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GEOREFERENCING AND GEOCODING EARTH OBSERVATION IMAGES

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THIS PRESENTATION INCLUDES MOVIES

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

1

READ

STUDY MATERIAL

- Basic text: GRGC_Read_Before_Class_2022.pdf
- Follow this lecture after reading and understanding the Basic text. If you did not read the Basic text, leave the room, read the text and then see the video of the lecture… and remember to read before coming to class.
- LTB: Search for Georeferencing, Geocoding. Study all the related relations.

2

READ

GOING FROM 'A' TO 'B' FOR RASTERS (MAPS & IMAGES)

A

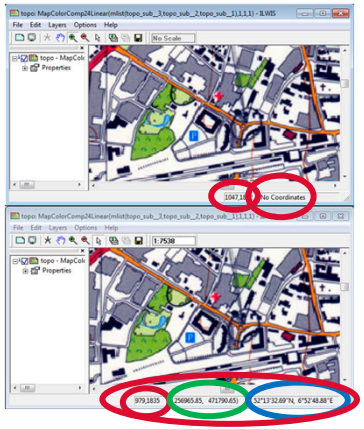
B

3

READ

GEOREFERENCING TOPOGRAPHIC MAPS: WHAT'S DIFFERENT?

- These are both scanned maps
- Both images are identical in geometry
- Upper: not georeferenced
  - Pixel size, location is unknown
- Lower: with georeference
  - Pixel size and location is known
- Upper only having image coordinates.
- Lower having image coordinates, Cartesian coordinates and global coordinates.
- Georeferencing topographic maps is easy: the coordinate grid is seen on the scanned image!!

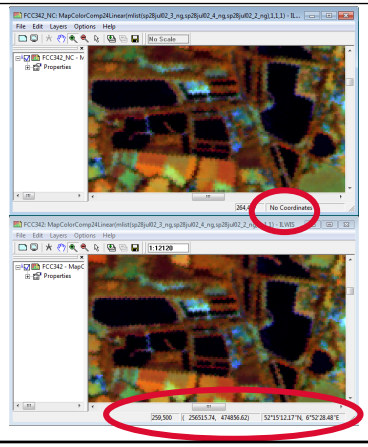


4

READ

GEOREFERENCING OF IMAGES: WHAT'S DIFFERENT?

- These are FCC images. (It can be any)
- Upper, not georeferenced and lower is georeferenced.
- Georeferencing images is similar to georeferencing maps, but…
- FCC's are composed of different bands of identical geometry: the individual bands must be georeferenced. There are methods to do all together.
- Georeference of images is more difficult: clear Ground Control Points (GCP) in the image need to be found. No grid available!!,… no easy way to collect GCP with assigned coordinates.



READ

GR= POSITIONING A PIXEL IN A COORDINATE SYSTEM

- In a GIS/RS package the user needs to impose of a referenced geometry.
  - Images/maps without a georeference cannot be used for any kind of geometrical information in a GIS/RS system:
    - No pixel size or scale possible… no location.
    - Most GIS operations are not operational.
    - Many RS operations are not possible.
    - *However, radiometric information in the raster is not affected.*
  - **Georeferencing** is the process executed over an image/map to assign to each pixel a real world coordinate.
    - After georeferencing, GIS and RS operations are all possible
  - In other words: georeferencing is the process of fixing a raster data set (2D or 3D) in a space with cartographic coordinates.

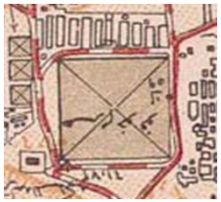
READ

POINTS TO FIX A SHAPE IN SPACE.

- In a 2D plane, 3 points (minimum)
  - After fixing 3 points (GCP's), the "solid" mantle does not move.
  - The GCP points must be located in a plane: (X,Y)
  - To avoid errors: the bigger the number of points, the better.
- In 3D, we require to fix the height of some points.
  - The GCP points are then located in the space: (X, Y, Z)
  - What can bring many X,Y,Z points in a GIS?: i.e. A DEM

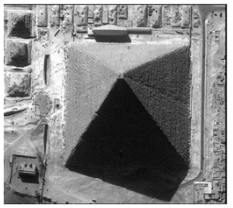
READ

WHEN HEIGHTS (THE "Z" COORDINATE) ARE IMPORTANT?



Map

Medium resolution image



High resolution image

- When heights are neglected due to poor resolution of imagery or lack of interest to our study: PERFORM a 2D (x,y) georeferencing.
- If heights are of interest to our study, look for a high resolution imagery and PERFORM a 3D (x, y, z) georeferencing (limited in this course)

READ

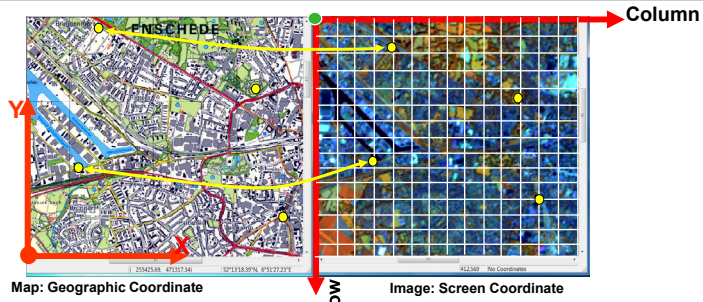
GEOMETRIC ASPECTS OF IMAGE DATA

- 2D approaches: Solves X, Y (medium and coarse satellite imagery)
  - Heights of objects are negligible
  - Possible operations:
    - Georeferencing: Allows location of points
    - Geocoding (resampling): allows location and reorientation of points
- 3D approaches: Solves X, Y, Z (Aerial Photos and very high resolution satellite imagery)
  - Heights of objects are essential
  - Deals with relief displacement
  - Possible operations after a 3D Georeferencing:
    - Monoplotting
    - Orthoimage production
    - Stereoplotting

Challenge:
• You need to have clear concepts of location and orientation?
• Location (absolute position)
• Orientation (relative to)

READ

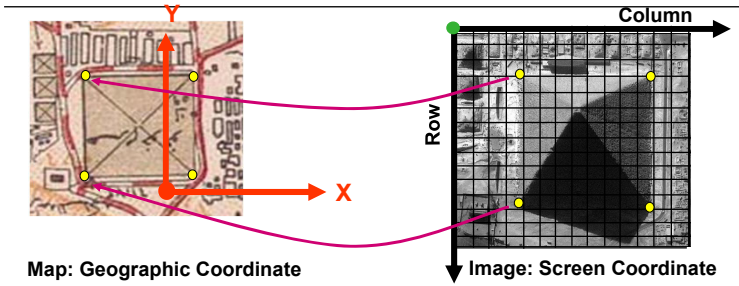
GEOREFERENCING IN 2D



- We find a **mathematical relation between**.
  - *Pixel coordinates* (Row, Column) inherent of the image.
  - *Map coordinates* (a coordinate system for the Earth point where the pixel is x,y)
- The distortion of the image as seen by the satellite is NOT CORRECTED, but the geographic coordinate of every pixel will be acceptable.

READ

GEOREFERENCING IN 2D



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READ

INTRO TO GEOREFERENCE (2D)

- Georeferencing solves 2 problems:
  - Assigns coordinates to pixels, via a model that solves the coordinate distortion.
  - Distortions in a 2D images are produced by several causes but are treated altogether!!
- After Georeferencing it is possible to:
  - Measure in the image
  - Spatially combine vector and raster data (ANY GIS operation is possible
  - Compare and fuse images (software dependent)
  - But to produce images in a certain map projection you need GEOCODING!!! (1 step more, but easy)

READ

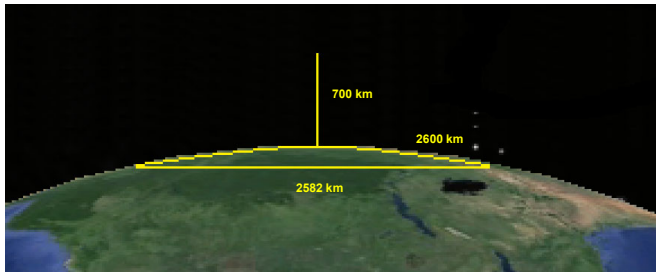
CAUSES OF GEOMETRIC DISTORTION

- The perspective of the sensor optics (oblique viewing)
- The curvature and rotation of the earth.
- The terrain relief: Relief Displacement
- Others

- The motion of the scanning system.
- The motion and instability of the platform.
- The platform attitude, altitude and velocity.

READ

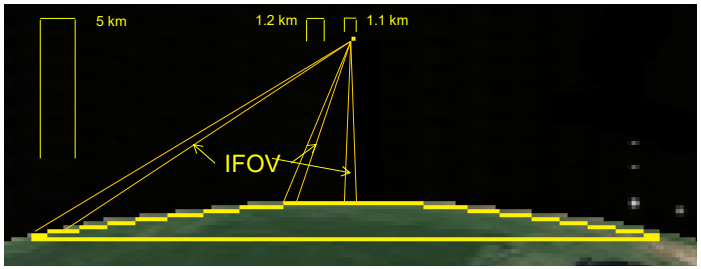
HOW A SENSOR AT 700 KM SEES EARTH (COARSE RESOLUTION)



In this example: NOAA AVHRR image
2600 km width seen, Earth curvature creates distortion

READ

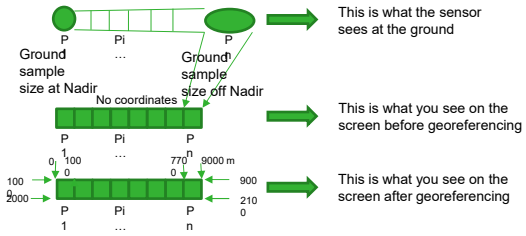
GEOMETRY OF THE SATELLITE: COARSE RESOLUTION

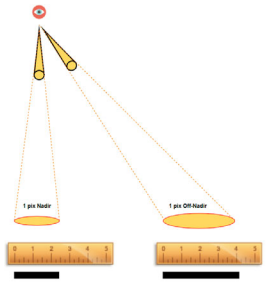


IFOV is constant. IFOV defines the sampling area (Ground Resolution Cell size)
Depending on the viewing angle from nadir one “pixel” on the image represent different areas on Earth.

READ

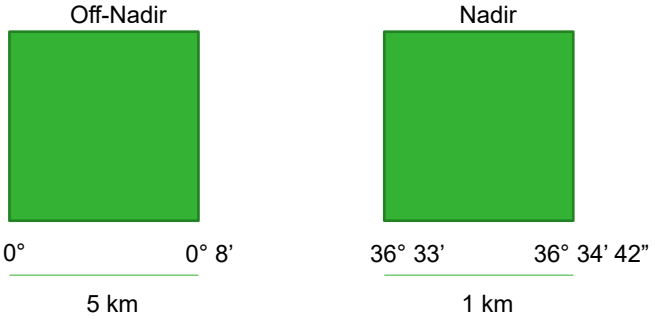
A HOME MADE SATELLITE





READ

WHAT ARE THE COORDINATES OF A SINGLE PIXEL?



For images taken under an angle, the relation between image coordinates and real coordinates is not linear!!

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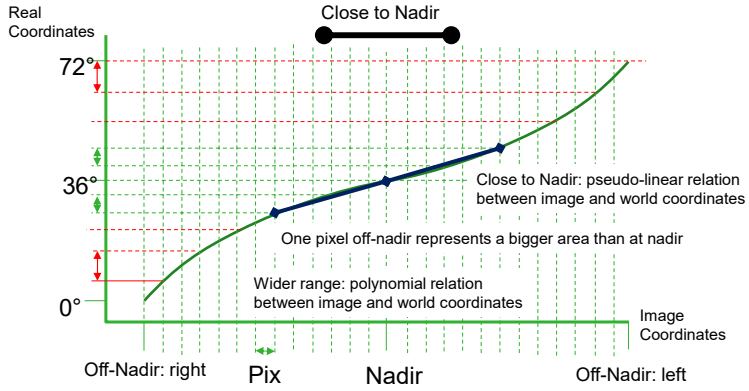
PLOTTING IMAGE VS REAL COORDINATES



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READ

WHAT FOR MEDIUM TO HIGH RESOLUTION IMAGES?

- Moderate to Very small swath:
  - Landsat 185 km
  - IRS 146 km
  - SPOT 117 km
  - Ikonos 11 km
- An almost Linear distortion stands for nadir and off-nadir pixels
- *The relation between image and real coordinates can be handled with an affine (or eventually polynomial degree 1) transformation*.

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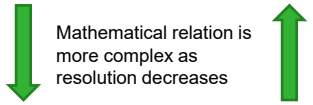
READ

SO… WHAT IS GEOREFERENCING?

- We need to find **the mathematical relation** that starting from the IMAGE COORDINATES, gives the MAP COORDINATES.
- NOTICE that this mathematical relation must solve the distortion model, but it does not affect the pixel values read by the sensor, only gives good coordinates!!

Planar distortion:	Local areas (maps or images)	i.e. cadastral scanned map.
Linear distortion	High resolution images	i.e. Landsat, Spot, etc.
Complex distortion	Moderate to low resolution images	i.e. MODIS, AVHRR, MSG, etc



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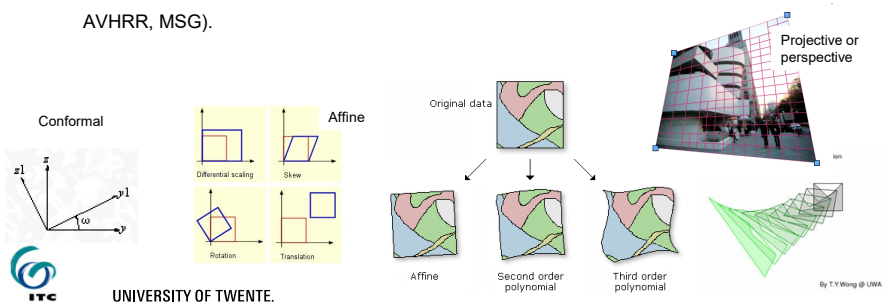
THE DISTORTION TYPE DECIDES THE MATHEMATICAL RELATION

READ

- Image is evenly distorted → a linear transformation (conformal, affine) is applied (small FOV images. i.e. Landsat).
- Image is unevenly distorted → higher order transformations (large FOV images. i.e. NOAA AVHRR, MSG).



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CONFORMAL TRANSFORMATION OF COORDINATES

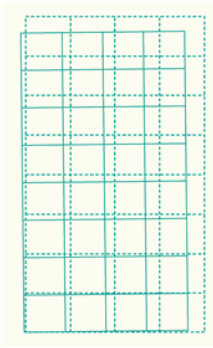
Addition

AFTER RICHARD KNIPPERS

- 2D Linear (or first-order) transformation that contains:
  - rotation,
  - a uniform scale change,
  - followed by a translation.

$$X' = s\,X\cos(\alpha) - s\,Y\sin(\alpha) + x_o$$
$$Y' = s\,X\sin(\alpha) + s\,Y\cos(\alpha) + y_o$$

- The rotation is defined by one rotation angle (α), and the scale change by one scale factor (s). The translation is defined by two origin shift parameters (x_o,y_o)



In the equations, (X,Y) represent the image coordinates and (X', Y') the Calculated world coordinates

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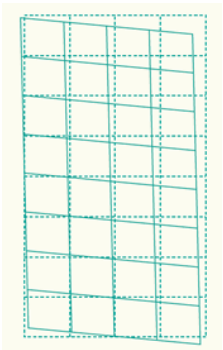
LINEAR OR AFFINE TRANSFORMATION OF COORDINATES

Addition

AFTER RICHARD KNIPPERS

- 2D Linear (or first-order) transformation that contains:
  - rotation,
  - a scale change in x- and y-direction,
  - followed by a translation.
- The transformation function is expressed with 6 parameters:
- one rotation angle (a),
- two scale factors, in "x" (s_x) and in "y" (s_y), and two origin shifts (x_o, y_o).

$$X' = s_x\,X\cos(\alpha) - s_y\,Y\sin(\alpha) + x_o$$
$$Y' = s_x\,X\sin(\alpha) + s_y\,Y\cos(\alpha) + y_o$$



In the equations, (X,Y) represent the image coordinates and (X', Y') the Calculated world coordinates

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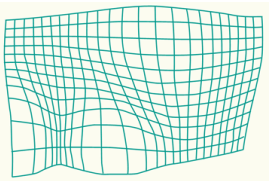
POLYNOMIAL TRANSFORMATION OF COORDINATES

Addition

AFTER RICHARD KNIPPERS

- It is a 2-D non-linear transformation containing
- *A translation,*
- a *rotation* and a
- *variable scale change.*
- The transformation function can have an infinite number of terms. Normally no more than order 3.

$$X' = x_o + a_1X + a_2Y + a_3XY + a_4X^2 + a_5Y^2 + a_6X^2Y + a_7XY^2 + a_8X^3 + \ldots$$
$$Y' = y_o + b_1X + b_2Y + b_3XY + b_4X^2 + b_5Y^2 + b_6X^2Y + b_7XY^2 + b_8X^3 + \ldots$$



Distortion in an aerial photograph. The coordinates can be approximated with a high order polynomial equation.

In the equations, (X,Y) represent the image coordinates and (X', Y') the Calculated world coordinates

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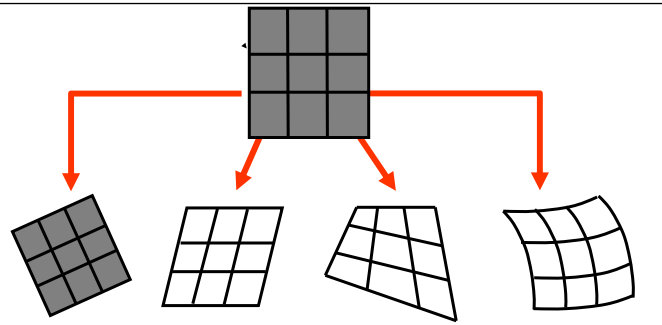
READ

GEOREFERENCE MODELS



Conformal (4 Parameters) | Affine (6 Parameters) | Perspective (8 Parameters) | n -Polynomial (> 12 Parameters)

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GEOREFERENCING ON THE MAKING

HOW TO DO THIS IN PRACTICE (WITH THE SOFTWARE)

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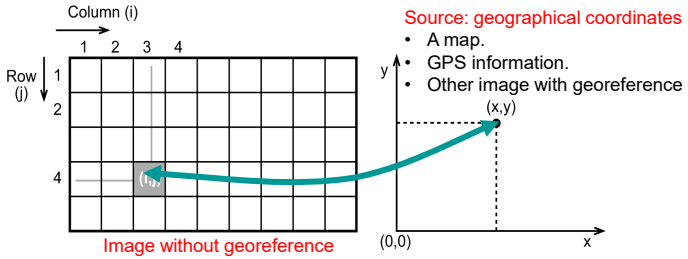
READ

2D GEOREFERENCE: LEAST SQUARES ADJUSTMENT



Source: geographical coordinates
- A map.
- GPS information.
- Other image with georeference

Data to be collected

Image		Source	
i	*j*	*x*	*y*
254	68	958	155
149	22	936	151
40	132	916	176
26	269	923	206
193	228	954	189

In general
$x = a + b(i) + c(j)$
$y = d + e(i) + f(j)$

Since (i,j) is known for each point, the coordinate can be calculated

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READ

2D APPROACHES: GEOREFERENCING: QUALITY CONTROL

	Measured				Modeled		Difference	
GCP	*i*	*j*	*x*	*y*	x_c	y_c	d_x	d_y
1	254	68	958	155	958.552	154.935	0.552	-0.065
2	149	22	936	151	934.576	150.401	-1.424	-0.599
3	40	132	916	176	917.732	177.087	1.732	1.087
4	26	269	923	206	921.835	204.966	-1.165	-1.034
5	193	228	954	189	954.146	189.459	0.146	0.459

$$m_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n} dx_i^2} \qquad m_y = \sqrt{\frac{1}{n}\sum_{i=1}^{n} dy_i^2} \qquad m_{total}(RMSE) = \sqrt{m_x^2 + m_y^2}$$

- After entering a limited number of GCPs the transformation model can be calculated.
- Entering more control points allows the estimation of errors!! This estimation is essential
- Errors are measured at the GCP's and not at any place in the image!!
- The accuracy of the georeference can be *characterized* based on this error, but strictly speaking, it applies only to the GCP's. Therefore, it cannot be ensured that the same error applies for all points in the map!!

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READ

PROCEDURE: IT IS A SEQUENCE [TO READ]

- Select appropriate transformation **based on the image characteristics**: (conformal, affine or polynomial)
- Decide on a required accuracy for the georeferencing (RMSE).
- Process to calculate the transformation parameters
  - Select ground control points
    - Sufficient to solve the transformation equations and derive an error estimate. They should be accurate and reliable
    - Well distributed all over the image, covering inside & outside the work area
  - Compute transformation (automatic)
- Assess GCP's residual errors and overall RMSE
  - If RMSE does not match requirements:
    - Review all GCPs. Correct, adapt, change or reject.
    - Very eventually: Review selected transformation

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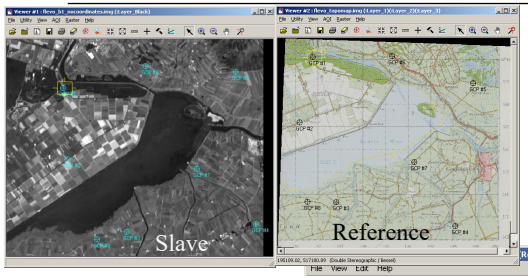
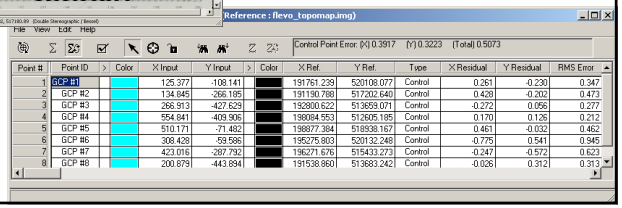
READ

GCP DISTRIBUTION & ERROR



1st order Transformation

More than sufficient GCPs



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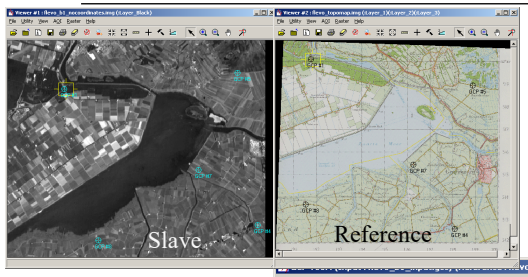
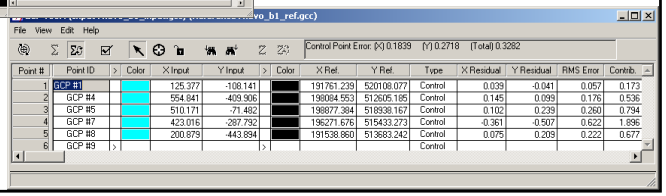
GCP DISTRIBUTION & ERROR



1st order Transformation

Sufficient distribution



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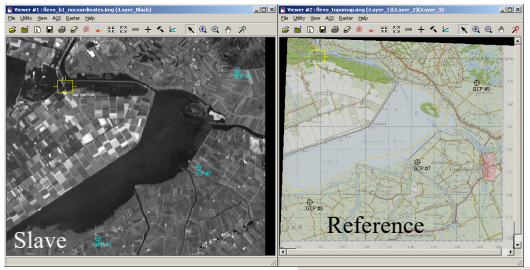
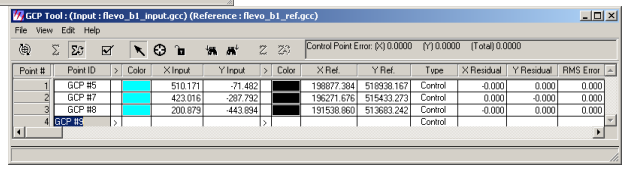
GCP DISTRIBUTION & ERROR



1st order Transformation

Insufficient # of GCP' to determine RMSE
Poor distribution (on a line)



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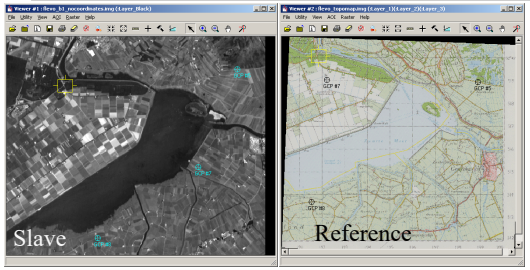
GCP DISTRIBUTION & ERROR



1st order Transformation

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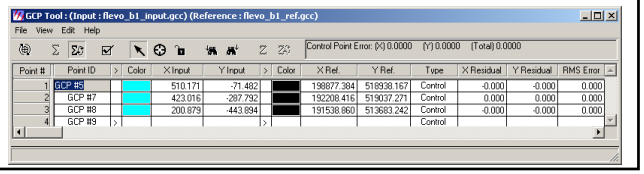

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GEOCODING

WHAT IT IS?

WHEN IS NEED IT?

HOW TO DO THIS?

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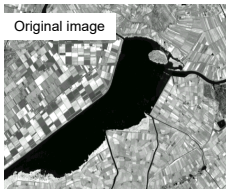
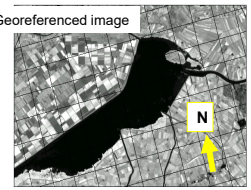
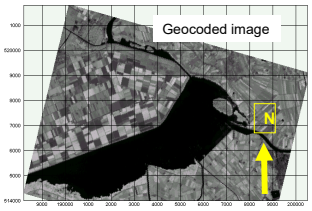
READ and Understand

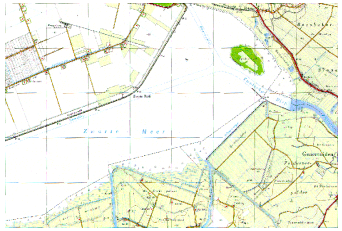
GEOCODING PROCESS: WHAT IT IS?







Map



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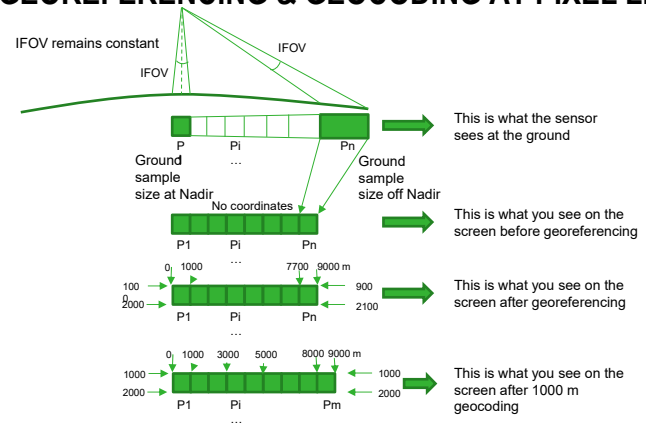
READ

GEOREFERENCING & GEOCODING AT PIXEL LEVEL



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READ

GEOCODING PROCESS

- Geocoding
- Georeference + Resampling
- The process allows
  - Select a new output coordinate/projection (any)
  - Define the new cell size
  - Define a new subset area of the map
  - Makes images North oriented & compatible with toposheets.
  - Disadvantage
    - The original geometry seen by the satellite changes
    - The original pixel needs to be shifted, so a new DN value needs to be calculated (resampling process)
    - DN value changes based on the resampling method

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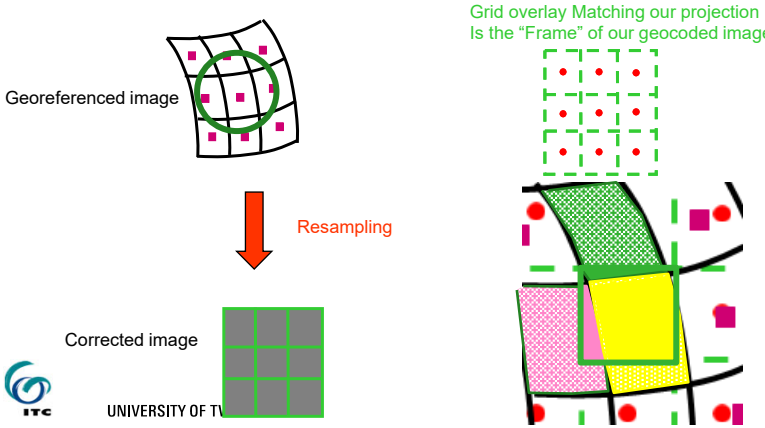
READ

GEOCODING AN IMAGE: PROCESS AND RESAMPLING



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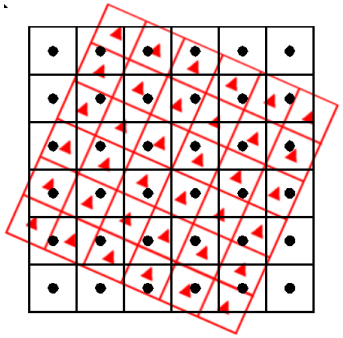
WHAT IS RESAMPLING?

▲ Center pixels for the georeferenced image

● Center pixels for the geocoded image.

Resampling: Method chosen by the user and assigns new DN values to the geocoded pixels.



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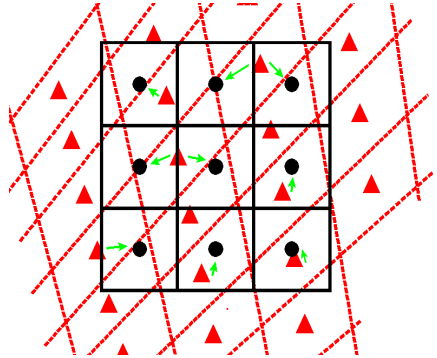
NEAREST NEIGHBOUR RESAMPLING

- Geocoded pixel (black) adopts the value of the closest georeferenced pixel (red)
- "Preserve" radiometry (DN) or the original value of the closest pixel
- Image becomes somehow "blocky" (not much)



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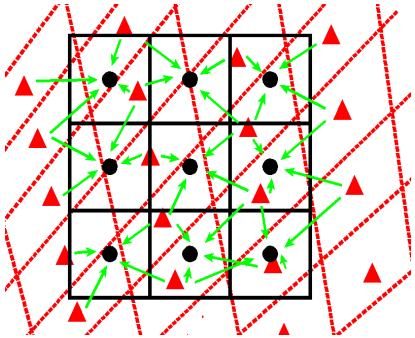
BI-LINEAR RESAMPLING

- Geocoded pixel value is a weighted linear calculation from the 4 closest pixel values of the georeferenced image.
- Weight ~ 1/d
- Distorted radiometry but smooth changes.



Challenge: Not advisable for DEM … Why?

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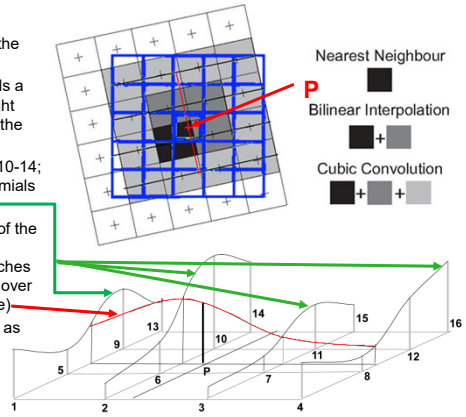
BI-CUBIC RESAMPLING: (GRAPHICAL EXPLANATION)

- Takes 16 closest pixels from the one to be resampled.
- From the center of these pixels a vertical line is built with a height equivalent to the DN value of the original pixel
- In groups of 4 (1-5-9-13; 2-6-10-14; etc), it creates 4 cubic polynomials (black curves)
- From the central position "P" of the newly geocoded image, a perpendicular is built till it reaches the polynomial curve passing over the interpolation point (red line)
- Interpolated value is obtained as the length of this raised line.



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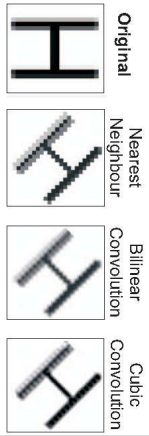
RESAMPLING METHODS: HOW VISUALLY APPEARS?

- Nearest neighbor (NN)
  - Maintains original DN values
    - Good for Quantitative RS (e.g Image Classification) and thematic images
  - Results in jagged edges
- Bilinear interpolation (BIL)
  - Smoothed look
- Bicubic (BIC)
  - Edges look enhanced, might be shifted
- BIL and BIC good for scanned maps!



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INTRODUCTION TO 3D GEOREFERENCING

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FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

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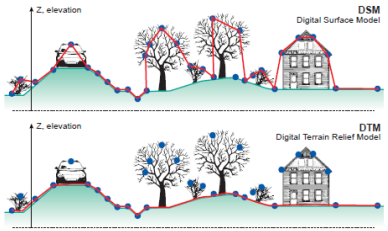
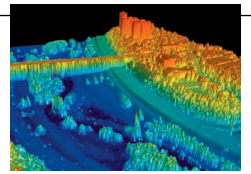
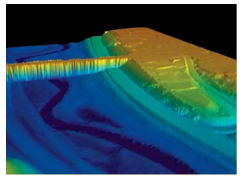
3D GEOREF: VERY HIGH RESOLUTION OR WHEN HEIGHTS ARE RELEVANT

- Necessary when:
  - 3D data (x, y, z) is needed.
  - 2D data is needed but the relief causes errors beyond requirements.
- Requirements:
  - It requires transformation of image coordinates to (X,Y,Z). The reverse process is also possible.
  - What data we need as input?
    - The original image as planar information (as in 2D) +
    - Height information (for the Z coordinates): DEM

DSM AND DTM (DEM)





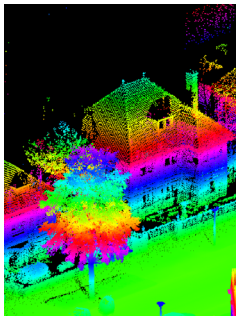


- DSM: Digital surface model
- DTM Digital Terrain (relief) model
- DEM: Digital Model for raster representations

Information

DSM ACQUISITION

- Digitising/vectorising
- Stereo models
- Radar Interferometry (INSAR)
- Laser Scanning/ LIDAR (airborne)



READ

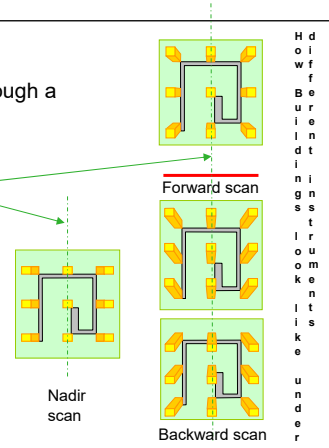
SCHEMA OF 3-D RELIEF DISTORTIONS FOR DIFFERENT SENSOR PERSPECTIVES

Vertical AP, Frame camera

- Central projection: ray light passes through a single point : “projection center”
- All in one shot

Line camera, scanner

- Pixels read line by line
- Continuous scan process



READ

AERIAL PHOTOGRAPHY: GEOMETRY CAMERA ORIENTATION

- To correct a 3D image for distortion, heights need to be measured
- Purpose: to obtain the parameter values from transforming the terrain coordinates (x,y,z) to image coordinates and vice versa.
- We base this process in the image co-linearity:
  - A point in the terrain passes through a projection center onto the film/array.

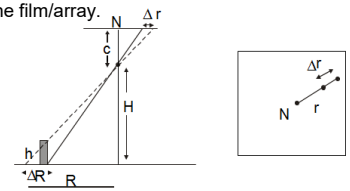
"C" is the focal distance (constant for a camera)

solving triangles

$\Delta r = r \cdot h/H$

$h = \Delta r \,.\, H / r$

So the heights "h" are calculated



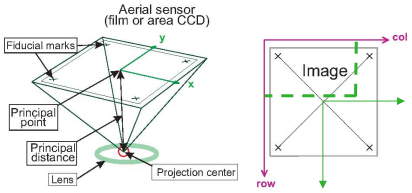
  - However the location of every pixel needs still to be found. To do that the image has to be oriented. The orientation of a single image is done after interior and exterior orientation process.

READ

3D APPROACH: INTERIOR ORIENTATION. INDIVIDUAL PHOTOS

Scanned photo

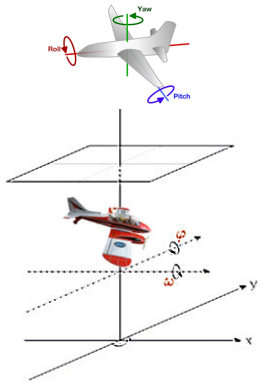
Fiducial marks



- Interior orientation: position of the projection center with respect to the image: Image Coordinate System.
- Each pixel in the image is measured in "cm" or pixels with respect to an orthogonal pair of axis. Origin could also be the principal point.
- Camera calibration report states the location of the principal point and the principal distance

READ

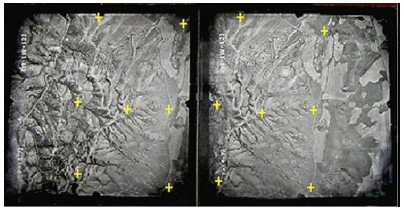
3D APPROACH: EXTERIOR ORIENTATION INDIVIDUAL PHOTOS

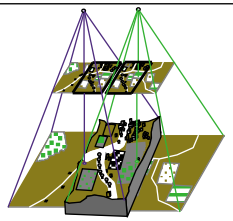


- Determines the position and orientation of the projection center with respect to the terrain (location (x,y,z) and orientation (ω, ψ, κ)
- Exterior orientation solved by RPC (rational polynomial coefficients), modern sensors/cameras. If not available, then:
  - ➢ Indirect camera orientation (GCP's)
  - ➢ Direct camera orientation (GPS and IMU)
  - ➢ Integrated camera orientation (combination of the two)

READ

RELATIVE ORIENTATION FOR STEREO PAIRS



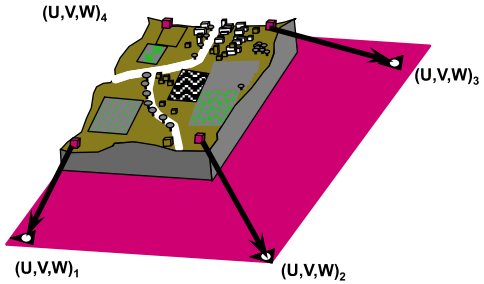


- Stereo pairs are overlapping photographs.
- Conjugate points are found in overlap area of the photo
- Relationship between the two Image Coordinate Systems
  - Instead of doing two independent exterior orientations, first a relative orientation of the two images can be done, followed by an absolute orientation of the pair to the terrain coordinate system
  - This process is nowadays automatic creating CLOUD POINTS. (Advance topics)

READ

ABSOLUTE ORIENTATION

- Follows relative orientation and defines the relationship between the stereo model and the terrain



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CORRECTION OF RELIEF DISPLACEMENT

- If relief prevents to derive accurate planimetric coordinates for a photo, then relief needs to be considered and corrected
- a DTM is required to correct for relief displacement on a single photograph
- After the geometry of this correction is built, then 2 mapping techniques become available
- digital monoplotting
  - Allows direct conversion between the measured image coordinates on the photo to terrain (real world) coordinates
- production of orthophotos or orthoimages
  - the photograph is scanned to provide a digital image
  - the pixels are transformed and resampled
  - An orthographically corrected map is obtained after this process

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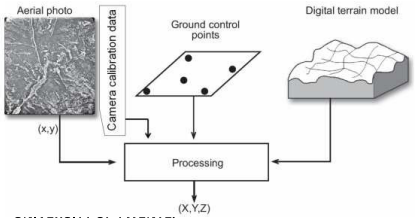
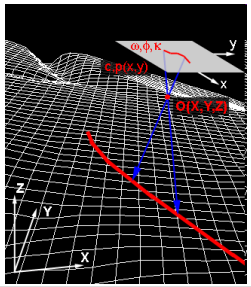
READ

DIGITAL MONOPLOTTING

- Monoplotting is a procedure applied to a single raw aerial image that allows to get corrected real 3D coordinates from direct digitizing on the raw photo.
- The required datasets are: a DTM and an aerial image with its orientation parameters or a georeferenced orthoimage respectively.
- No resampling is done! So image remain distorted but the digitised features have the correct coordinate.





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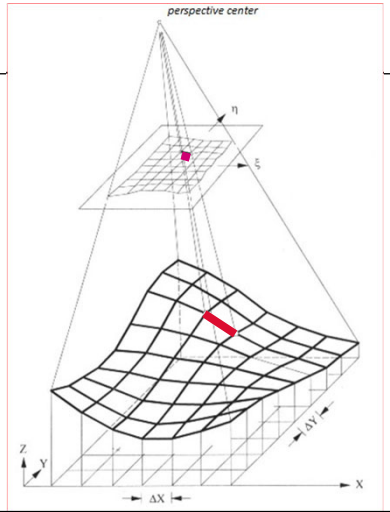
EXAMPLE

- Digitize directly on the photograph
- A vector that is produced is already orthographically corrected



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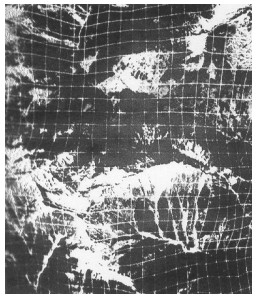
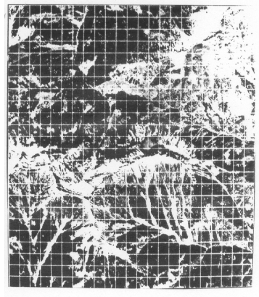
ORTHOPHOTO/ORTHOIMAGE

- Orthoimage delivers only (X,Y) coordinates!



On the original image the map grid is distorted



Geometrically correct orthoimage

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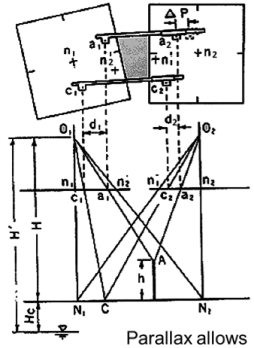

Hc : flight height

c : control point

Hc : height of control point

H : H' - Hc

$\overline{n_1 \cdot n_2}$: principal points on a pair of stereo photos

$\overline{n_1' \cdot n_2'}$: transferred points from each principal point of the photos

$\overline{n_1 \cdot n_2}$: principal distance

$\overline{c_1 \cdot c_2}$: distance between at point c on a pair of stereo photos

$\overline{a_1 \cdot a_2}$: distance between at point a on a pair of stereo photos

parallax at point c : $P = \overline{n_1 \cdot n_2} - \overline{c_1 \cdot c_2}$

parallax distance between point a & c : $\Delta P = \overline{c_1 \cdot c_2} - \overline{a_1 \cdot a_2}$

obtained height : $h = H \cdot \Delta P / (P + \Delta P)$

Parallax allows measurements of heights when Δr is very small

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Lecture End

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