle measurement
  - done manually, sextant, theodolite
- laser beams
  - maximum accuracy
  - Controlled by rotating mirrors
- Directional antennas
  - free joint-directional or parabolic antennas
- Smart Antennae (antenna array)
  - (still) low precision (up to 1-2 degrees)
- Gyroscope



[Wikipedia]

Determination of Ranges

- **Measuring tape**
- **Laser range finders: Measure phase shift**
- **Laser scanners: Depth imaging**
- **RF ranging: Radar**
- **Optical: ToF camera**

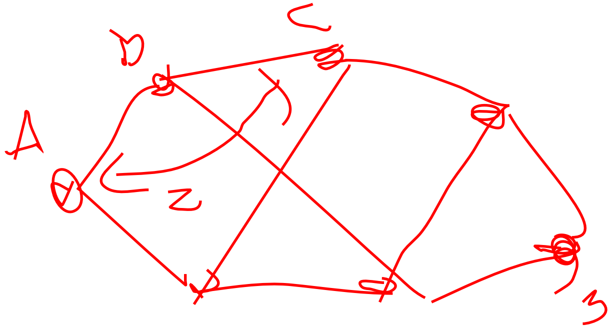
[Würth, 2010]

[Sick, 2014]

Odometry

- **Measurement of travel distance**
  - **number of footsteps**
  - **odometer of a wheeled machine,**
  - **Mobile robot: Monitor individual wheels and steering angle**
  - **optical flow of vision / camera**
- **Integrate trajectory from a starting point (“dead reckoning”)**
- **Problems:**
  - **Foot step size, wheel slip, different diameter of wheels**
  - **Error grows over time**

[AIS, University of Freiburg]



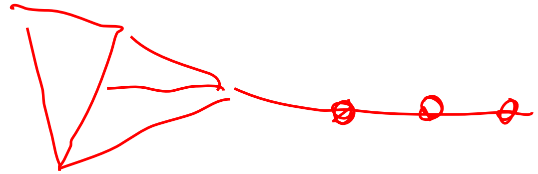
Coarse Localization Techniques

- **Hop-distance**
  - **in dense ad hoc networks or wireless sensor networks**
  - **approximate position by the number of hops to anchor points**
- **Overlapping connections**
  - **position at the intersection of the received transmission circuits**
- **Localization point in the triangle**
  - **determination of triangles of anchor points**
    - **in which the node lies**
  - **overlap provides approximate position**
- **“Fingerprinting” of signal strength measures**

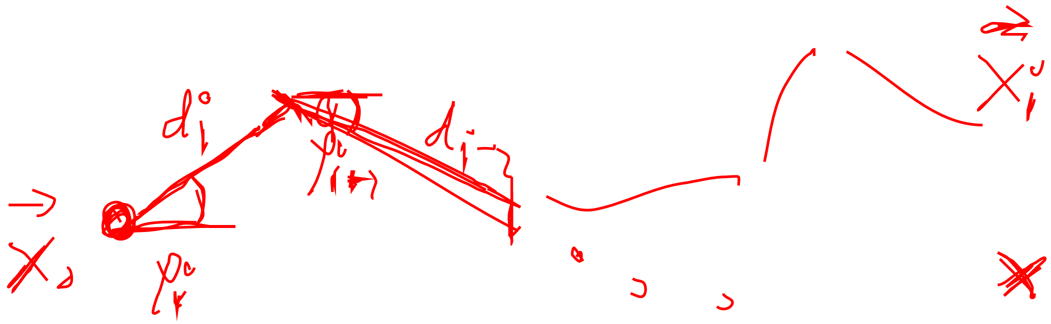
Localization methods

- **Dead Reckoning: Relative localization depending on course and traveled distance**
- **Triangulation: Calculate the intersection of angular bearings**
- **Trilateration: Calculate the intersection of three range measurements (circles)**
- **Multilateration with *absolute* ranges: Calculate the intersection of *at least four* range measurements**
  - **In the plane: circles, in space: spheres**
  - **May be over-determined equation system**
- **Multilateration with *relative* ranges: Hyperbolic multilateration**
  - **Multilateration with unknown send time**
  - **Calculate intersection of hyperbolas / hyperboloids**

Dead Reckoning



- **Relative vector navigation, vectors of orientation** ϕ_i **and distance** d_i
- **Animals: "path integration" by special regions in hippocampus of desert ants (Wehner, 2003)**
- **Dead reckoning scheme:**



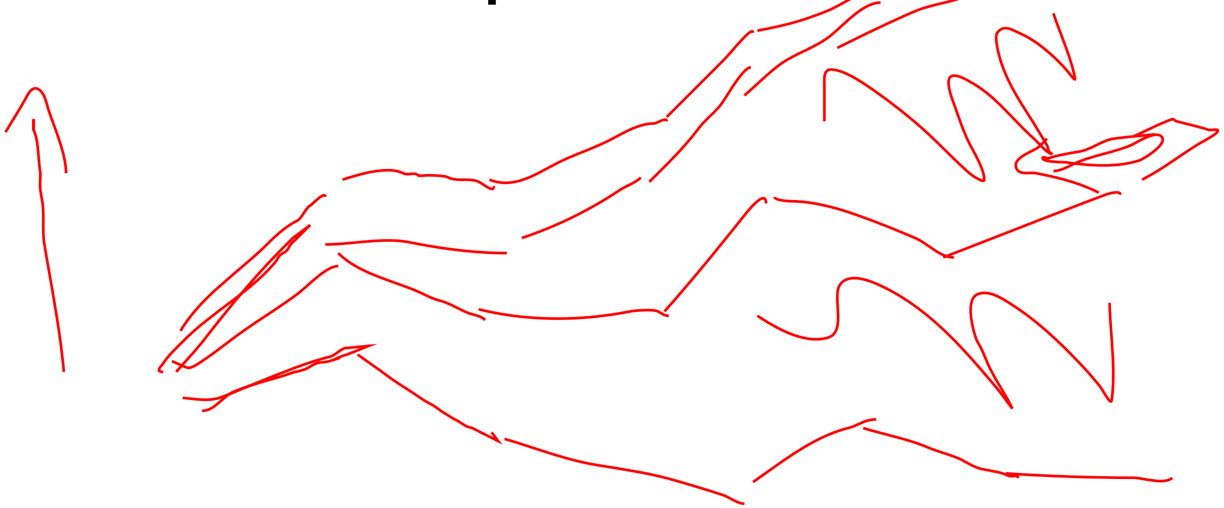
Recursive update

$x_{i+1} = x_i + d_i \cos \varphi_i$

$y_{i+1} = y_i + d_i \sin \varphi_i$

Dead Reckoning

- **Example: Navigation of ships / airplanes**
  - **if course is known (compass)**
  - **if traveled distance is known (ship log, pitot tube)**
- **Prone to drift (water current, wind, wheel slip)**
- **Errors add up over time**

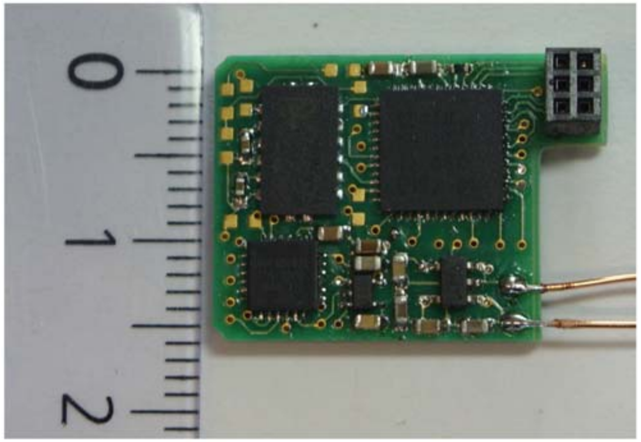


Inertial Navigation

- **Consider orientation and traveled distance as direction vector s_t at time t.**
- **What if only acceleration a_t is measured?**
  - ***Inertial navigation*, double integration**

$$\vec{s}(t) = \int\int \vec{a}(t)dt^2 + \vec{s_0} + \vec{v_0} \cdot t$$

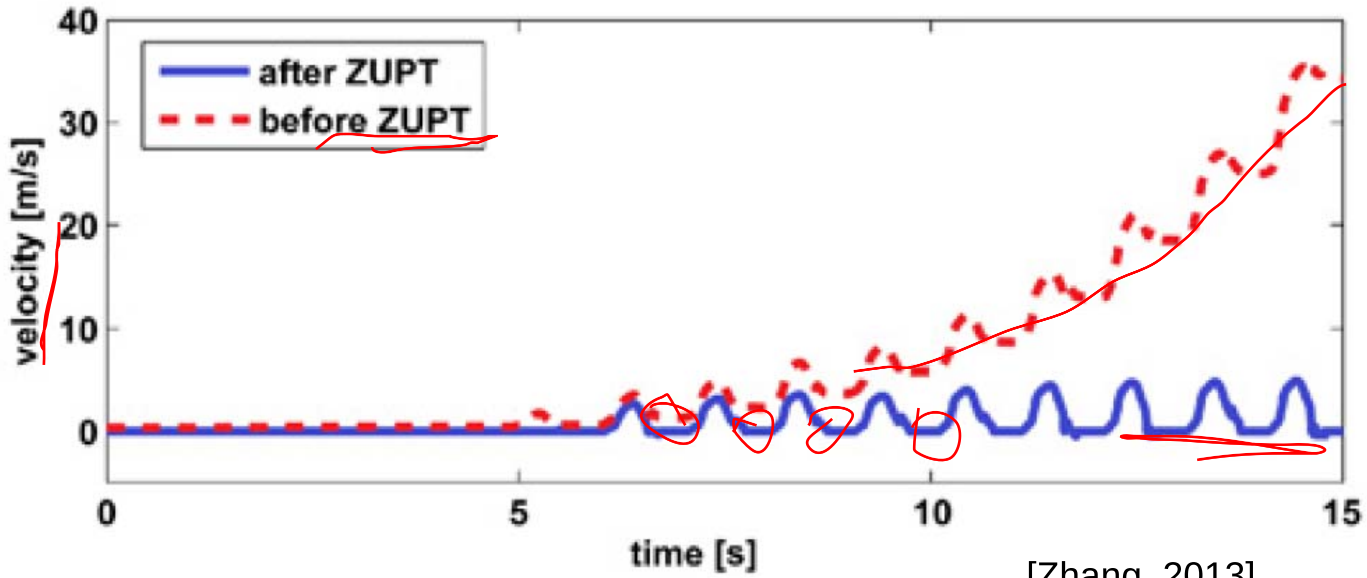
  - **Often also rotation is measured (angular velocity)**
- **Combine accelerometer, gyroscope, and compass:**
  - **Inertial Measurement Unit (IMU)**



[F. Höflinger, 2013]

Inertial Navigation

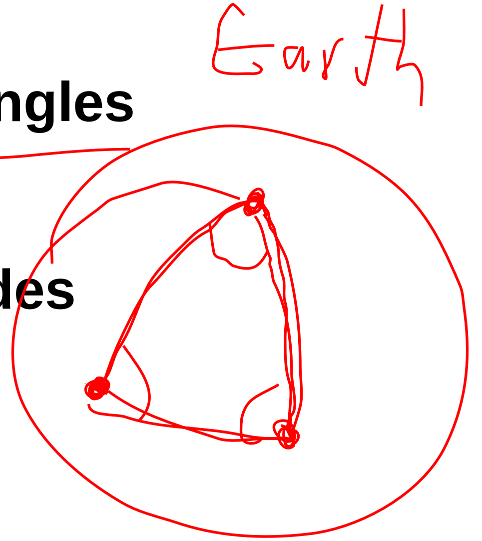
- Foot-mounted MEMS-IMU
  - Errors add up over time
- Compensation: Zero velocity update
  - Detect footstep
  - Translation velocity is zero at this moment!

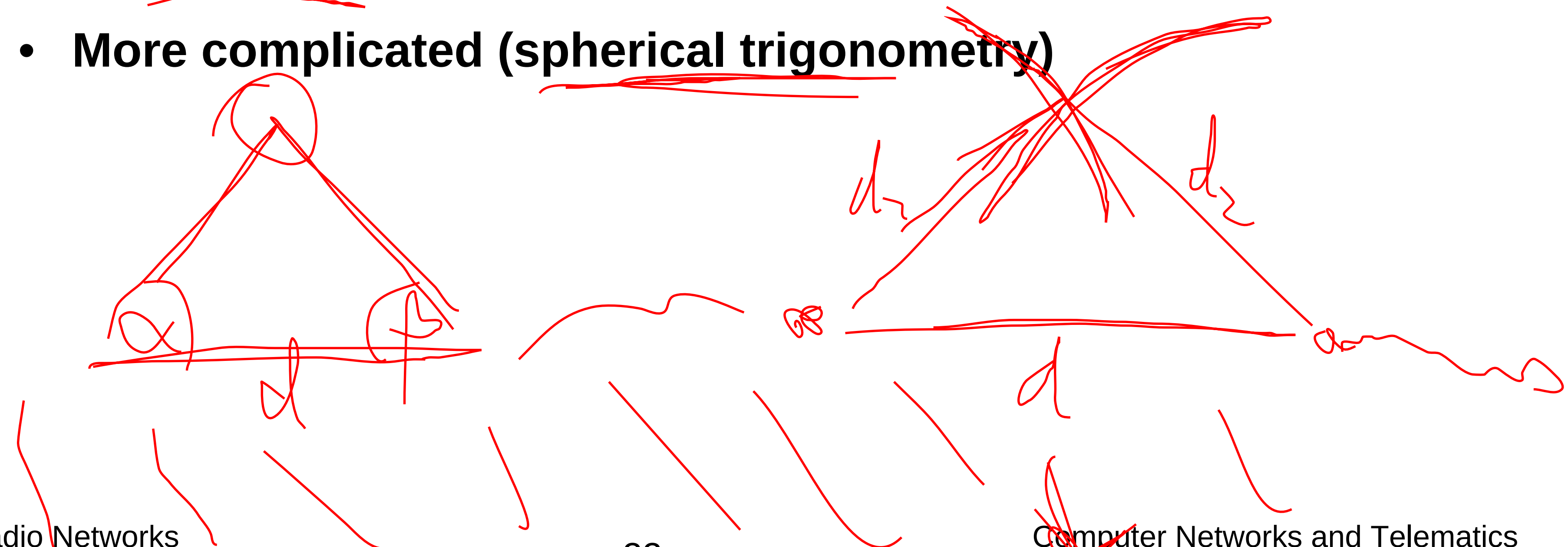


[Zhang, 2013]

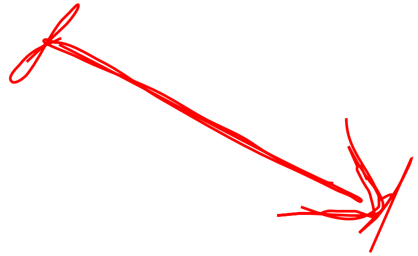
Triangulation

- Given a side of known length and two adjacent angles
- In the plane:
  - Calculate the intersection point of the other sides
  - Duality with trilateration: Triangle congruency (angle-side-angle) ←→ (side-side-side)
- On earth surface:
  - More complicated (spherical trigonometry)

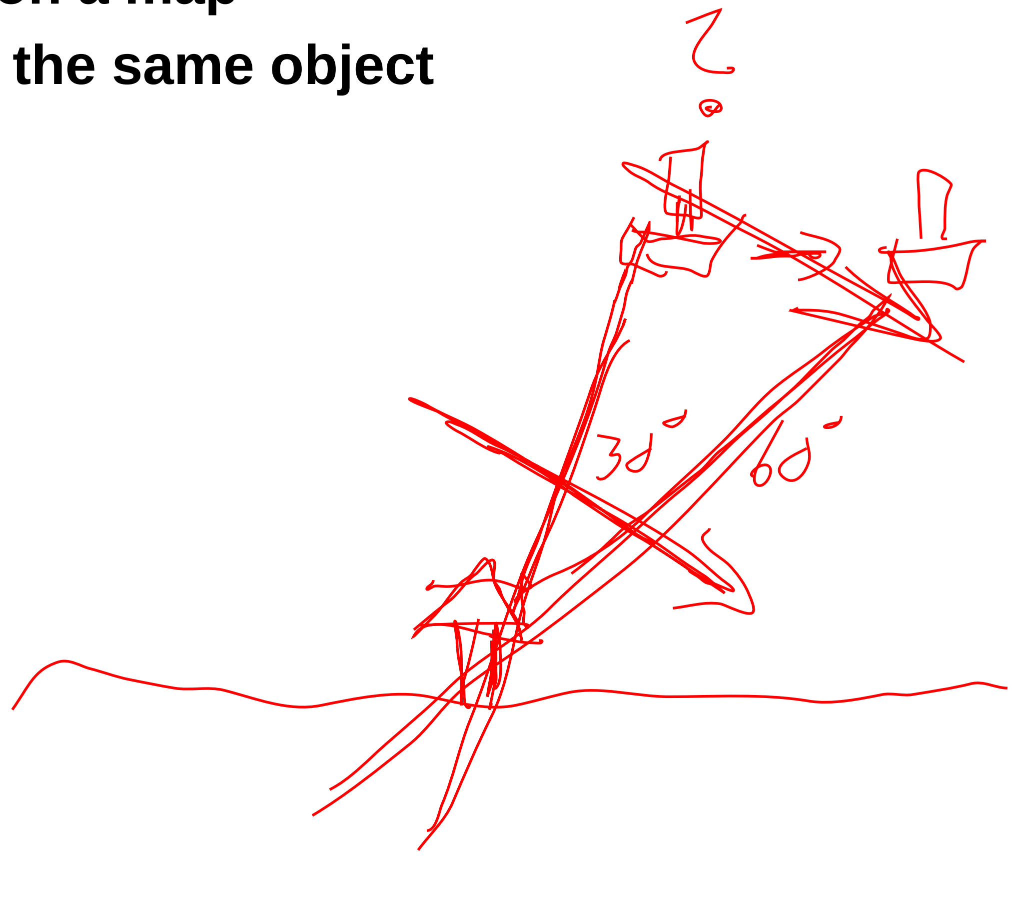




Triangulation

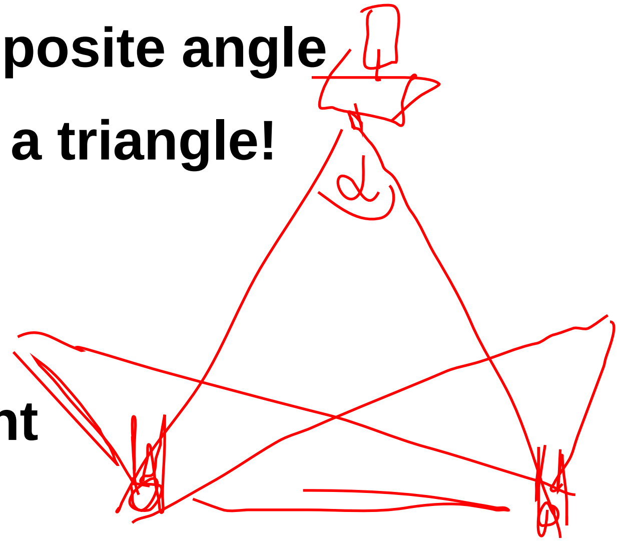


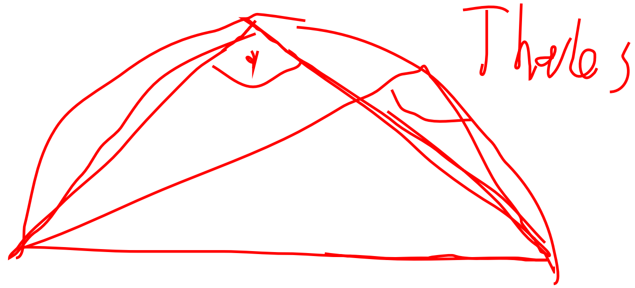
- **Example: Navigation of ships / airplanes (cross bearing triangulation)**
  - **1) Bearings of two objects on a map**
    2) Time-shifted bearings of the same object



Triangulation

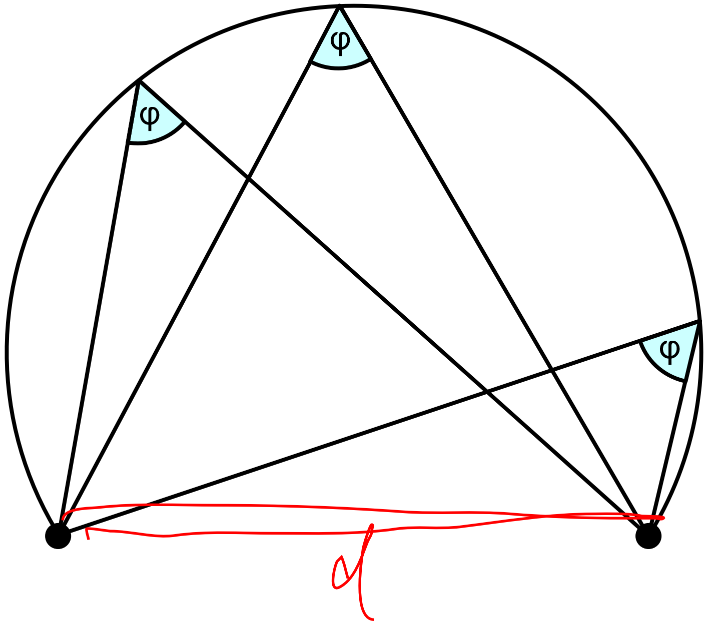
- Given a side of known length and the opposite angle
  - Triangle congruency: Does not define a triangle!
  - What else is possible?
- Given a lighthouse of known height h
  - Measurement of angle ϕ, use a sextant
  - Calculation of distance $d = h / \tan(\phi)$
  - Measurement of lighthouse bearing
  - ➔ position in polar coordinates
- Height of lighthouse not known
  - Sail towards lighthouse





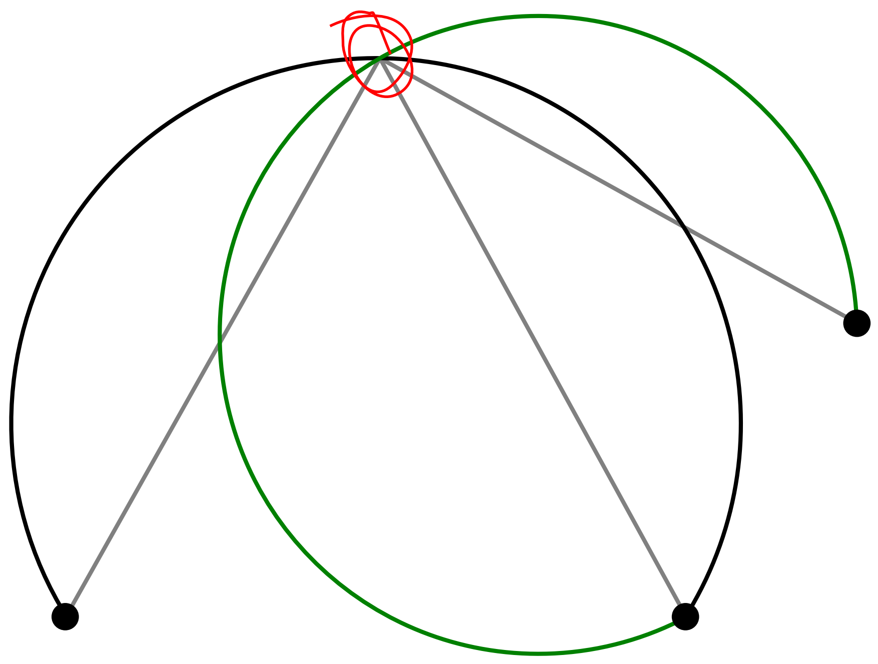
Triangulation

- **Given a side of known length and the opposite angle**
  - **Measure angle ϕ of two landmarks (by theodolite or by laser scanner)**
  - **If $\phi = 90°$: Ship's position resides on Thales' circle**
  - **Other angles: generalization of Thales' circle**
  - **Circle of equal angles ("Fasskreisbogen")**



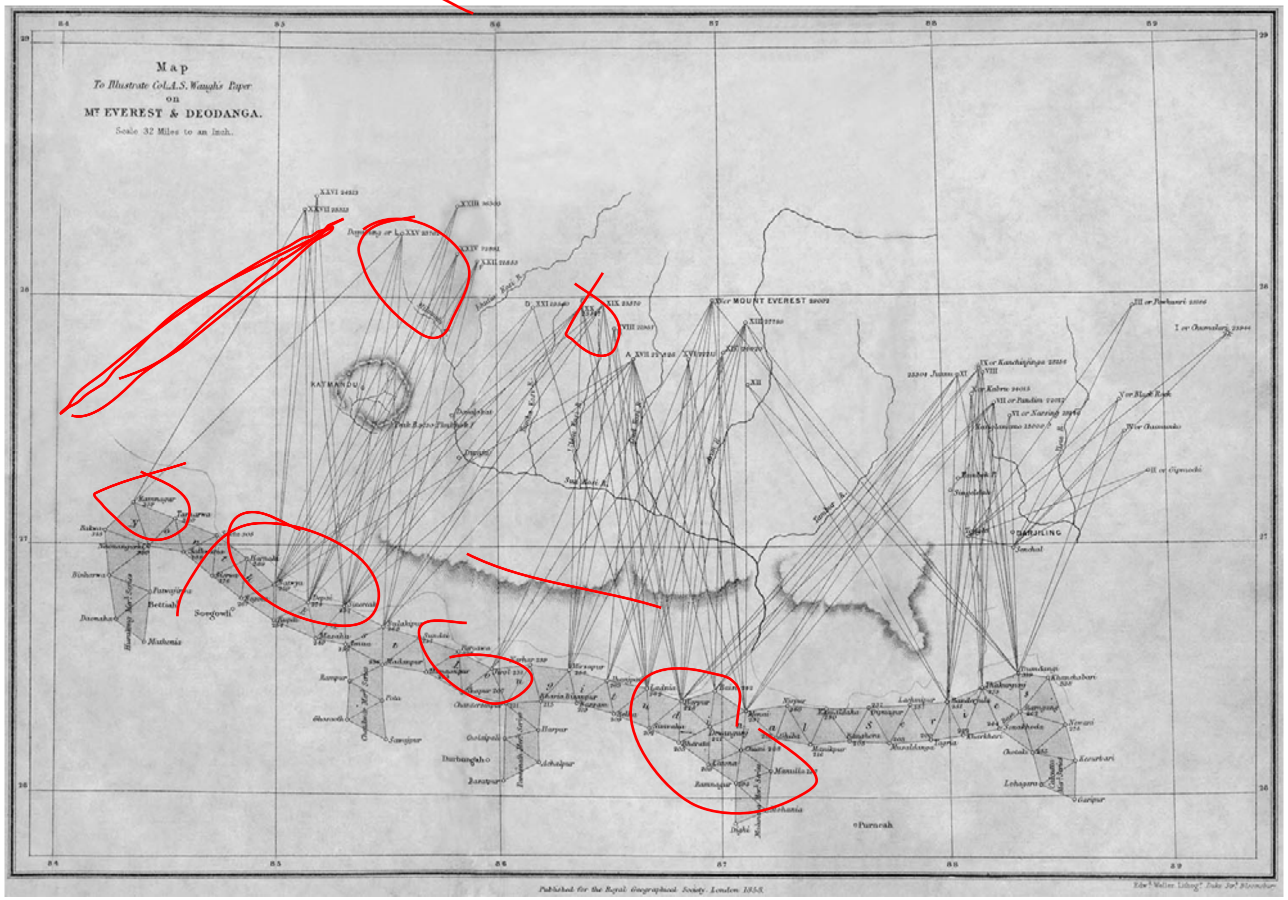
Triangulation

- **Given a side of known length and the opposite angle**
  - **Calculate position by a third landmark**



Triangulation

- **Height of Mt. Everest**
  - **8,840 m above NN (Sickdhar, 1856)**
  - **8,848 m (Survey of India, 1955)**
  - **8,850 m (GPS, 1999)**
  - **8,849 m (Radar reflectors, 2004)**
  - **...**



[A. Waugh, Mt. Everst & Deodanga, 1862.]

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