INTRODUCTION

WHAT IS A GIS?

Def: a system that uses spatial (i.e., geographically referenced) and non-spatial (i.e., attribute) data and includes operations that support spatial analysis

Alternative names:

- AM/FM (automated mapping and facilities management)
- geographically referenced information system
- land information system
- natural resources information system
- spatial data management (or handling) system
- spatial database

FIELDS THAT ARE INVOLVED IN GIS

1. Cartography—display of visual information
2. Civil Engineering—transportation
3. Computer science—databases, computer graphics, image processing
4. Geodesy—high accuracy positional control
5. Geography—spatial analysis, relation of man to world
6. Mathematics—geometry, graph theory
7. Operations research—optimization
8. Photogrammetry—aerial photographs are best sources for topography
9. Remote sensing—images from space
10. Statistics—models, analysis of error
11. Surveying—position of land boundaries, buildings, etc.

SOME TYPICAL GIS QUERIES

1. What feature is at location *X*?
2. Does feature *F* exist anywhere?
3. Report the identity of all features present
4. Select all the locations where feature *F* is present
5. Where is object *A* with respect to object *B*?
6. Simulate the effect of phenomenon *P* for time period *T* in area *A*
7. What is the cheapest, fastest, or least resistant path from *A* to *B*?
8. What is the value of function *f* at location *X*?
9. What is the result of overlaying a given set of map layers?
10. What is the result of intersecting a given set of map layers?
11. What combination of features is at location *X*?
12. Where is object *A* in relation to object *B* or location *X*?
13. Report all features within distance *d* of location *X* or object *A*
14. Reclassify certain ranges of feature values
15. Proximity queries such as what objects are next to other objects having certain attribute values
16. Measure properties such as area, perimeter, etc.

GIS OPERATIONS

1. Display the data
2. Find a pattern in the data
3. Predict the behavior of the data at another time or place

GIS ANALYSIS FUNCTIONS

1. Local operations
   - retrieval
   - classification and recoding
   - generalization—reducing detail
   - measurement
2. Overlay operations
3. Neighborhood operations
   - search
   - proximity—e.g., Voronoi diagrams
   - TIN generation
   - interpolation
   - contour generation
   - buffer or corridor generation
4. Connectivity operations
   - network functions—e.g., flow, routing, siting
   - spread functions—i.e., phenomena accumulate with distance
   - seek or stream functions—e.g., drainage
   - intervisibility

EXAMPLE OF GIS (MUNICIPAL DATABASE)

1. Basemap data
   - control points
   - topographic contours
   - building sites
2. Natural area data
   - soil types
   - landuse (e.g., industrial, agricultural, zoning, etc.)
   - vegetation
   - water (e.g., rivers, ponds, etc.)
3. Manmade area data
   - school districts
   - emergency service areas (e.g., fire, police, etc.)
4. Land records data
   - lot boundaries
   - zoning
   - easements and rights-of-way
5. Network data
   - utilities (e.g., phones, sewers, water, electricity, etc.)
   - roads
     a. road centerlines
     b. road intersections
     c. street lights

LAND RECORDS (CADASTRAL) DATABASES

- Keep track of the nature and extent of interests in land
  1. conveyance of real property
  2. taxation
  3. delivery of public services
- Information
  1. copies of deeds
     - legal description of the property
     - chronological tabulation of names of grantors and grantees
  2. plat maps
     - graphical representation of legal description of property which contains:
       a. subdivision name
       b. block number
       c. lot number
     - parcel number
       a. combination of adjacent lots with common owner
       b. a subdivided lot
     - usually indexed by block number
  3. copies of legal documents pertaining to the interest in the property
     - usually indexed by names of grantor and grantee

HISTORY OF GIS

1. Canada Geographic Information System (late 1960's)
   - early use of layer approach
2. Harvard Laboratory for Computer Graphics and Spatial Analysis (1970's)
   - SYMAP—first use of computers to make maps (line printer)
   - POLYVRT—conversion between different area representations
   - ODYSSEY—many functions based on vector format including polygon overlay
3. Bureau of the Census
   - DIME (1970 census)
     a. use of geocoding to match street addresses to geographic coordinate and census reporting zones
     b. only urban areas
   - TIGER—entire country (1990 census)
4. ESRI
   - spinoff of ODYSSEY from Harvard
   - combine attribute data management (INFO) with spatial data management (ARC)
   - vector-based approach

WHAT IS A MAP?

- Cartographic definition: a representation, usually to scale and on a flat medium, of a selection of material or abstract features on, or in relation to, the surface of the Earth
- Mathematical definition: a function (usually single-valued) from a domain to a range
- A map is really an abstraction (has little to do with reality!)
  1. especially true for atlas and road maps
     - hairpin symbol indicates winding road but not the number of turns
  2. not so true for large-scale maps
  3. not good for measuring distance
     - e.g. effects of elevation cannot be taken into account easily
- Cartographic abstraction requires:
  1. selection of the features that are to be included
  2. classification of the features into groups (e.g., roads, buildings, etc.)
  3. simplification of the features (e.g., coastlines)
  4. exaggeration of important features that the scale of the map renders too small to be shown
  5. symbolization (e.g., hairpin symbol for winding roads)

MAPS ARE CHARACTERIZED BY SCALE

- Three types
  1. ratio
     - relate a unit of distance on a map to a specific distance on the ground
     - dimensionless (i.e., the units are the same)
     - large scale means a small area is covered with much detail (small denominator)
     - what ratio is considered large scale and what is small?
  2. verbal
     - useful for relating units for measuring distance on paper to those which are used on the ground
     - e.g., "one inch represents one mile"
     - more meaningful than 1:63360
     - not necessary if use the metric system
  3. graphical
     - safest especially if enlarge or reduce the map
     - e.g., reducing a 1:1000 map by 2 makes it a 1:2000 map
- Ratio and verbal are meaningless on a display screen
- Should say “represents” and NOT “equals”

USE OF RATIO SCALES IN MAPS

1. Atlas maps
   - 1:1,000,000 and smaller
   - general view of earth's surface
   - shapes of continents, borders of countries, major mountains, major cities, rivers
2. Topographic maps
   - 1:1,000,000 to 1:10,000
   - for military and civilian purposes
   - creeks, ponds, trails, etc.
3. Cadastral maps or plans
   - 1:1,000 or even 1:500
   - show property interests
   - useful for administration of local government — e.g., subdivisions, fire hydrants, taxes, etc.

NATURE OF MAPS

- Projections of three dimensional data on a flat surface
- Cartograms
  1. distance
     - distance is proportional to some cost function (e.g., postage)
     - does not involve shape
     - distorts distance to represent distance-related concepts such as travel time, transport cost, postage, telephone fee, etc.
     - like azimuthal equidistance map projection in that it has a single focus
     - can still find some mathematical transformations so that additional features such as boundaries, rivers, contours, etc., can be shown even though the time or cost distorts the map
  2. area
     - area unit is proportional to an attribute associated with it such as population
     - try to preserve shape
- Cognitive maps
  1. distort shape but preserve topological relationships
  2. usually use non-linear scales for distances

TYPES OF MAPS: SOURCE

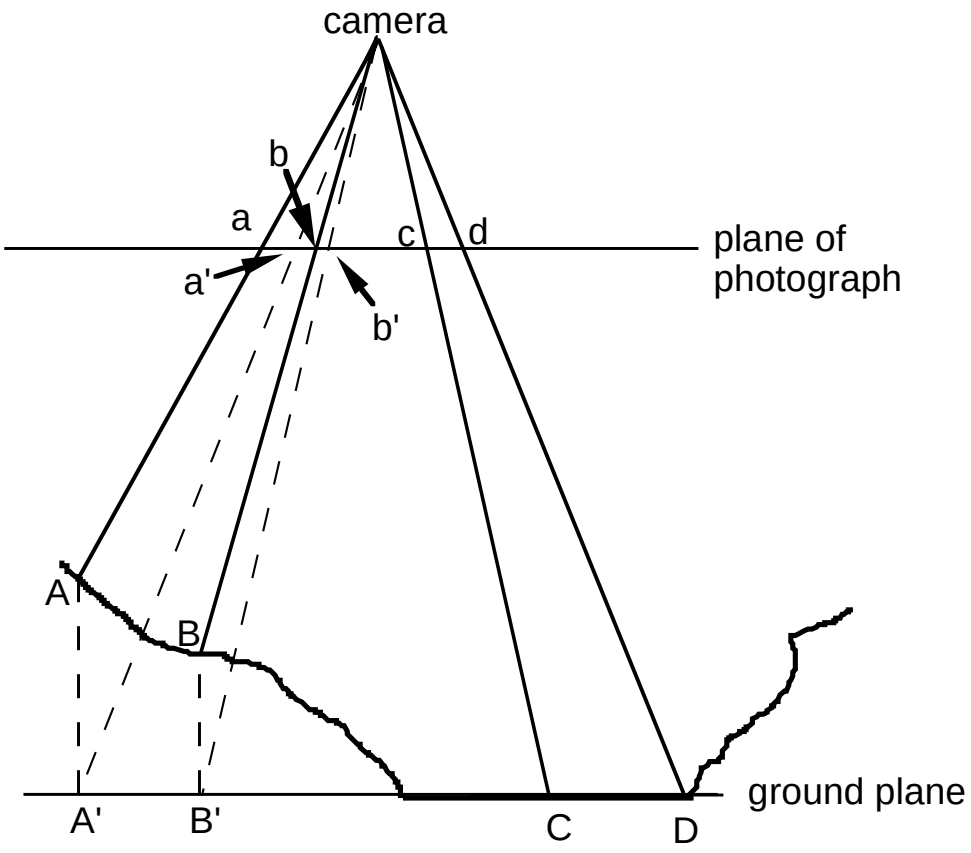
1. Line map
   - features depicted by conventional symbols and boundaries
2. Photo map
   - derived from a photographic aerial images
   - features are depicted as they are seen
   - subject to distortions

PLANIMETRIC MAPS

1. Created from field surveys or aerial photos
2. Contain physical features
   - curbs, sidewalks
   - roadways, bridges
   - rivers, washes, lakes
   - manhole covers, fire hydrants, street lights, traffic signals
   - buildings
3. Don't contain legal features
   - rights of way, easements, property lines
   - must be visible!
4. Use stereo process to obtain elevations and hence topographic maps
5. Aerial photos can be combined in a mosaic pattern
   - photos are usually taken at one point in time
   - field surveys have errors since taken over a long period of time
     a. gaps can exist
     b. different surveying techniques and precision

ERRORS IN AERIAL PHOTOGRAPHS

- Distortions caused by fact that surface of the earth is not flat
- Once a scale has been chosen, relative distances between objects may be erroneous since they can appear at different elevations and hence at different scales



- Observations:
  1. surface of earth between A and B is at a higher elevation than the surface of the earth between C and D
  2. assume scale is determined by the ground plane

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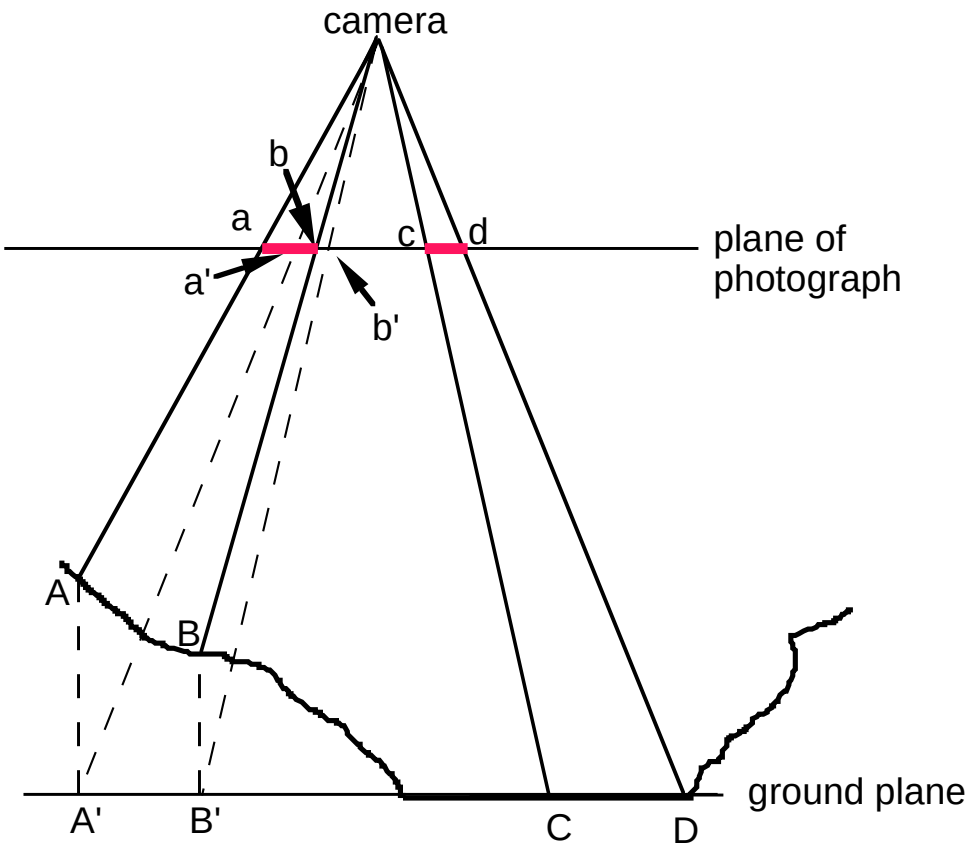

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  3. actual distance on the ground (i.e., ground truth) between A and B is not accurately represented on the photo by the points a and b as the scale along ab is different than the scale along cd even though their lengths are the same

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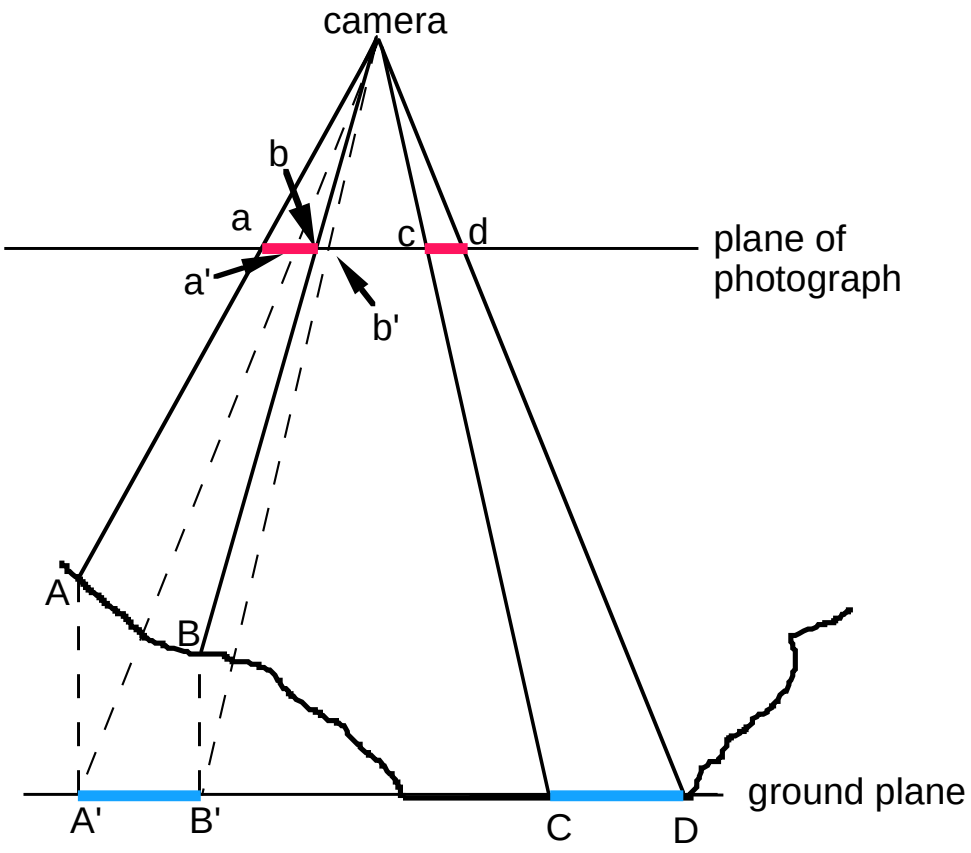

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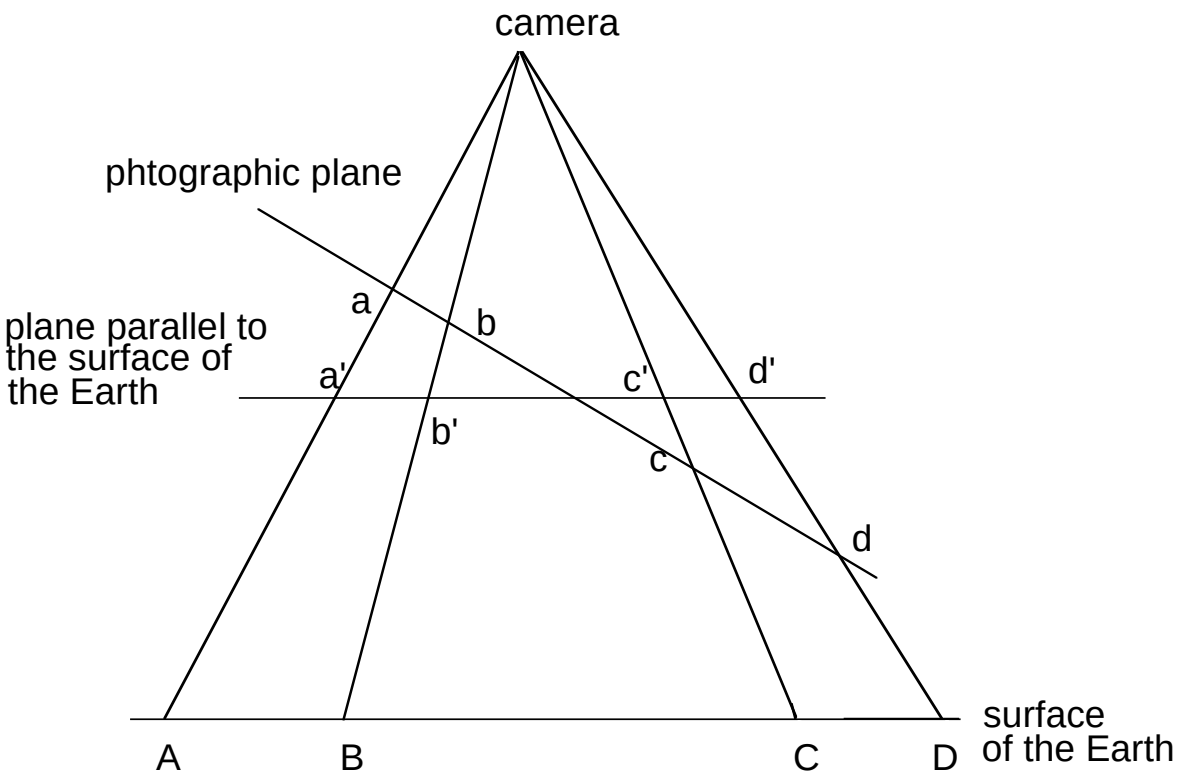
  4. scale of the length A'B' is the same as the scale of the length CD but A'B' is not on the photo

AIRPLANE AND CAMERA ERRORS IN AERIAL PHOTOGRAPHS

- Tilt of airplane and camera
- Photo is not parallel to the ground or surface of the earth



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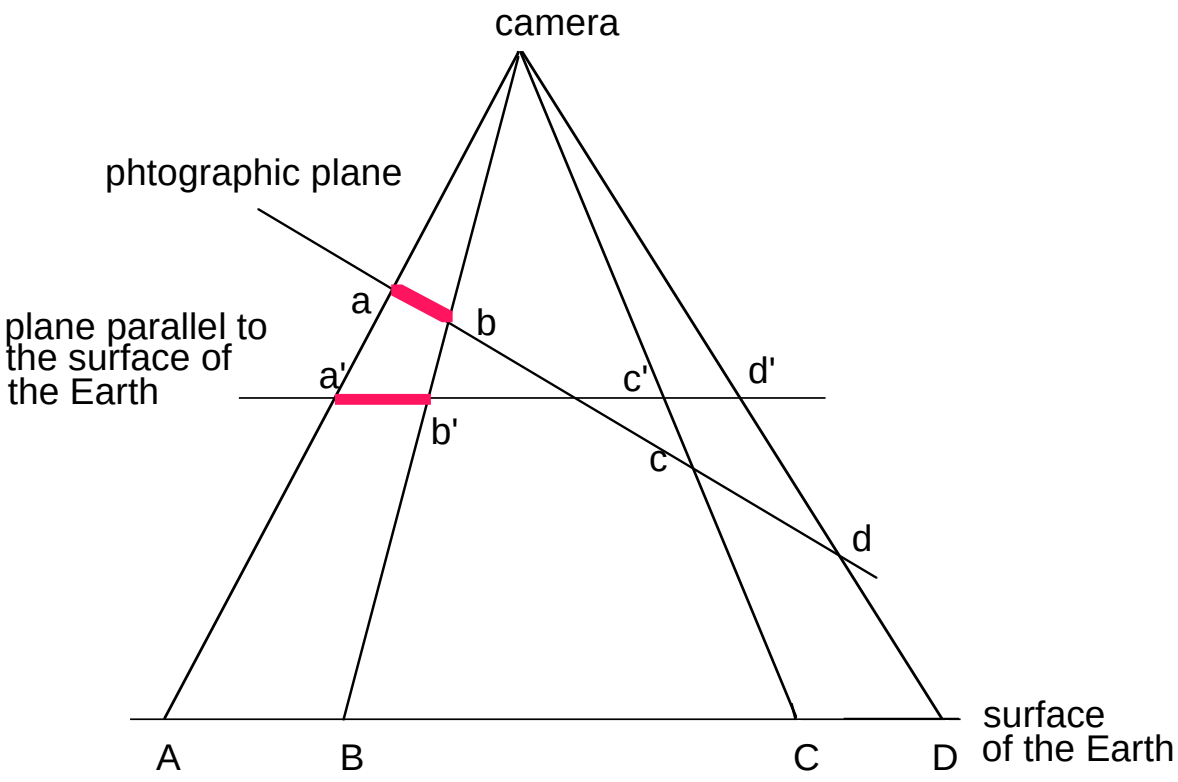

- Observations:

1. distance between A and B (ab) appears smaller than expected a'b'

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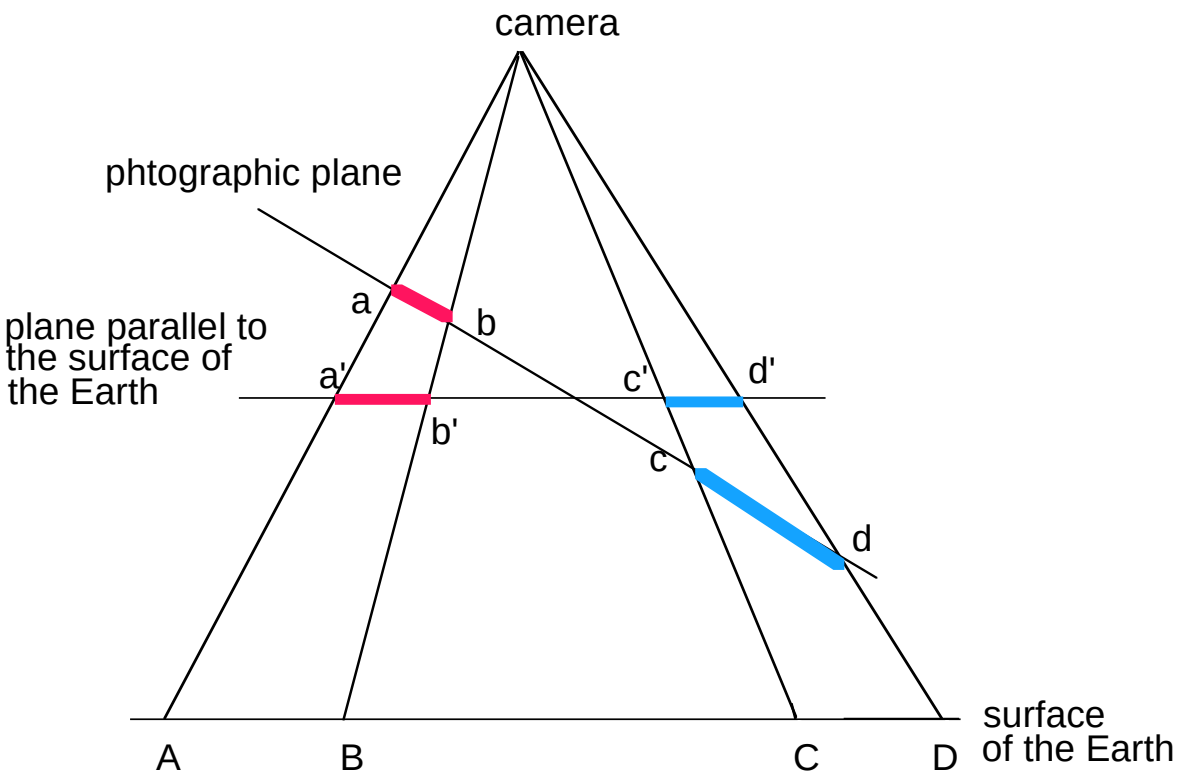

- Observations:

1. distance between A and B (ab) appears smaller than expected a'b'
2. distance between C and D (cd) appears larger than expected c'd'

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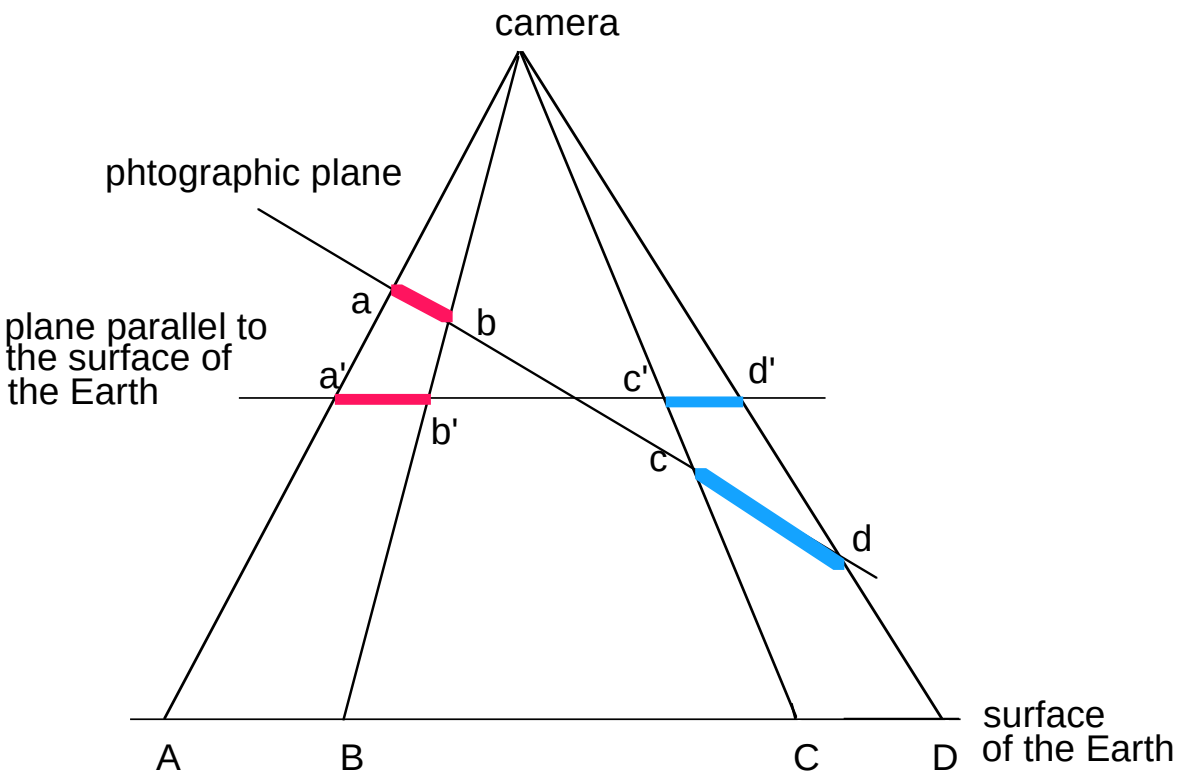

- Observations:

1. distance between A and B (ab) appears smaller than expected a'b'
2. distance between C and D (cd) appears larger than expected c'd'
3. correction process is called orthogonal rectification

TYPES OF MAPS: OUTPUT:

1. Topography map
   - outlines of natural and man-made features
   - refers to shape of the surface but also shows roads and other features
     a. represented by contours, OR
     b. shading
2. Thematic map
   - geographic concepts such as rainfall, crop coverage, population density, per capita income, etc.
   - types of maps
     a. choropleth—display a particular feature such as average rainfall in a predefined partition of a region of interest
        - the boundaries of the elements of the partition are independent of the data (e.g., counties, Congressional districts)
     b. area class map—partition into zones with the same attribute value
        - the boundaries of zones depend directly on the data values (e.g., crop coverage map)
     c. isopleth map—lines are drawn between points of equal value (similar to contour lines)
        - assumes an imaginary surface
        - useful for data that varies continuously across the map (e.g., elevation, temperature, rainfall, etc.)
        - describes higher dimensional data on a medium of lower dimensionality

DATA INPUT: SAMPLING STRATEGIES

1. Random—all equally likely
2. Systematic—choose a sample every *x* units …
3. Stratified—different sampling strategies in different regions
   - more samples in rugged terrain

DATA INPUT: DATA CAPTURE

1. Digitizers
   - cursor position is detected by the computer as it is moved (e.g., using a mouse and a digitizing tablet)
   - point mode—operator identifies points to be captured (which can be tedious)
   - stream mode—automatically by elapsed time or movement of cursor by a predetermined distance
2. Scanners
   - yield a raster image which can be converted to a vector
   - video—television camera
     a. produces array of brightness or color values
     b. difficult to use due to distortion
   - electromechanical such as a drum
   - can use a laser beam to scan surface of a map
3. Global Position System (GPS)
   - computes position in three-dimensional space based on signals from satellites that cover the earth (NAVSTAR)
   - can determine location on Earth's surface within meters
4. Rasterization
   - sometimes easier to scan the endpoints of vector data and then rasterize by vector-to-raster conversion
5. Vectorization
   - conversion of raster input to vectors
   - not easy