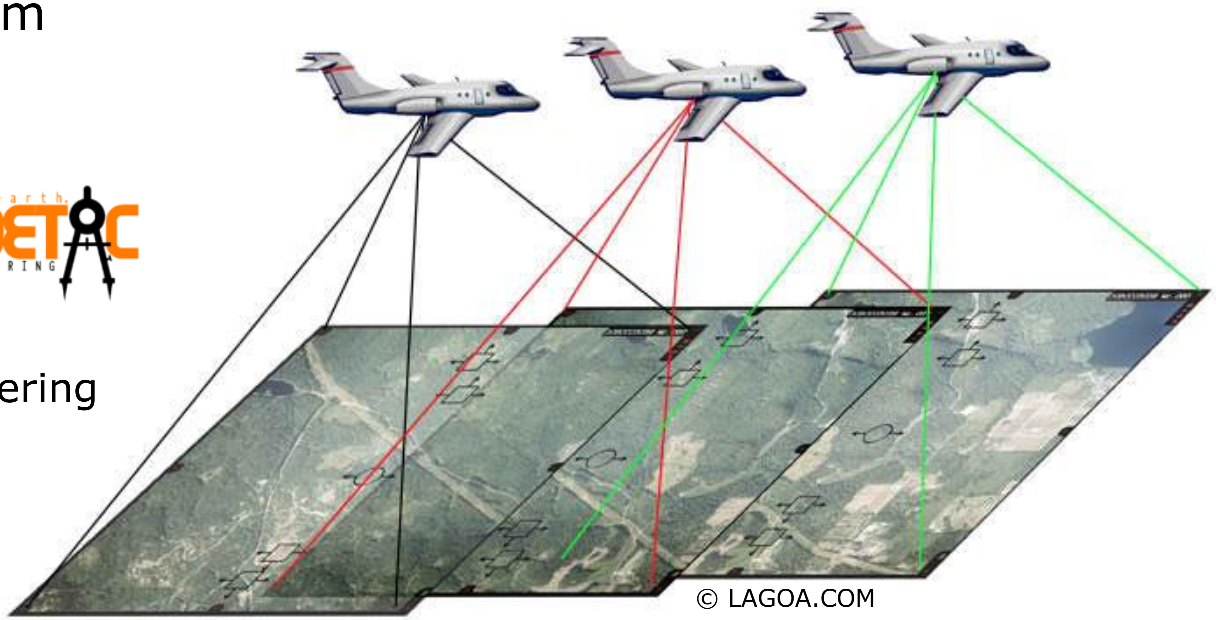
GE 119 – PHOTOGRAMMETRY 2

Topic 3. Principles of Stereophotogrammetry

Instructor: **Engr. Jojene R. Santillan**
jrsantillan@carsu.edu.ph
santillan.jr3@gmail.com



Division of Geodetic Engineering
College of Engineering and Information Technology
Caraga State University

Outline

- Principles of Stereoscopy
- Stereoscopy in Photogrammetry
  - Stereoscopic Viewing of Aerial Photographs
- Stereopairs and Image Parallax
  - Object height and ground coordinate location from parallax measurements

Intended Learning Outcomes

- After this lecture and hands-on exercises, the students must have:
  - Understood the principles of stereoscopy and stereophotogrammetry
  - Described stereopair characteristics
  - Explained the principles of image parallax and its importance and role in stereoscopic viewing and stereophotogrammetric measurements
  - Explained the principles of stereoscopic viewing
  - Created 3D/anaglyphs glasses for stereoscopic viewing
  - Created 3D anaglyph images
  - Performed 3D stereoscopic viewing using stereoimages/stereopairs, stereoscopes and 3D/anaglyph glasses.

Recall:

- **Monophotogrammetry versus Stereophotogrammetry**

REVIEW OF PRINCIPLES OF STEREOSCOPY

Activity #1

- Hold a sharpened pencil or ballpen about 12 inches in front of your eyes with the point nearest and the eraser farthest from you.

- By looking at the point with both eyes, you can see that it has depth and tapers to a point.

- Now close one eye and look directly at the point with your open eye.

Activity #1 Results

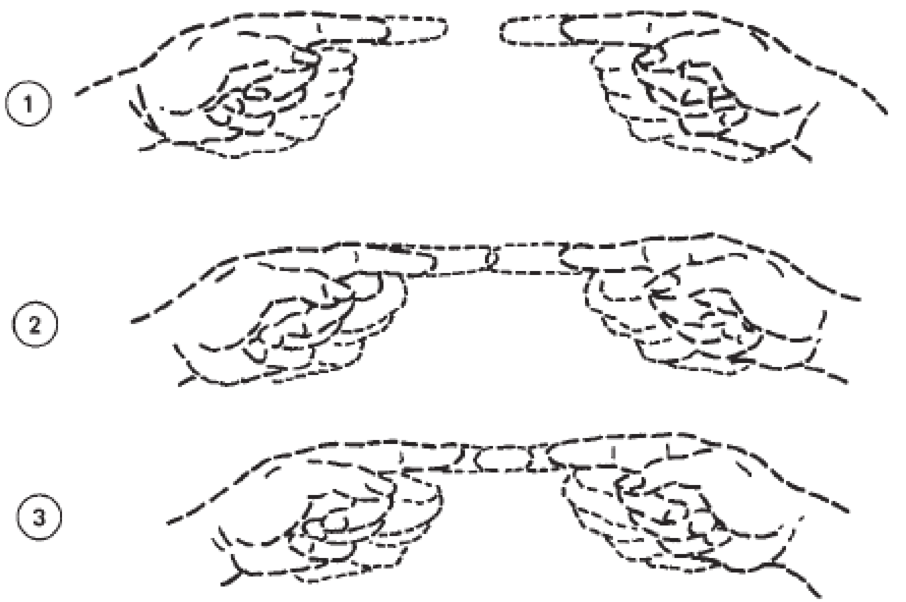
- The end of the pencil/pen appears flat as though it had not yet been sharpened (or not pointed).

- You cannot perceive the depth of the pencil/pen point with just one eye.

- This is how stereoscopy works!

Activity #2: The "sausage exercise"

- Focus your eyes on a distant object
- Slowly bring your forefingers into the line of vision.



- The farther apart your fingers, the larger the sausage forms
- This is an example of **stereoscopic vision**

Stereoscopy

- The art and science of **stereoscopy** deals with the use of **binocular vision** to achieve three-dimensional (3-D) effects.

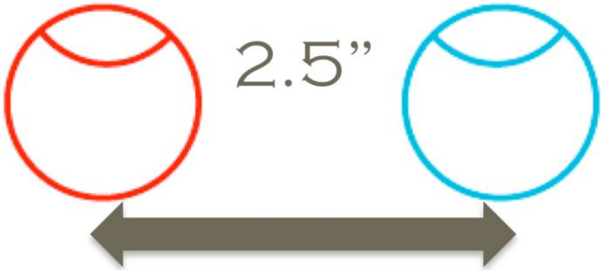
- From Greek στερεός *(stereos)*, meaning 'firm, solid', and σκοπέω *(skopeō)*, meaning **'to look, to see**'.

- Also called "**stereoimaging**"

What is binocular vision?

- Your eyes are approximately two-and-a-half inches or 6cm apart ('interocular distance')

- So they see the same image from slightly different angles and perspectives.



- Your brain then combines these two images in to a single 3-D model.

- This is called **binocular vision**.

- Example:
  - Use of a binocular

- Binocular vision allows us to gauge distance or depth

Source: Stereoscopic 3D, Simon Reeve & Saon Flack

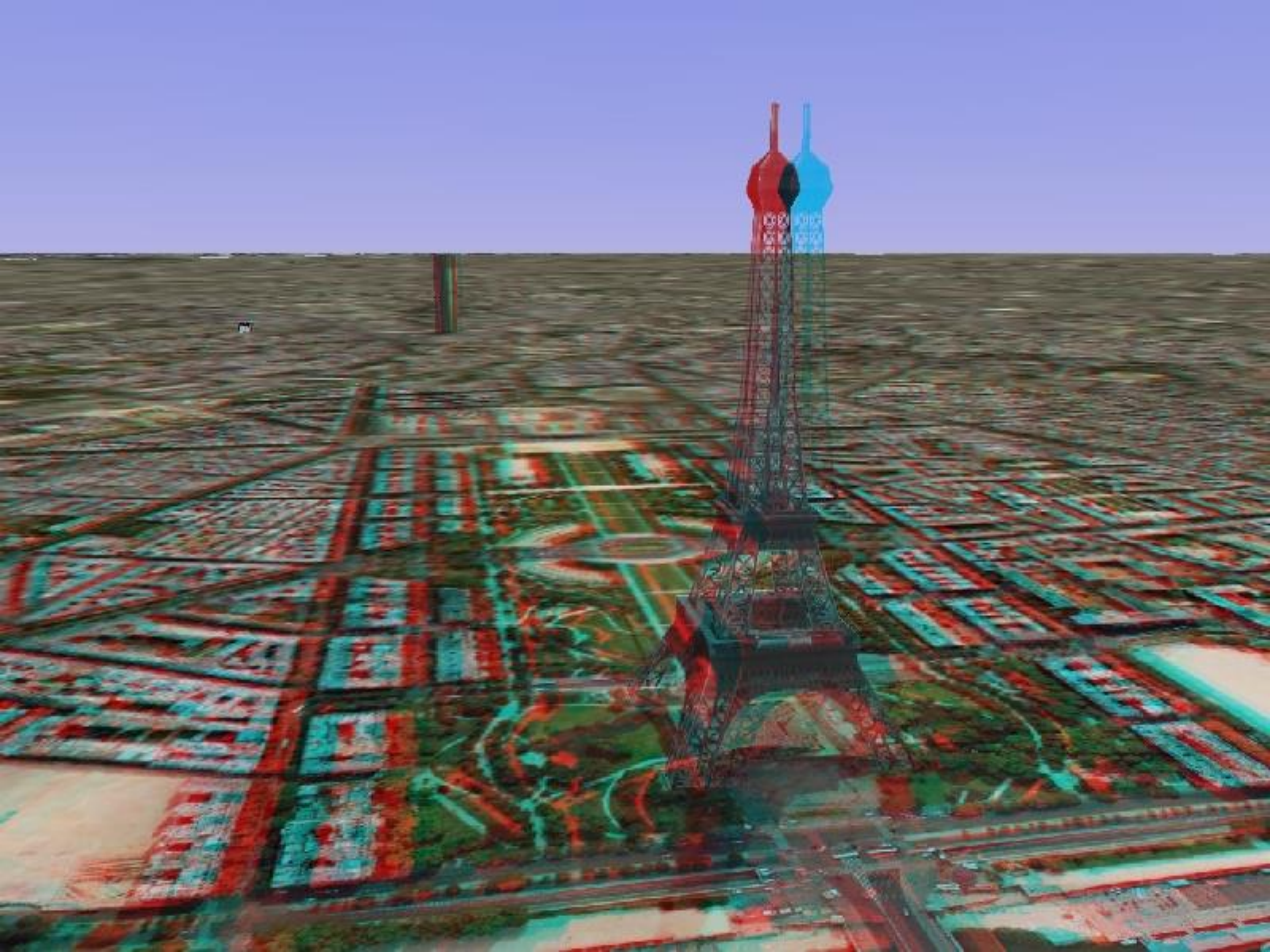
- Most stereoscopic methods present two offset images separately to the left and right eye of the viewer.

- These two-dimensional images are then combined in the brain to give the perception of 3D depth.

Source: Wikipedia

- **Stereo vision**, or '**Stereopsis**', is a result of good binocular vision, wherein the separate images from two eyes are successfully combined into one 3D image in the brain.

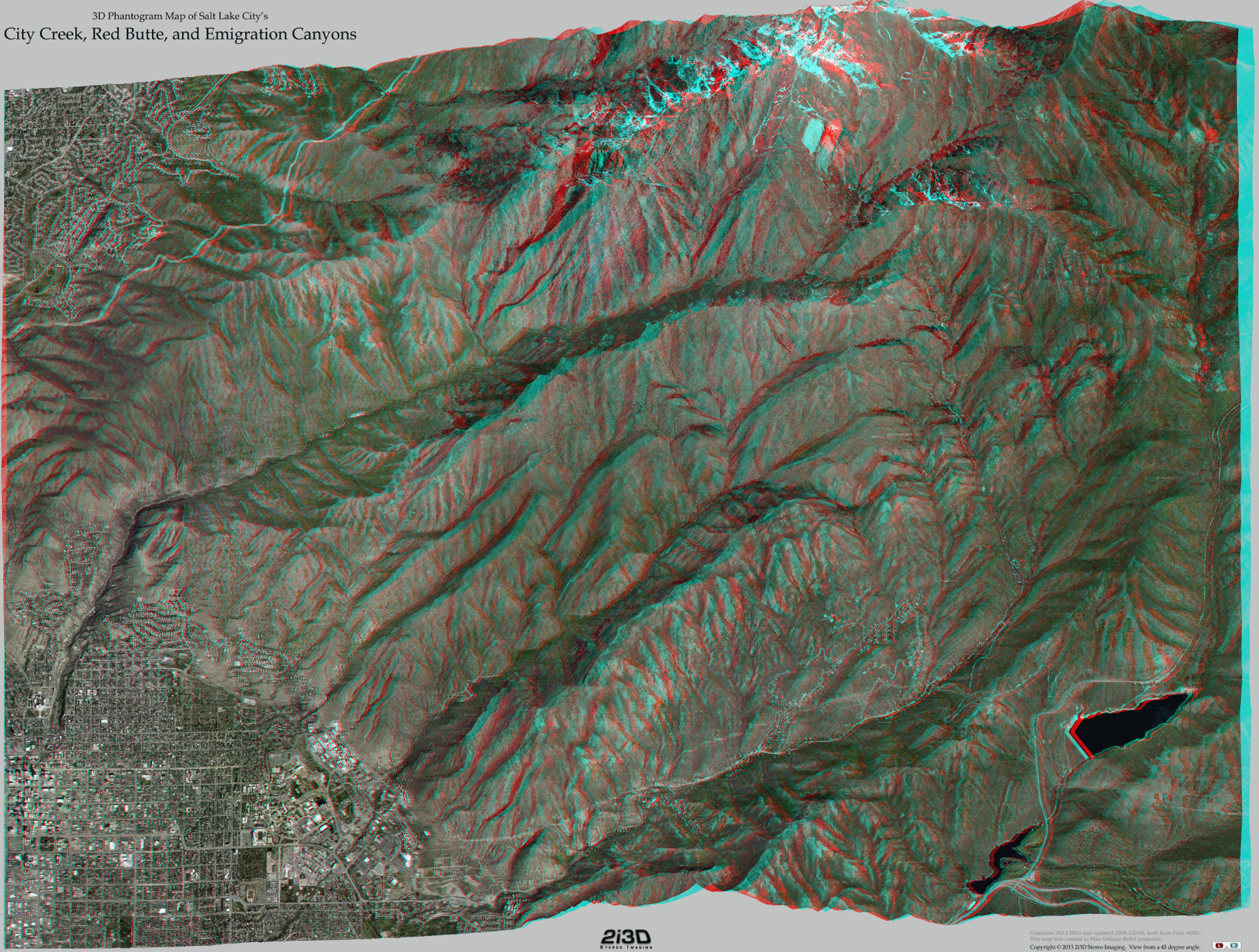
Activity #3



https://en.wikipedia.org/wiki/File:Anaglyph_-_formerly_attributed_to_Piero_della_Francesca.png

3D Phantogram Map of Salt Lake City's

City Creek, Red Butte, and Emigration Canyons



Combines 2012 HRO and updated 2006 LiDAR, both from Utah AGRC.
This map was created in Plan Oblique Relief projection.

- What you have just experienced are demonstration of “stereoscopic vision” using the **Anaglyph 3D method**

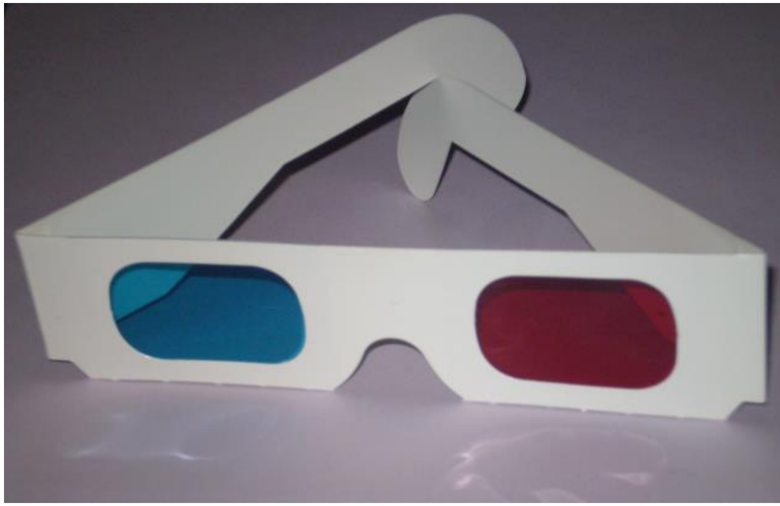
Anaglyph 3D

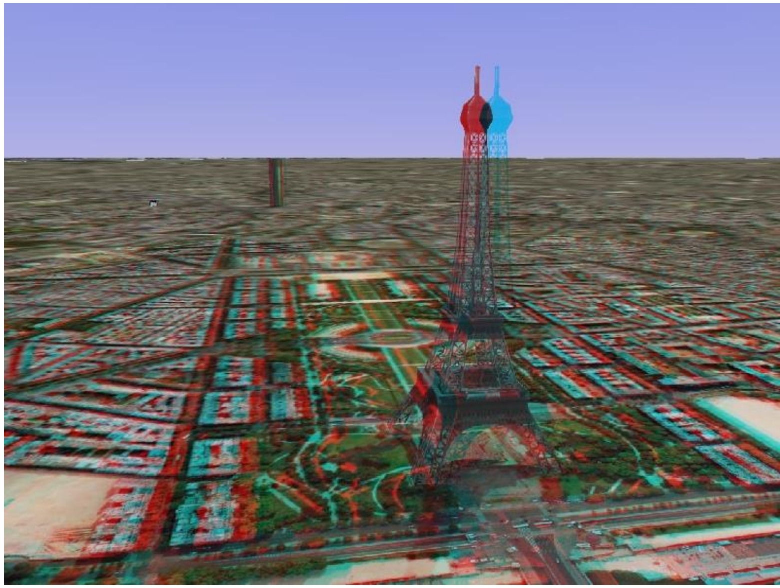
- **Anaglyph 3D** is the name given to the stereoscopic 3D effect achieved by means of encoding each eye's image using filters of different (usually chromatically opposite) colors, typically red and cyan.

- Anaglyph 3D images contain two differently filtered colored images, one for each eye.

- When viewed through the "color-coded" "anaglyph glasses", each of the two images reaches the eye it's intended for, revealing an integrated stereoscopic image.

- The visual cortex of the brain fuses this into the perception of a three-dimensional scene or composition.





Source: Wikipedia

How is “stereoscopy” applied in Photogrammetry?

STEREOSCOPY IN PHOTOGRAMMETRY

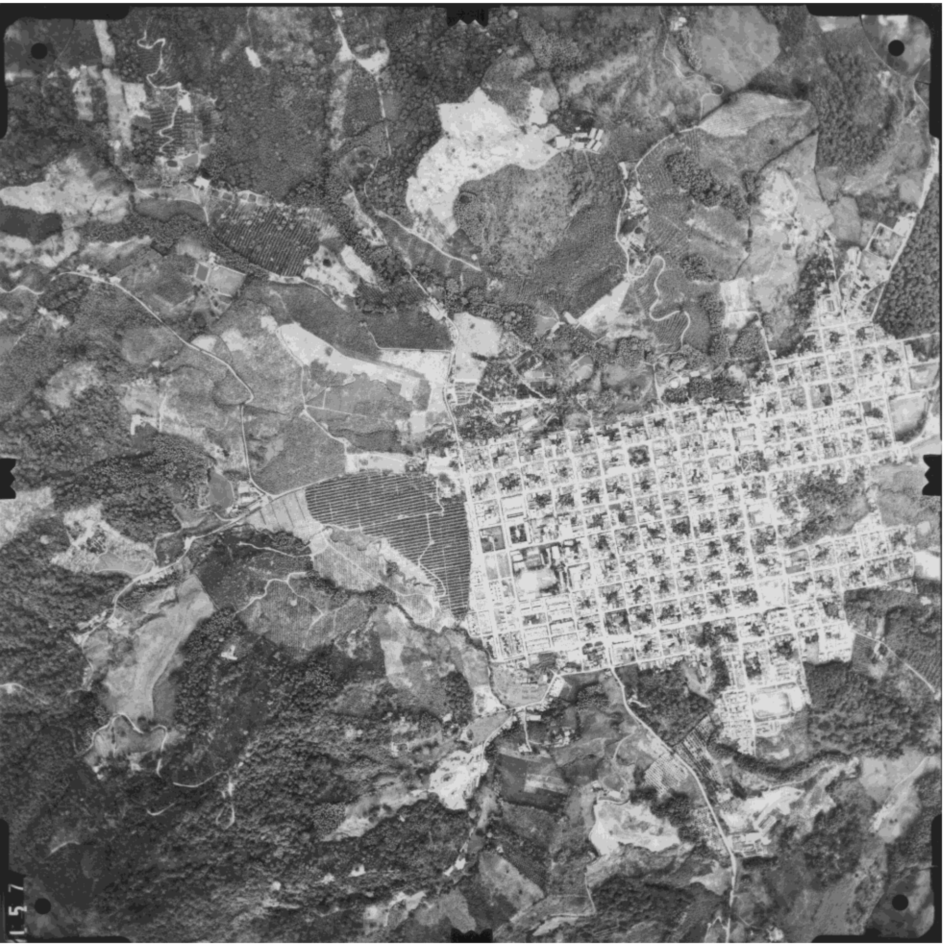
Stereoscopy in Photogrammetry

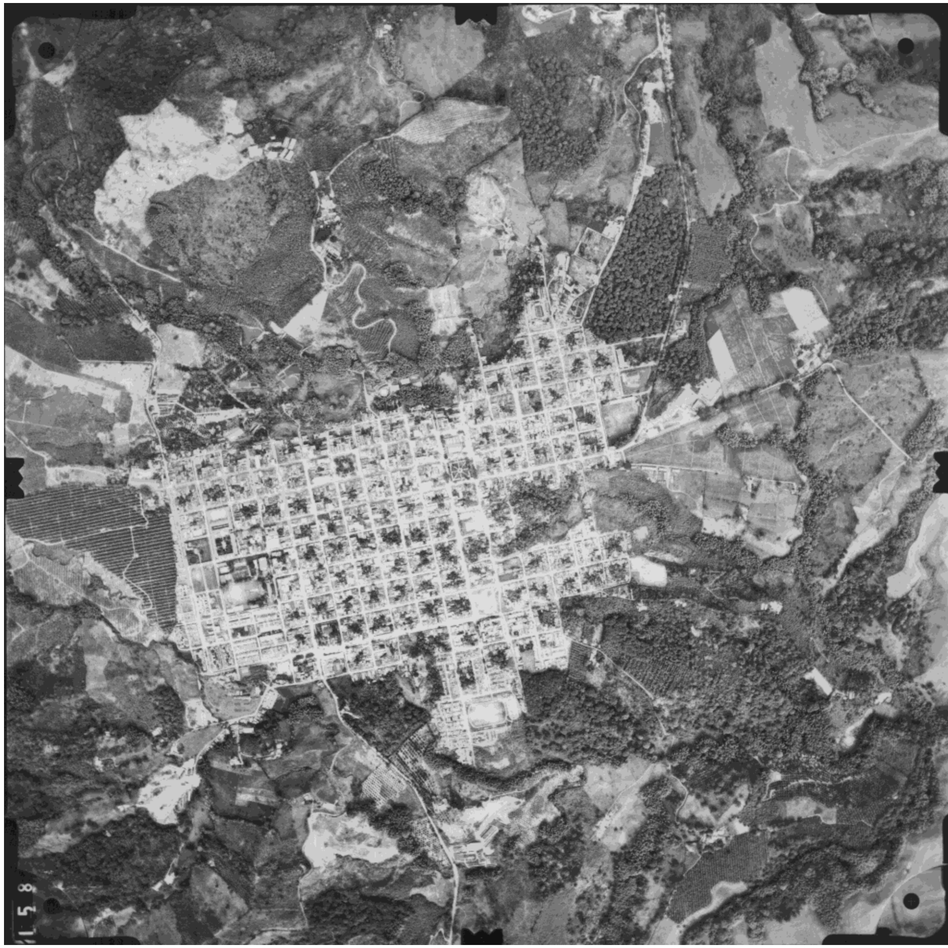
- We can **visualize 3D** information in aerial photographs through the use of a **"stereoscopic pair"** or **"stereopair"** of aerial photographs
  - If digital, we call it "model", "stereo model", or "image pair"
- This pair of aerial photographs consists of two adjacent, overlapping photos in the same flight line
- The stereoscopic view is seen only in the overlapped portion of the photos

Example of a Stereopair

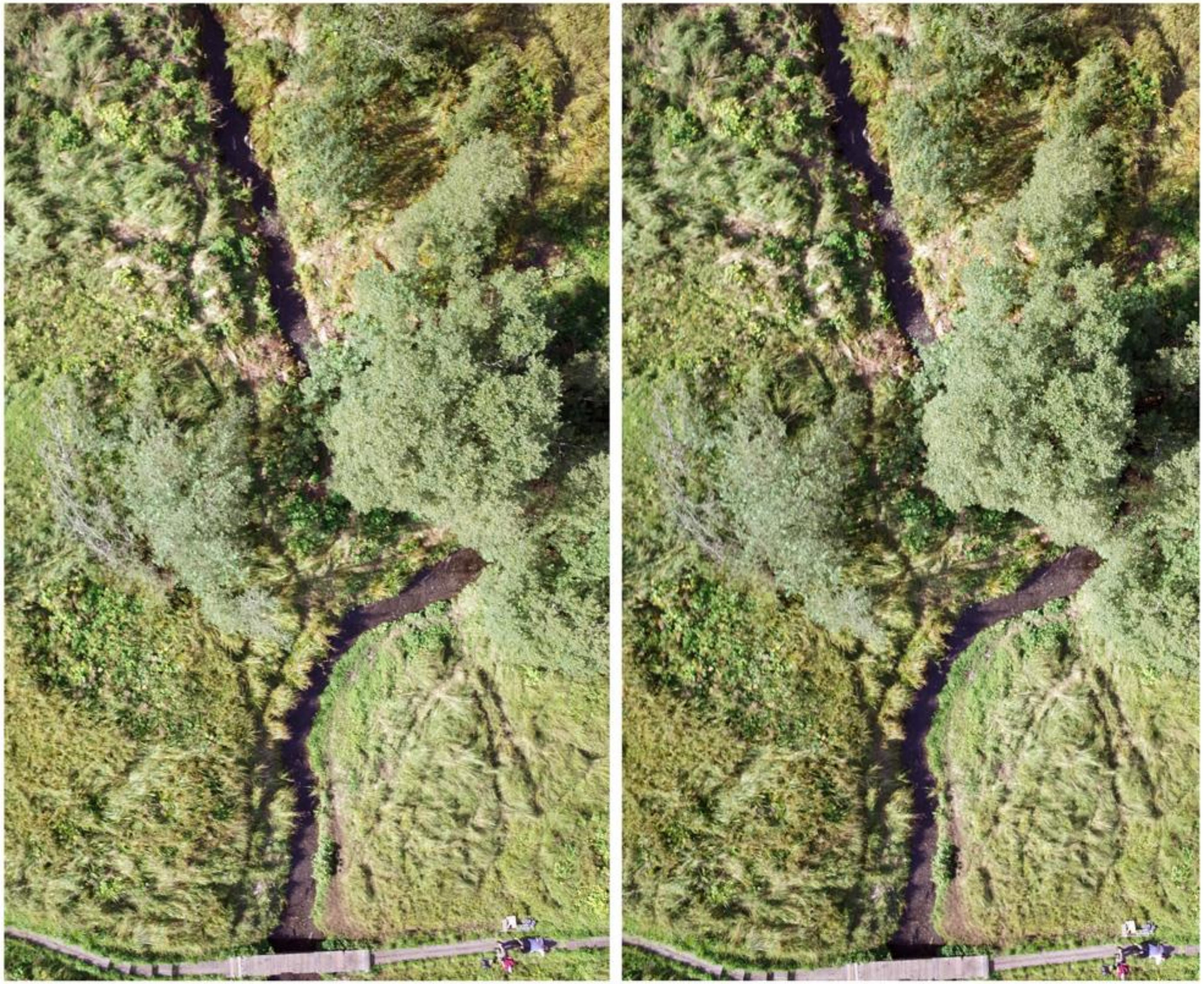
- A minimum **50% endlap** is necessary for complete stereoscopic view of the are photographed.
- This is the reason why in aerial photography missions, 60% endlap is set as a safety factor (i.e., to ensure 50% overlap is achieved)

Another Example of a Stereopair



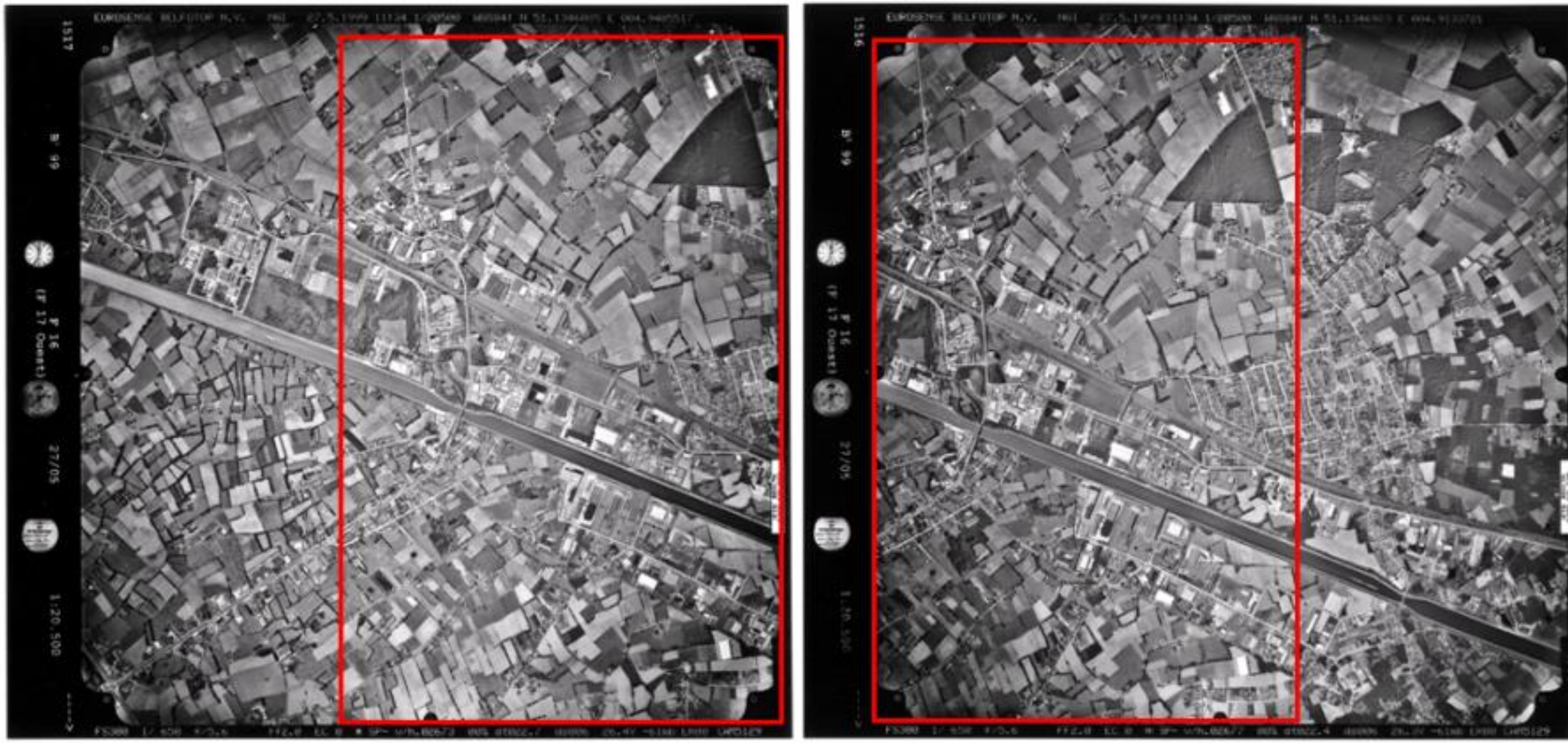


Another Example of a Stereopair



https://www.discoverysoutheast.org/wp-content/uploads/2016/02/stereo3.jpg

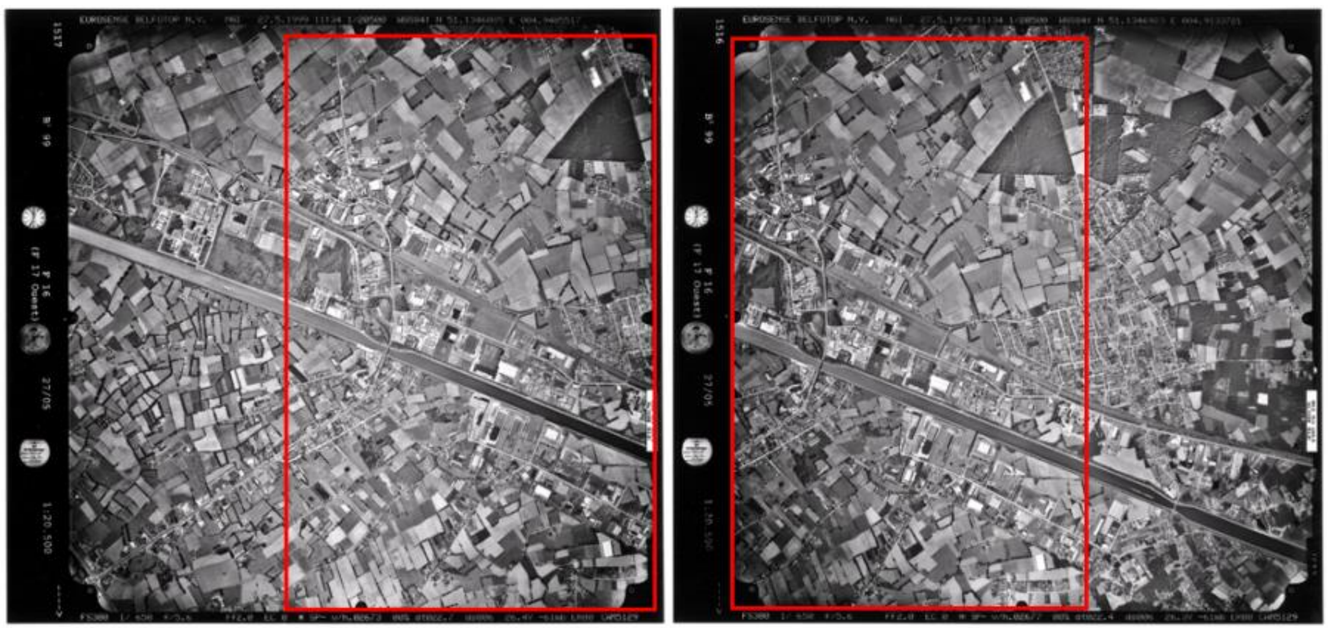
Another Example of a Stereopair



Source: http://www.seos-project.eu/modules/3d-models/images/stereopair_overlap.png

Stereogram

- If we take a stereoscopic pair of aerial photos, cut out of each photo the part that shows the same area of interest on the ground, then correctly orient and mount them side by side, we have a ***stereogram!***

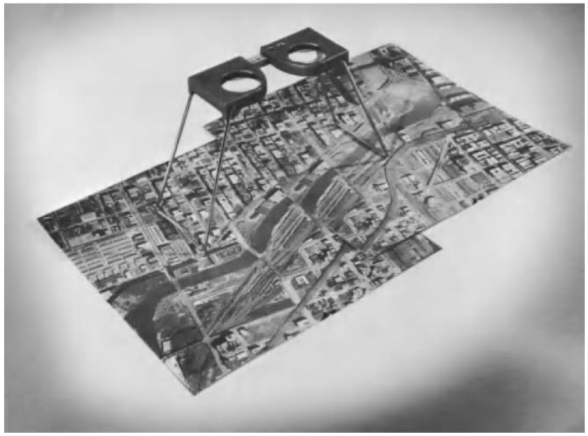


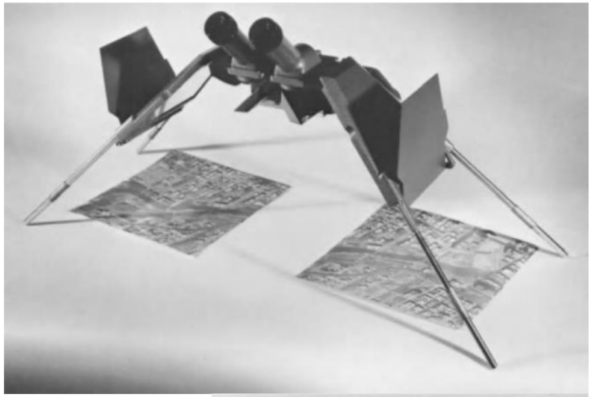
How can we achieve a stereoscopic image using a stereopair?

(i.e., how can we convert a stereogram into a 3D?)

Analog Stereoscopic Viewing Instrument

- **Stereoscope**
  - A binocular optical instrument that helps us view two properly oriented photographs to obtain the mental impression of a three-dimensional model.
  - Most stereoscopes also magnify the images
- **Types of stereoscope**
  - Lens stereoscope
  - Mirror stereoscope
  - Scanning stereoscope
  - Zoom stereoscope

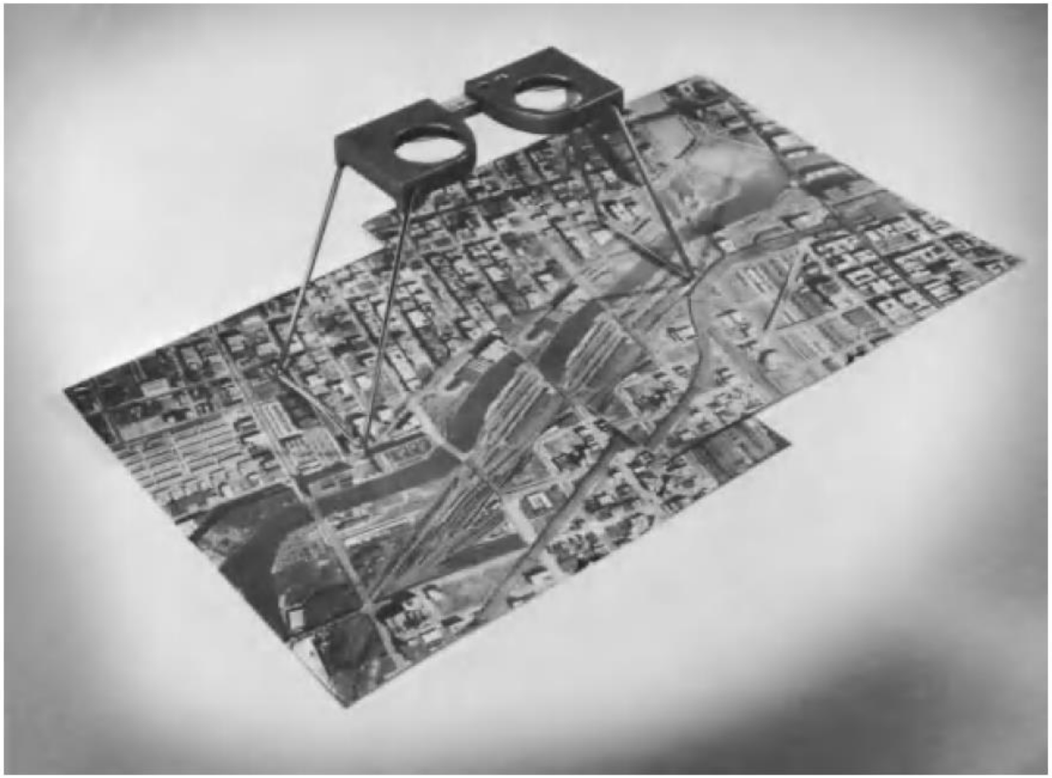




Paine and Kiser, 2012. Aerial Photography and Image Interpretation, 3rd Edition, John Wiley & Sons, Inc.

Lens (or pocket) Stereoscope

- Simplest and less expensive
- Consist of 2 magnifying lenses mounted with a separation equal to the average **interpupillary** distance of the human eye
  - There is a provision to adjust the separation distance
- The legs are foldable making it possible to carry it in a pocket
- Disadvantage: **the two photos must be so closed together so that you can see a stereoscopic image**

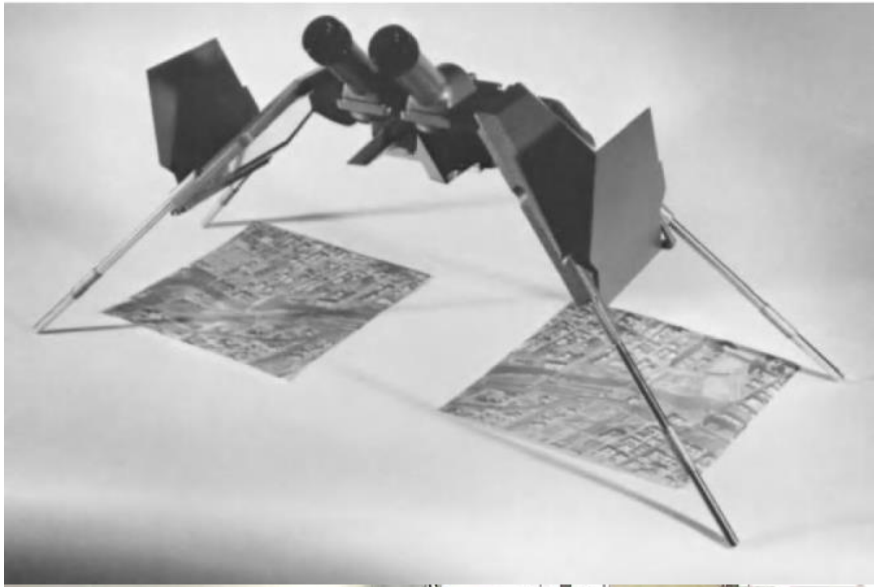


Paine and Kiser, 2012. Aerial Photography and Image Interpretation, 3rd Edition, John Wiley & Sons, Inc.

Mirror Stereoscope

- Consists of a pair of small eyepiece mirrors and a pair of larger wing mirrors, each of which is oriented at a 45^0 angle with respect to the plane of the photographs

- **Advantage**: the photographs may be completely separated for viewing, and the entire overlap may be seen stereoscopically



Paine and Kiser, 2012. Aerial Photography and Image Interpretation, 3rd Edition, John Wiley & Sons, Inc.

Scanning Stereoscope

- A mirror stereoscope equipped with magnifying eyepieces which can be individually focused, or can be spread apart or pulled together to suit the viewer

- It also consist of highly corrected lenses and prisms which allow the forming of a very sharp stereoscopic image

- **Advantage**: There are two knobs that allow the viewer to scan the stereoscopic image in both the x and y directions without moving the instrument of the photograph

- **No longer produced.**

Paine and Kiser, 2012. Aerial Photography and Image Interpretation, 3rd Edition, John Wiley & Sons, Inc.

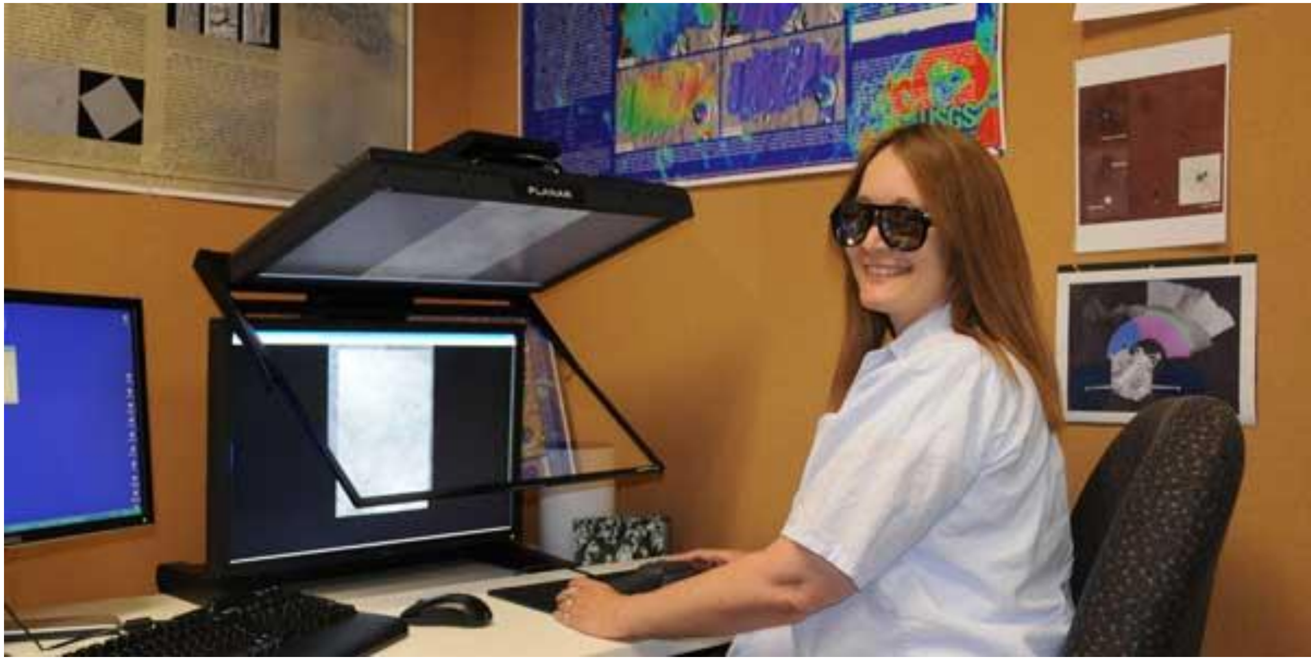
Zoom Stereoscope

- Provides a continuously variable in-focus magnification with a single set of eyepieces
- Has high magnification capability
  - Useful for intrepreting very-high photographs taken by high-resolution cameras.

Paine and Kiser, 2012. Aerial Photography and Image Interpretation, 3rd Edition, John Wiley & Sons, Inc.

Digital Stereoscopic Viewing

- Use of specialized monitors and 3D glasses
  - Example: Planar System's StereoMirror™



http://mms.businesswire.com/bwapps/mediaserver/ViewMedia?mgid=52810&vid=5&download=1

http://www.planar.com/

Digital Stereoscopic Viewing

- 3D Anaglyph Method

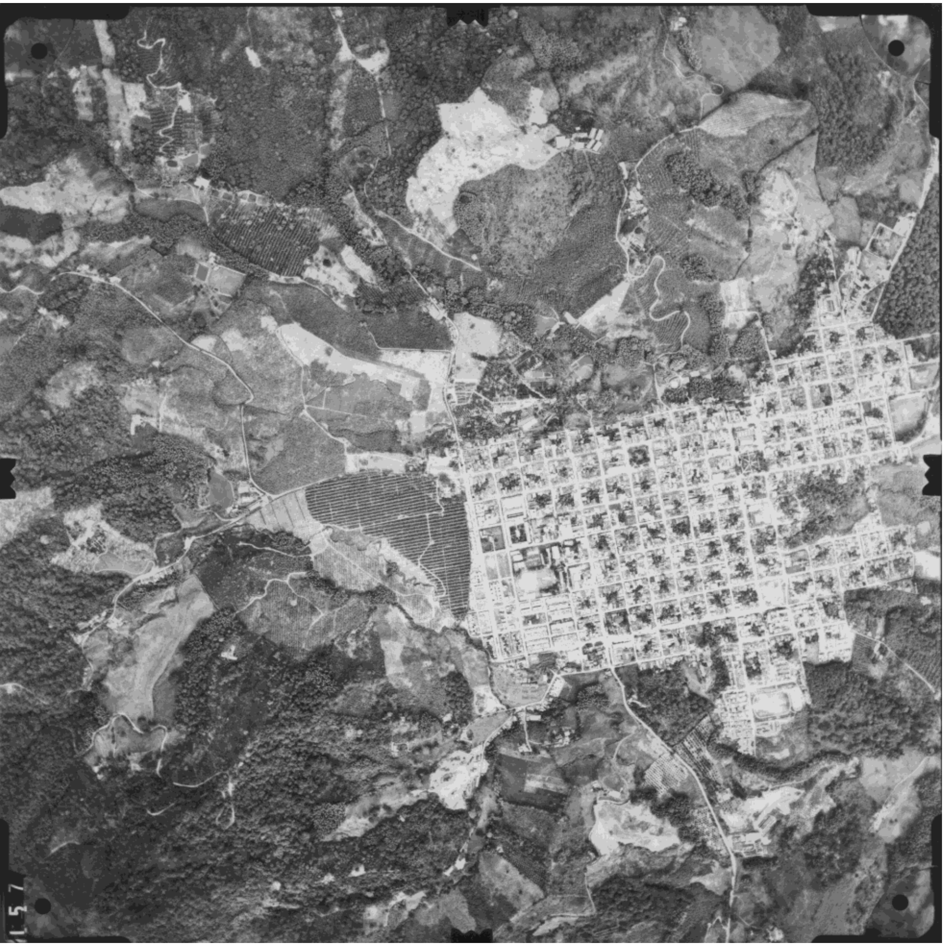
http://www.gpsi-corp.com/service8_photogrammetric_map.asp

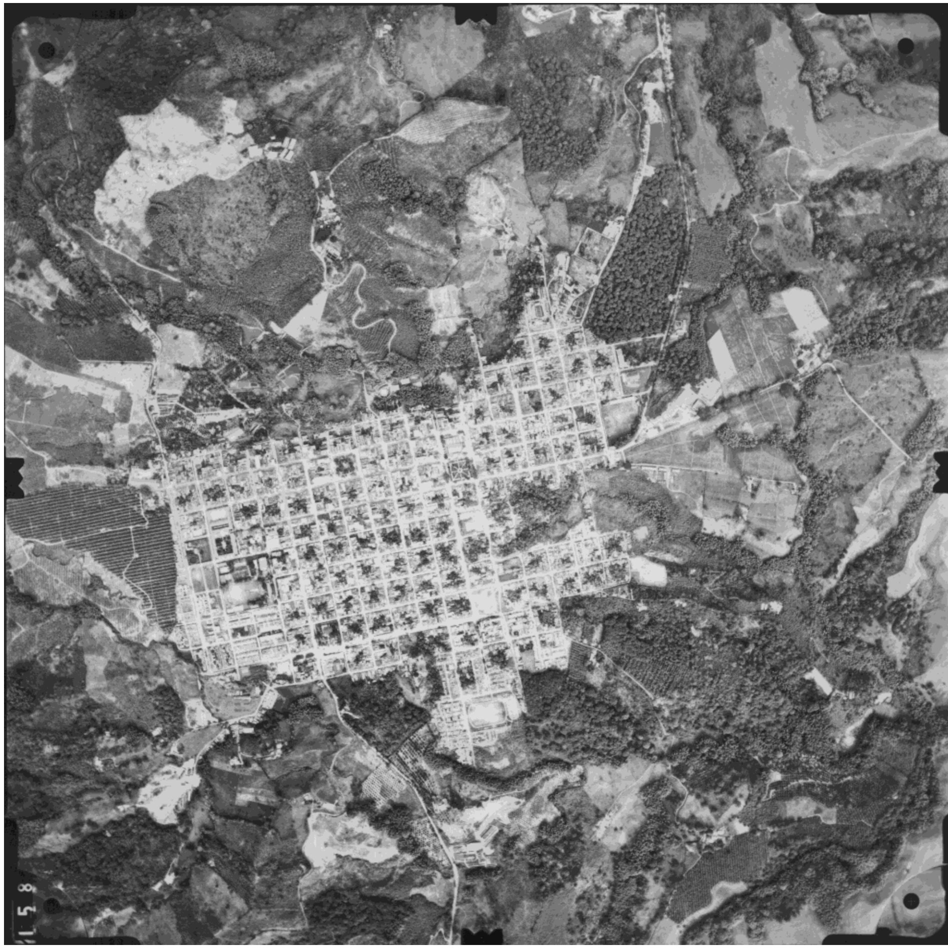
Some software that can be used to create 3D Anaglyphs

- Free:
  - **Anaglyph Maker:**
    - http://www.stereoeye.jp/software/index_e.html

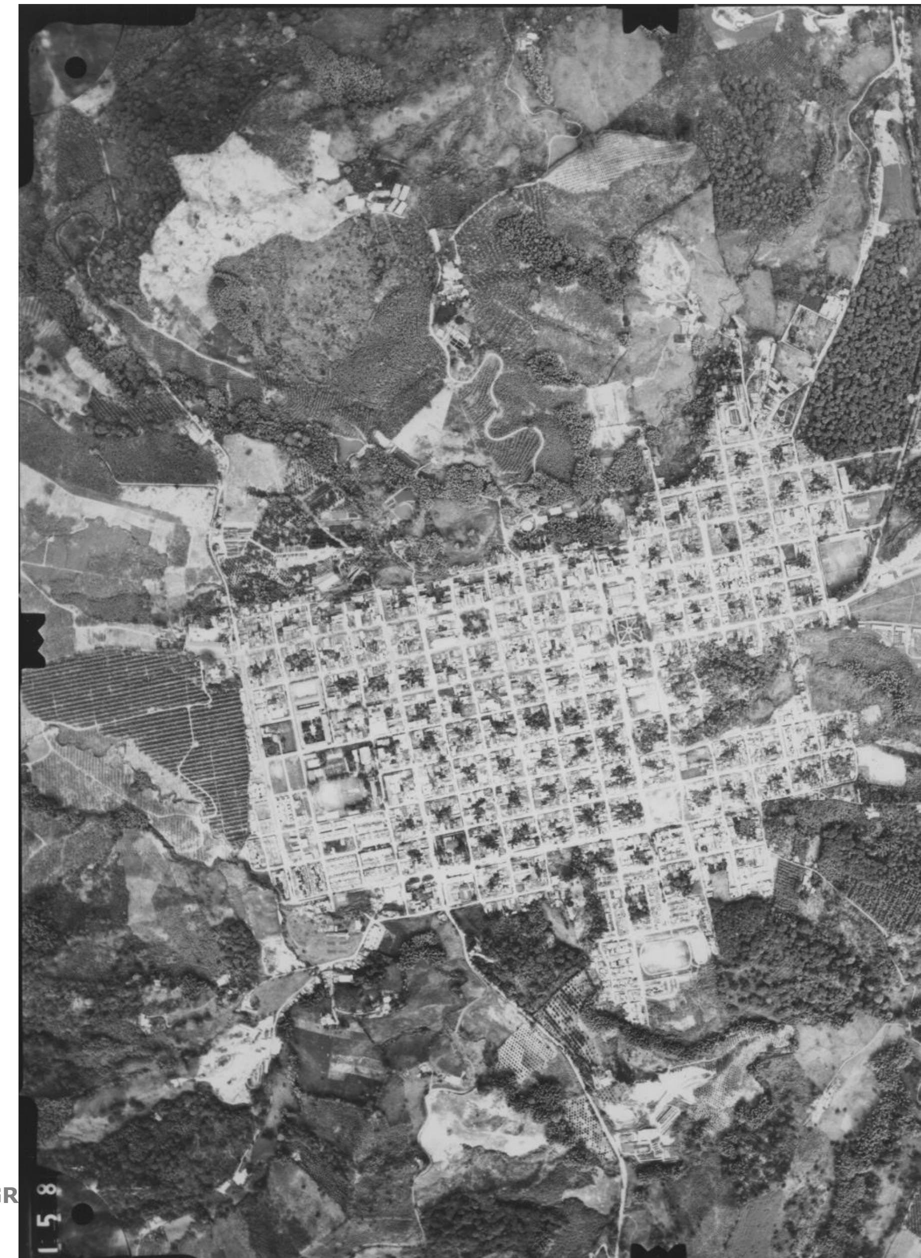
- Not free:
  - Adobe Photoshop
  - ArcGIS
  - Agisoft PhotoScan (Trial version available)
  - Pix4D (Trial version available)

Example Stereopair to be converted into a 3D Anaglyph (Using Anaglyph Maker)

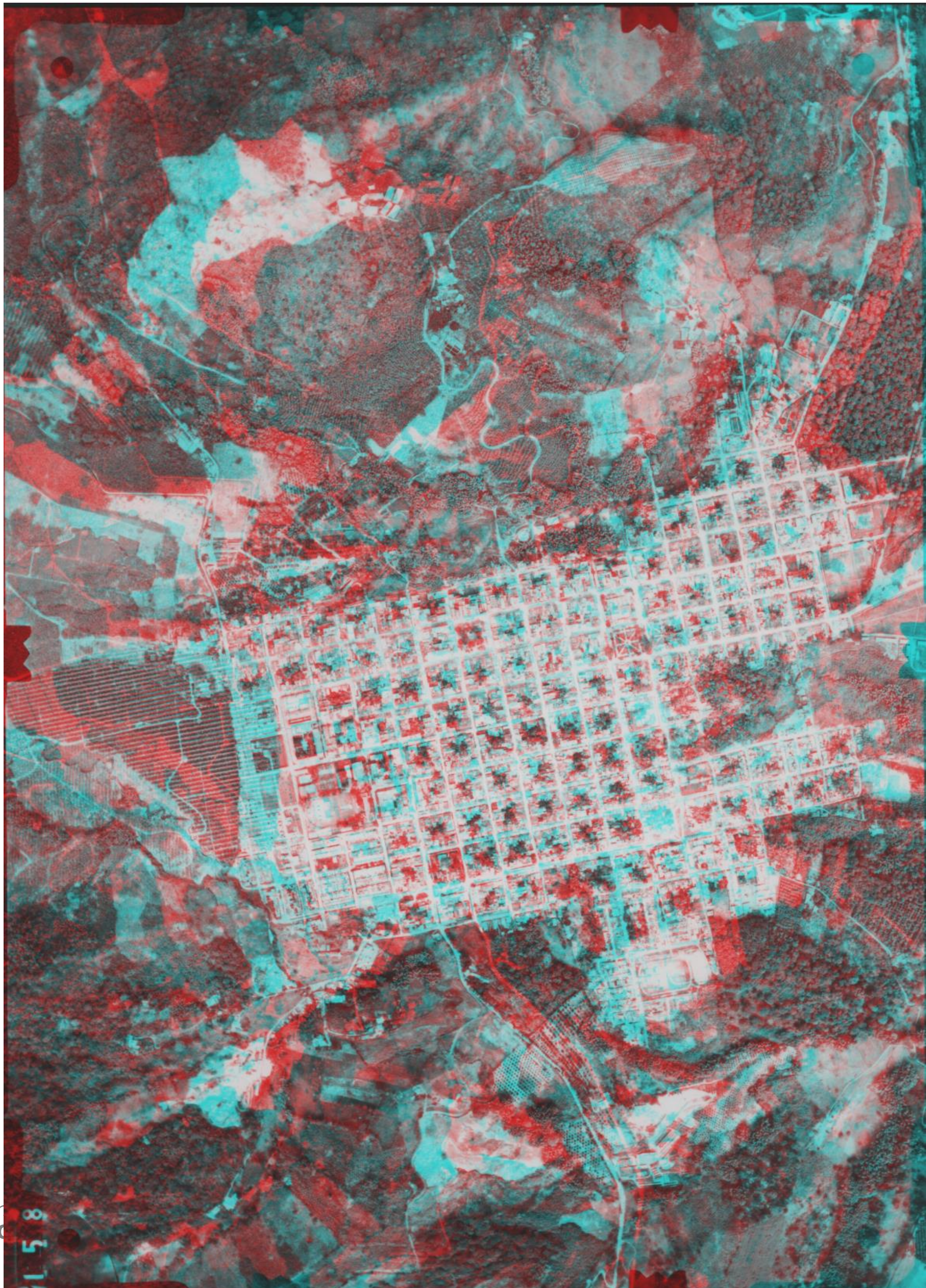




Stereogram generated (separated into left and right)



The 3D Anaglyph Image



Remarks

- Stereoscopy is useful in stereophotogrammetry as it allows the viewing in 3D of adjacent aerial photographs
- Since stereoscopic viewing provides 3D images, differences in heights of objects in a stereopair can be viewed also
- We can view heights, but can we measure it?

STEREOPAIRS AND IMAGE PARALLAX

- Analysis of **stereopairs** and using the principle of **parallax** are utilized in numerous applications of photogrammetry

- **Parallax**
  - the apparent change in relative positions of stationary objects caused by a change in viewing position

Illustration of Parallax (looking at objects through a side window of a moving vehicle)

https://www.shutterstock.com/video/clip-3984934-stock-footage-window-view-from-a-car-bus-train-traveling-hd-videos-no.html?src=rel/9337565:1/3p

Concept of Parallax

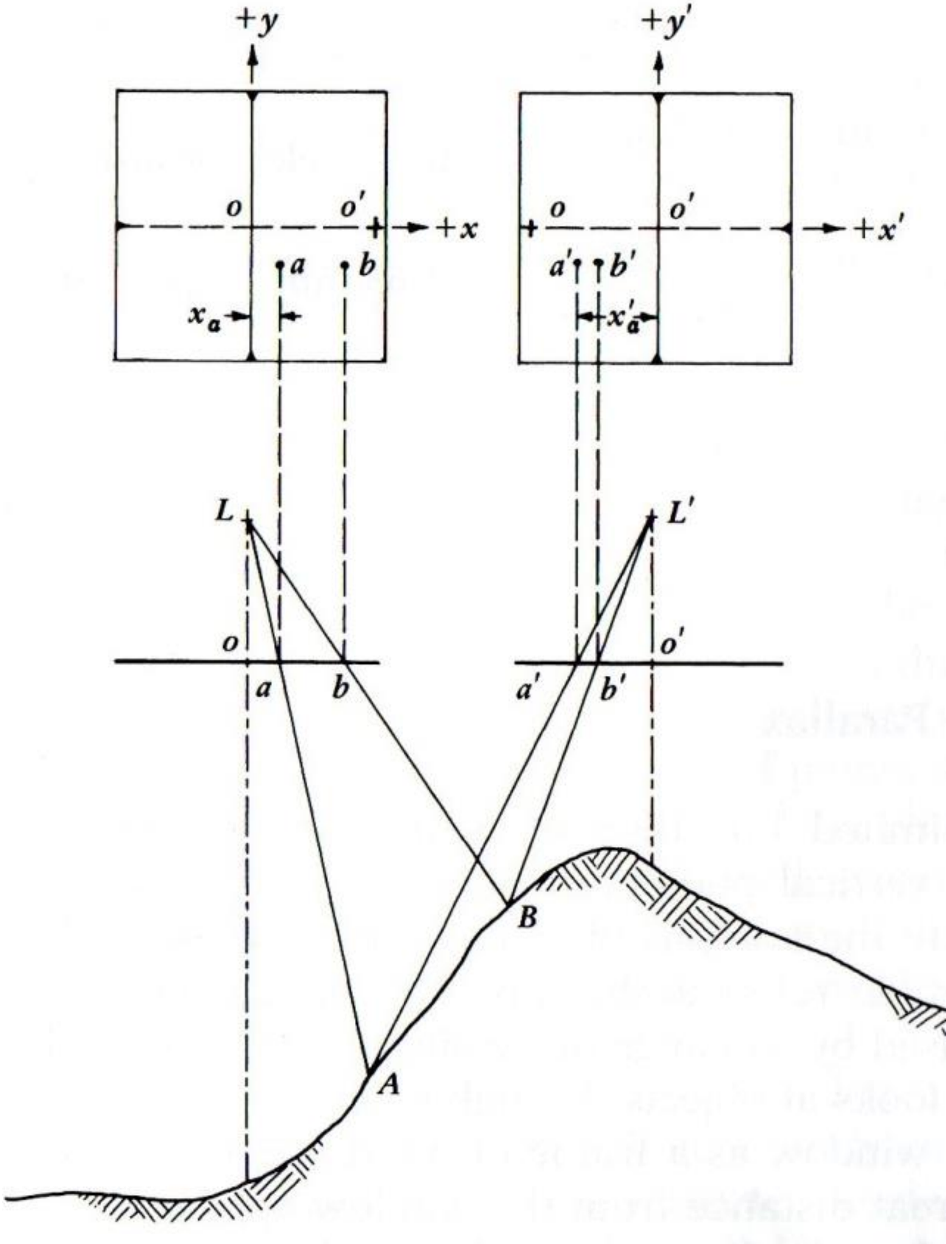
- Objects such as mountains that are at relatively great distance from the window appear to move very little

- Objects close to the window, such as trees, appear to move through a much greater distance.

https://www.shutterstock.com/video/clip-3984934-stock-footage-window-view-from-a-car-bus-train-traveling-hd-videos-no.html?src=rel/9337565:1/3p

Parallax in Aerial Photography

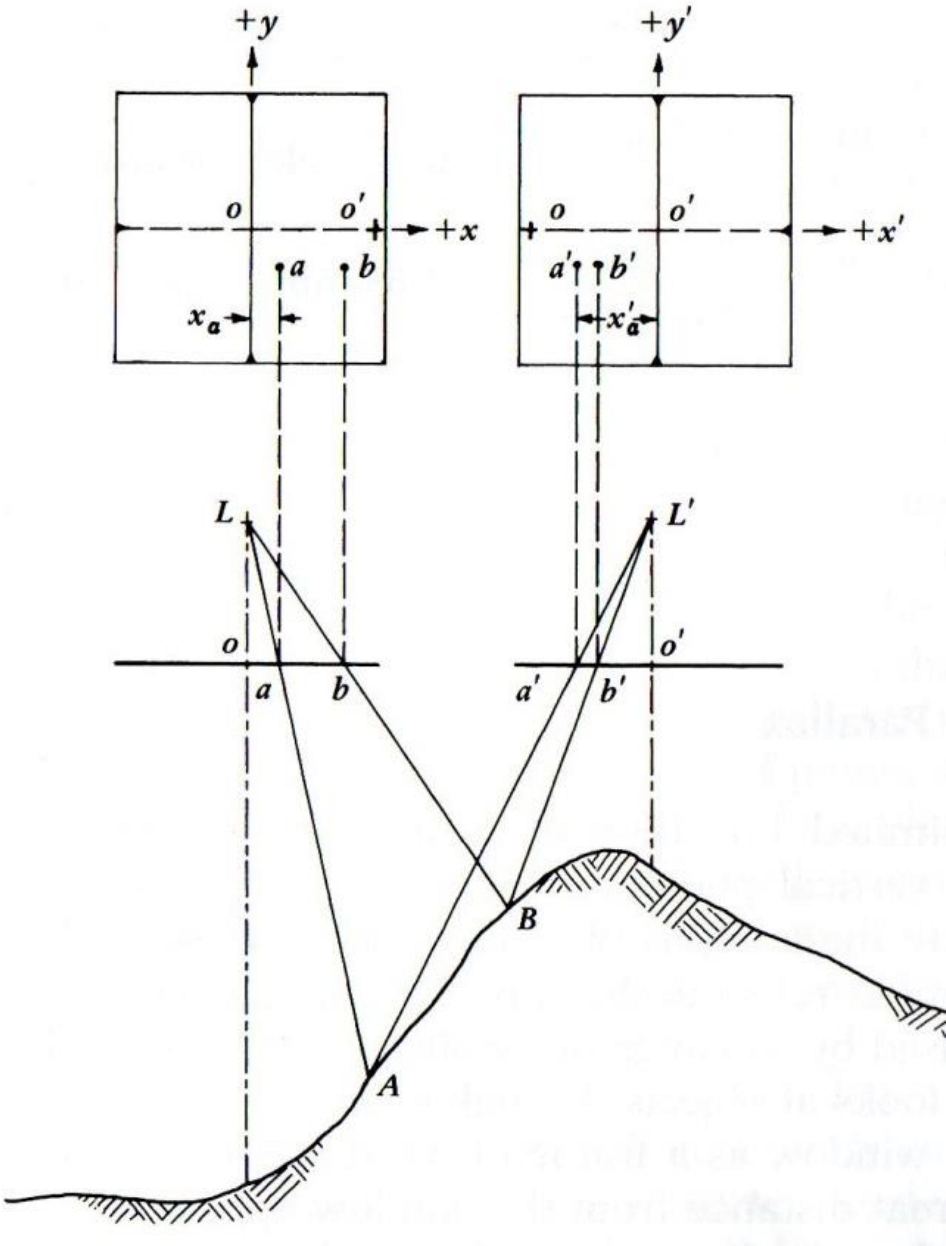
- During aerial photography:
  - Terrain features close to the aircraft (i.e., those features that are at **higher elevation**) will appear to move relative to the lower elevation features when the **point of view changes** between successive exposures.
  - In the figure: Relative positions of **A** and **B** in the photographs **change** with the **change in viewing position** (i.e., the change in the exposure station location)



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Parallax in Aerial Photography

- This **relative displacements** (e.g., in the positions of **A** and **B**) form the basis for 3-dimensional viewing of overlapping photographs or **stereopairs**.
  - These relative displacements can also be measured and use to compute the **elevation** of terrain points, and the **differences in elevation** of those points.



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Notes about Image Parallax

- Parallax displacements occur only **parallel** to the line of flight.
- In theory: the direction of flight should correspond precisely to the fiducial x axis.
- In reality: unavoidable changes in the aircraft orientation will usually slightly offset the **fiducial axis** from the **flight axis**.

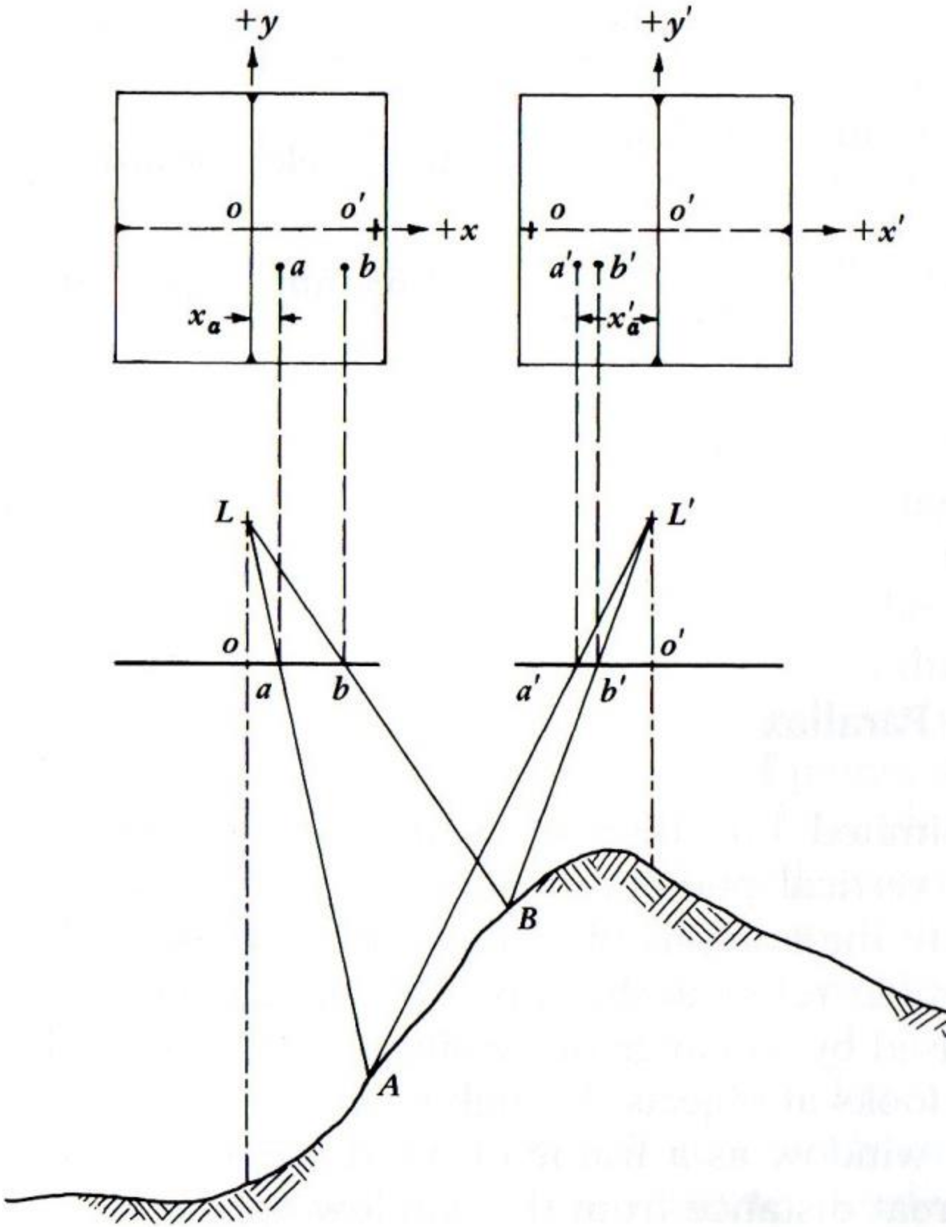


Illustration of the offset in the fiducial and flight axes

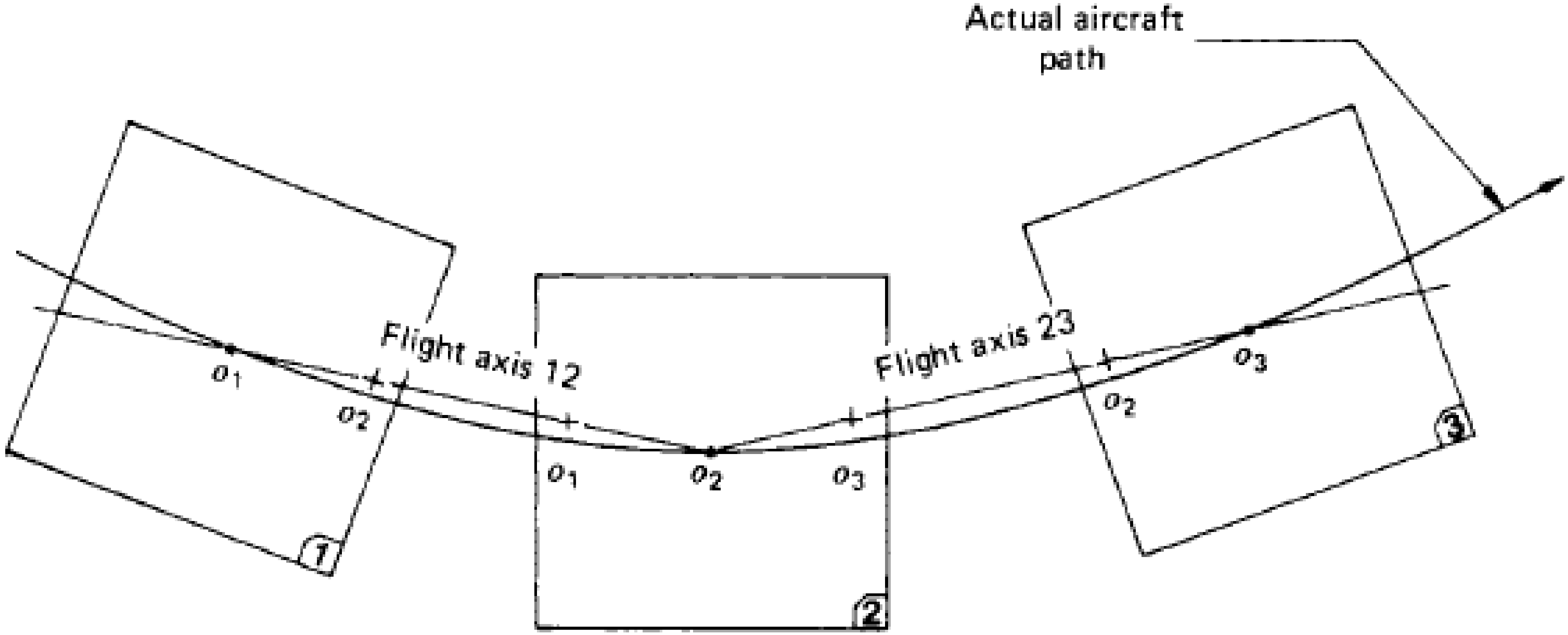


Figure 3.16 Flight line axes for successive stereopairs along a flight strip. (Curvature of aircraft path is exaggerated.)

Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Finding the true flight line axis (1)

- Locate on the photographs the points that correspond to the image centers of the preceding and succeeding photographs
  - E.g., $\mathbf{o_1}$, $\mathbf{o_2}$ and $\mathbf{o_3}$ are the image centers of the 3 successive photographs
  - These points are called the **conjugate principal points**
    - E.g., on the first photo, o_2 is a conjugate principal point; on the 2nd photo, o1 and o3 are conjugate principal points; and so on…

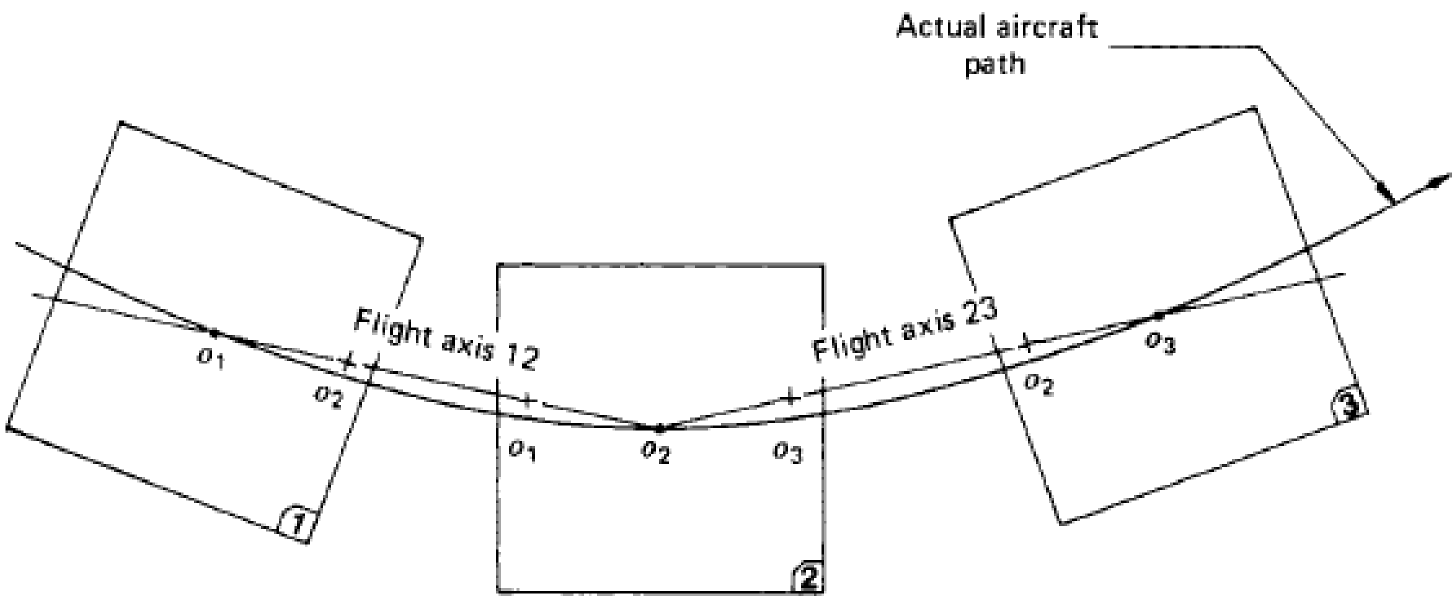


Figure 3.16 Flight line axes for successive stereopairs along a flight strip. (Curvature of aircraft path is exaggerated.)

Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Finding the true flight line axis (2)

- A line drawn through the principal points and the conjugate principal points defines the **flight axis**
- All photographs **except those on the ends of a flight strip** normally have **two sets of flight axes**.
- Cause: aircraft's path between exposures is usually slightly curved.

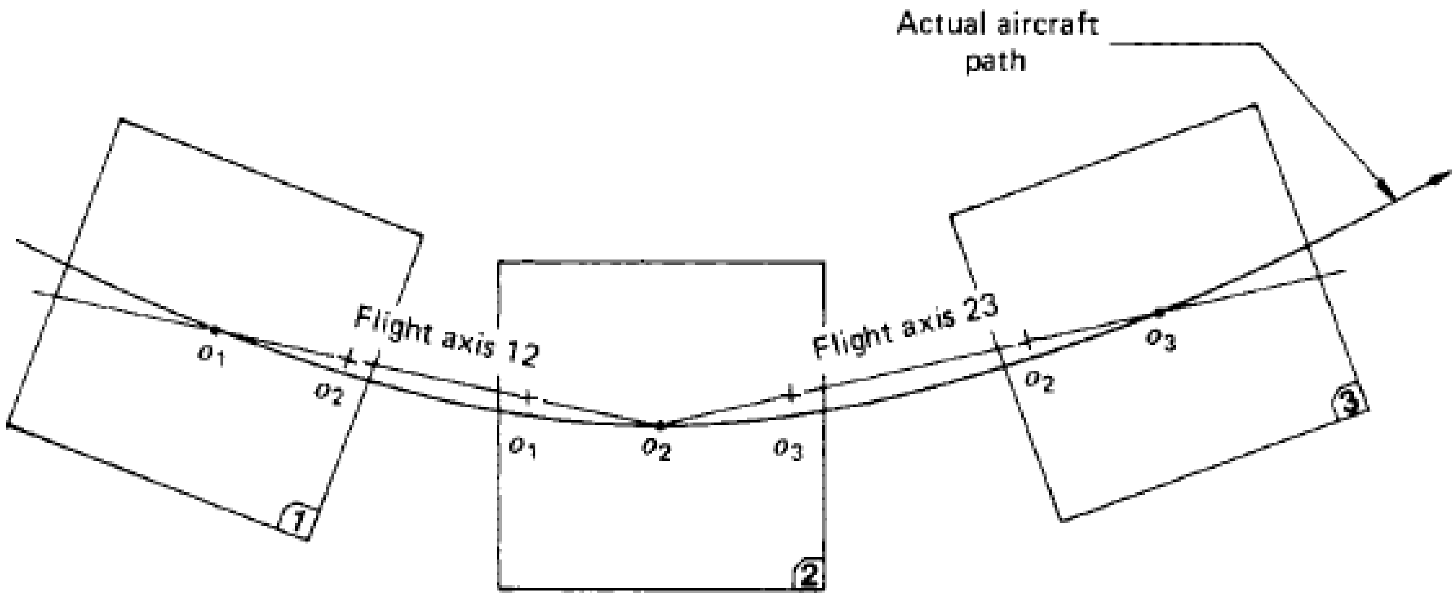


Figure 3.16 Flight line axes for successive stereopairs along a flight strip. (Curvature of aircraft path is exaggerated.)

Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Computing Image Parallax

- The line of flight for any given stereopair defines a photocoordinate ***x* axis** for use in parallax measurement

- Lines drawn perpendicular to the flight line and passing through the principal point of each photo form the photocoordinate ***y* axes** for parallax measurement

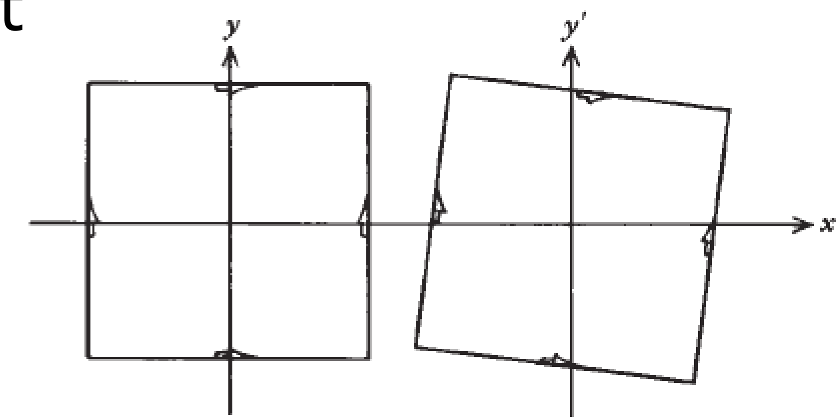


Figure 3.6. Coordinate axes of a stereoscopic pair of photographs. The *x* and *y* axes do not pass through the fiducial marks on the crabbed (rotated) photo on the right.

Paine and Kiser, 2012. Aerial Photography and Image Interpretation, 3rd Edition, John Wiley & Sons, Inc.

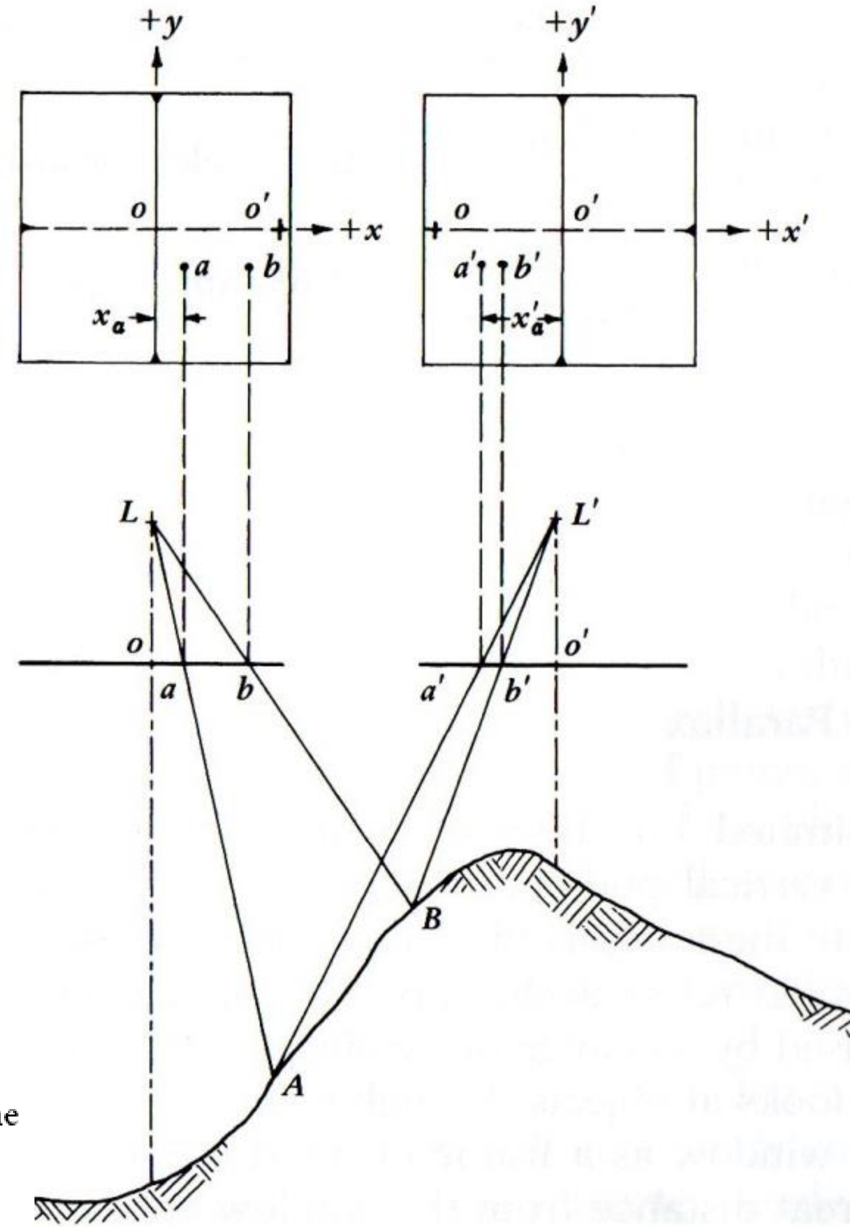
Computing Image Parallax

- The parallax of any point (such as **A** in the figure) is expressed in terms of the flight line coordinate system

- $p_a = x_a - x'_a$

where

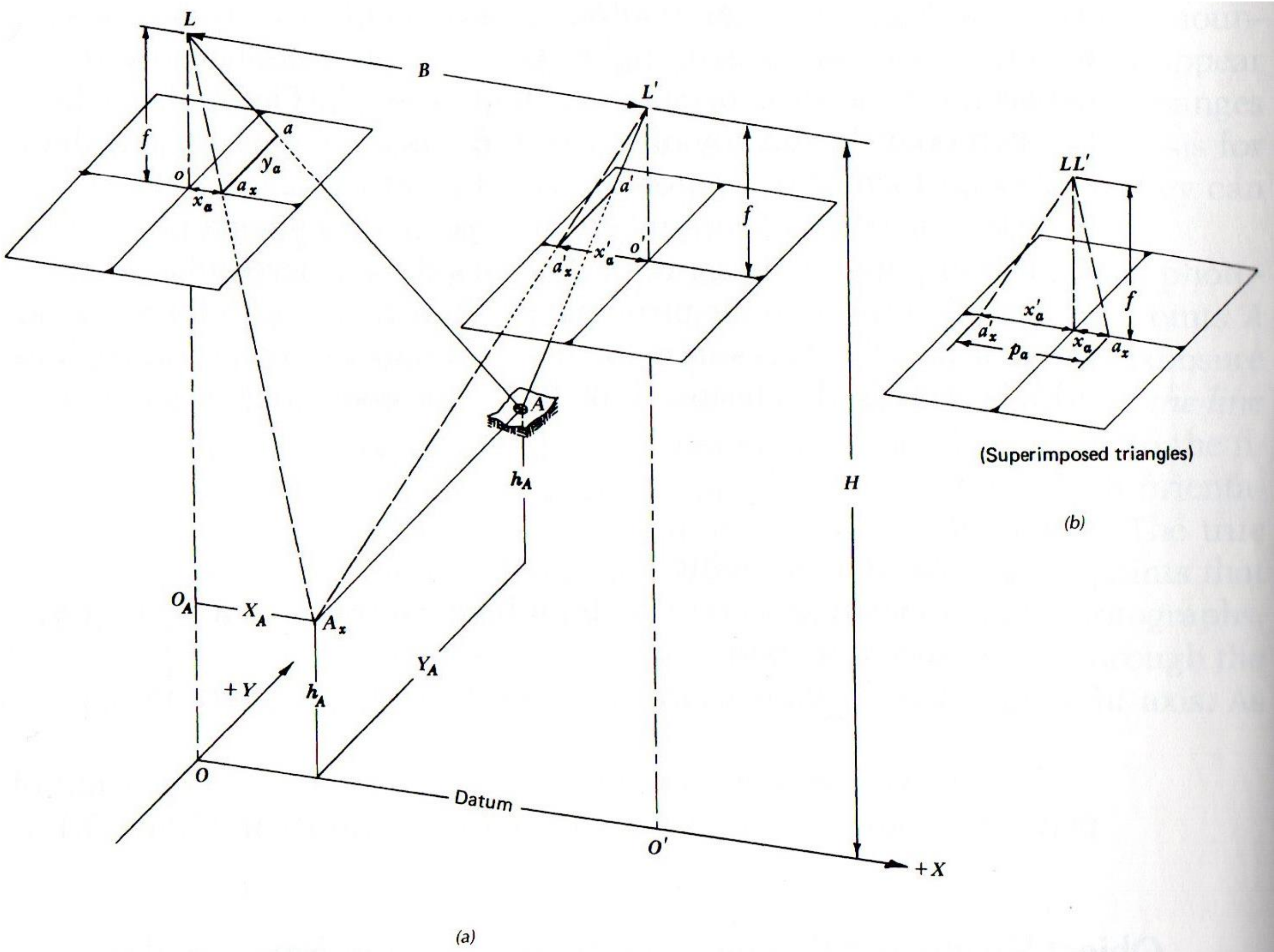
p_a = parallax of point *A*
x_a = measured *x* coordinate of image *a* on the left photograph of the stereopair
x'_a = *x* coordinate of image *a'* on the right photograph



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Object Height and Ground Coordinate Location from Parallax Measurement

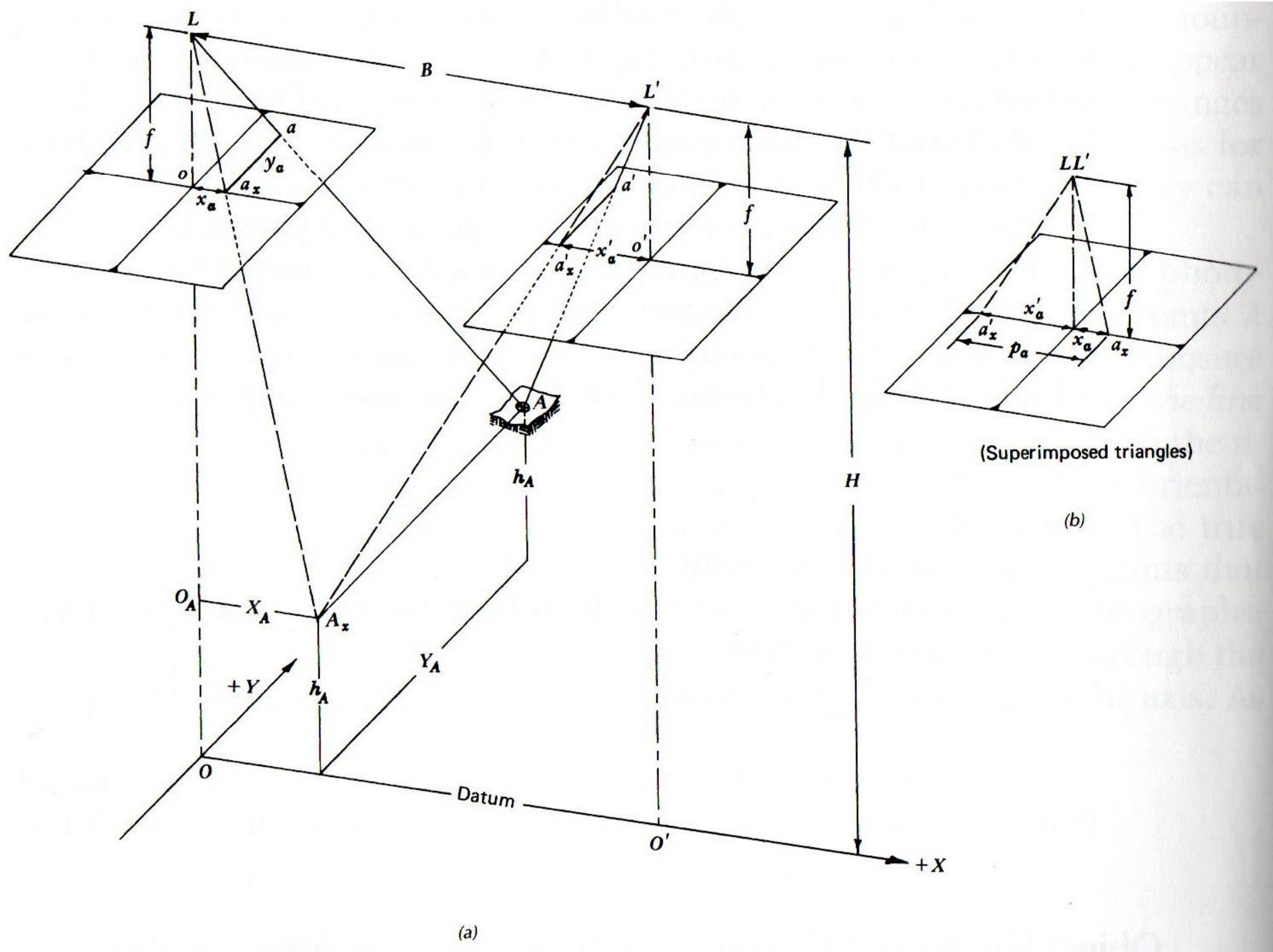
- Shown in the figure are overlapping vertical photographs of a terrain point **A**
- Using parallax measurement, we may determine the **elevation at A** and its **ground coordinate location**.



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Object Height and Ground Coordinate Location from Parallax Measurement

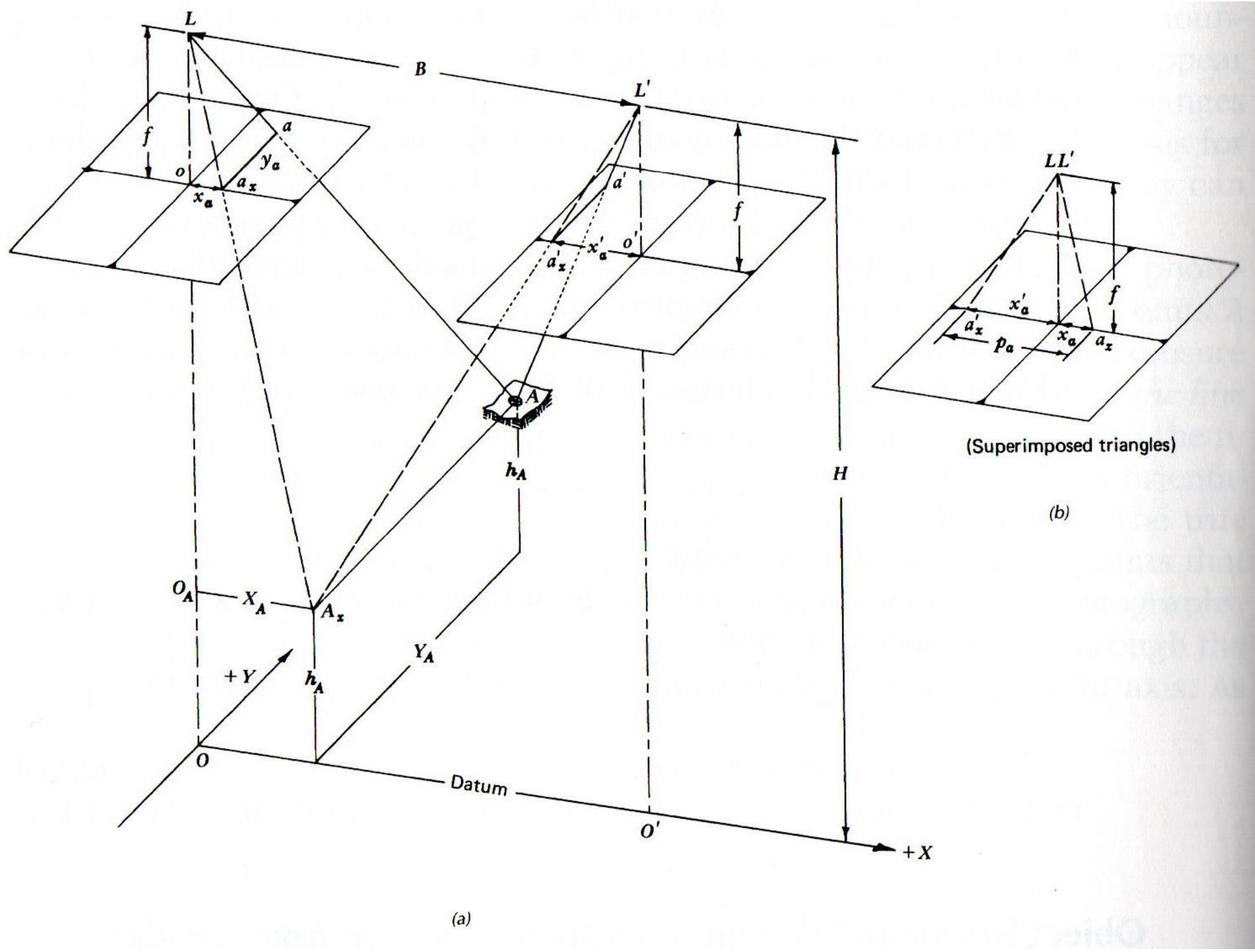
- **L** and **L′** are exposure stations
- The distance between **L** and **L′** is **B**
- **B** is called the ***air base***



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Object Height and Ground Coordinate Location from Parallax Measurement

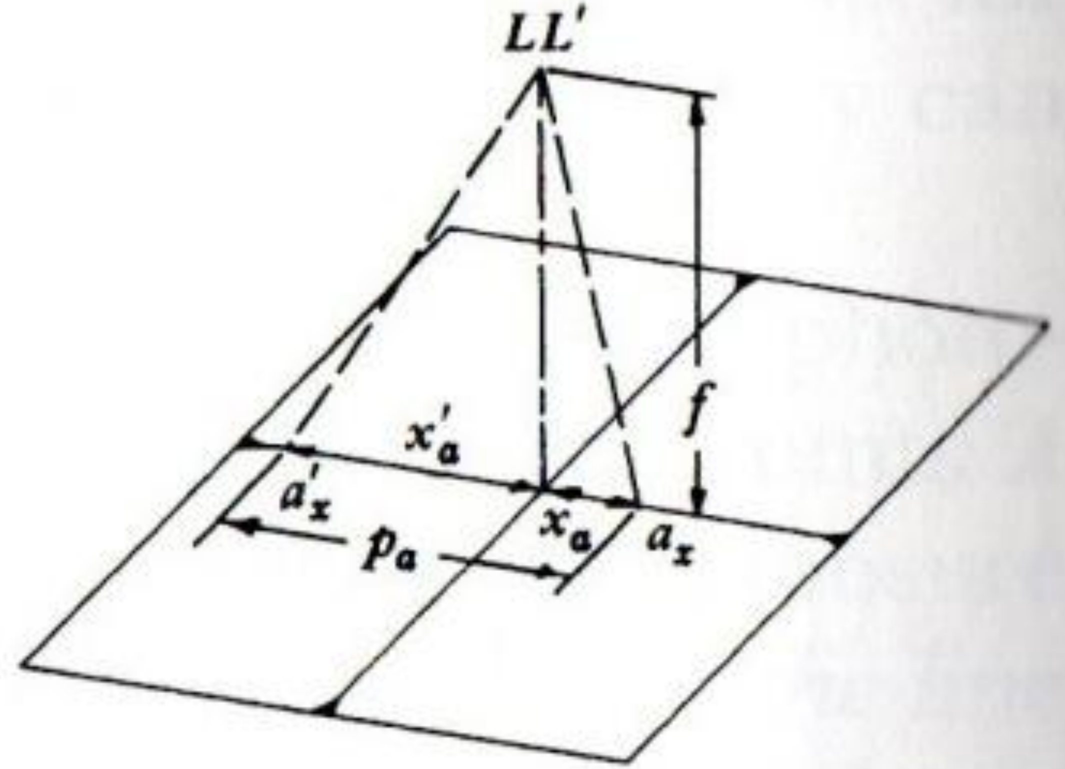
- The triangle resulting from the superimposition of the triangles at L and L′ depict the nature of parallax $\boldsymbol{p_a}$



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Object Height and Ground Coordinate Location from Parallax Measurement

- The triangle resulting from the superimposition of the triangles at L and L′ depict the nature of parallax p_a



(Superimposed triangles)

Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

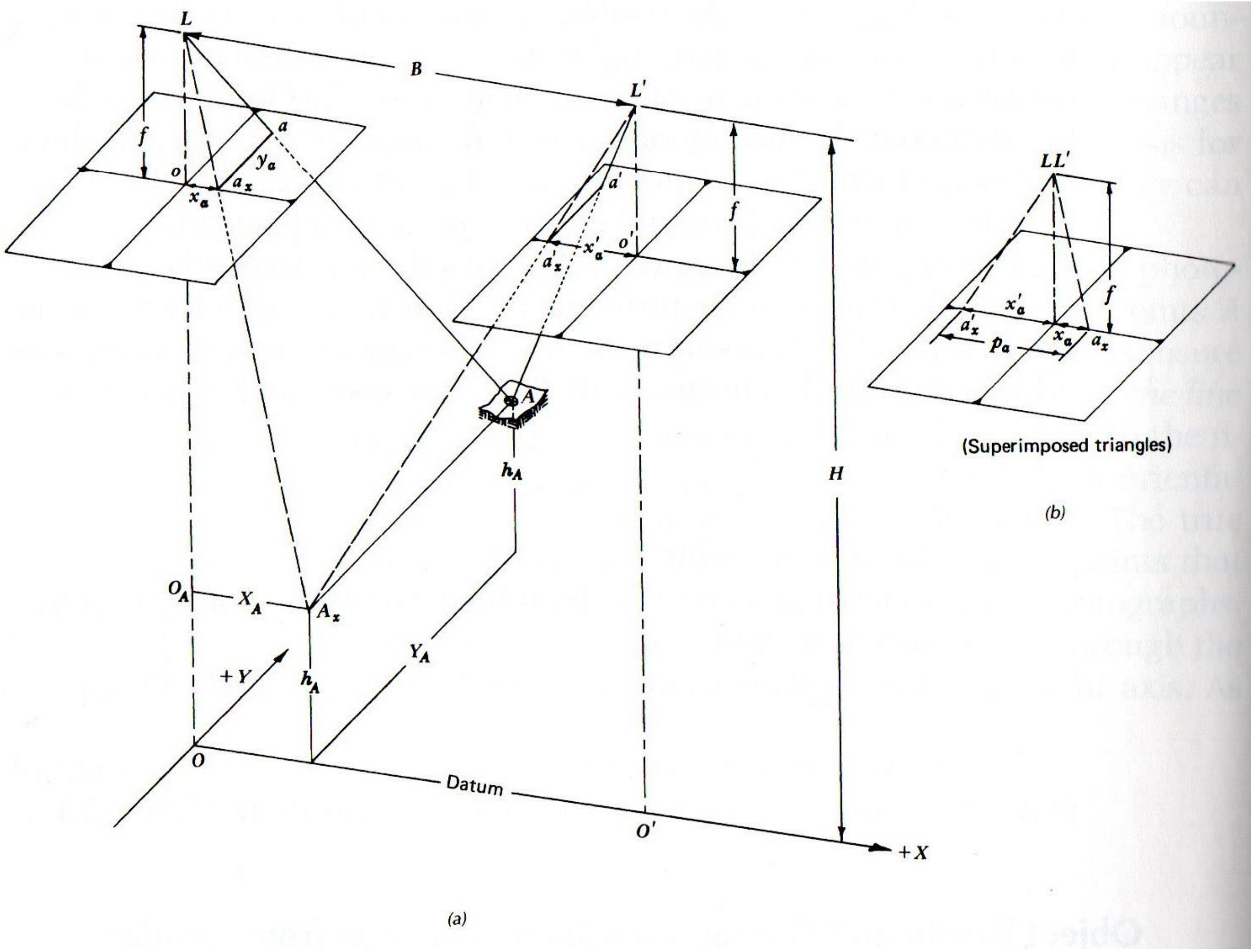
Object Height and Ground Coordinate Location from Parallax Measurement

- Using similar triangles $La'_x a_x$ and $LA_x L'$, we get:

$$\frac{p_a}{f} = \frac{B}{H - h_A}$$

$$H - h_A = \frac{Bf}{p_a}$$

$$h_A = H - \frac{Bf}{p_a}$$



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Object Height and Ground Coordinate Location from Parallax Measurement

- Also, from similar triangles LO_AA_x and Loa_x, *we get:*

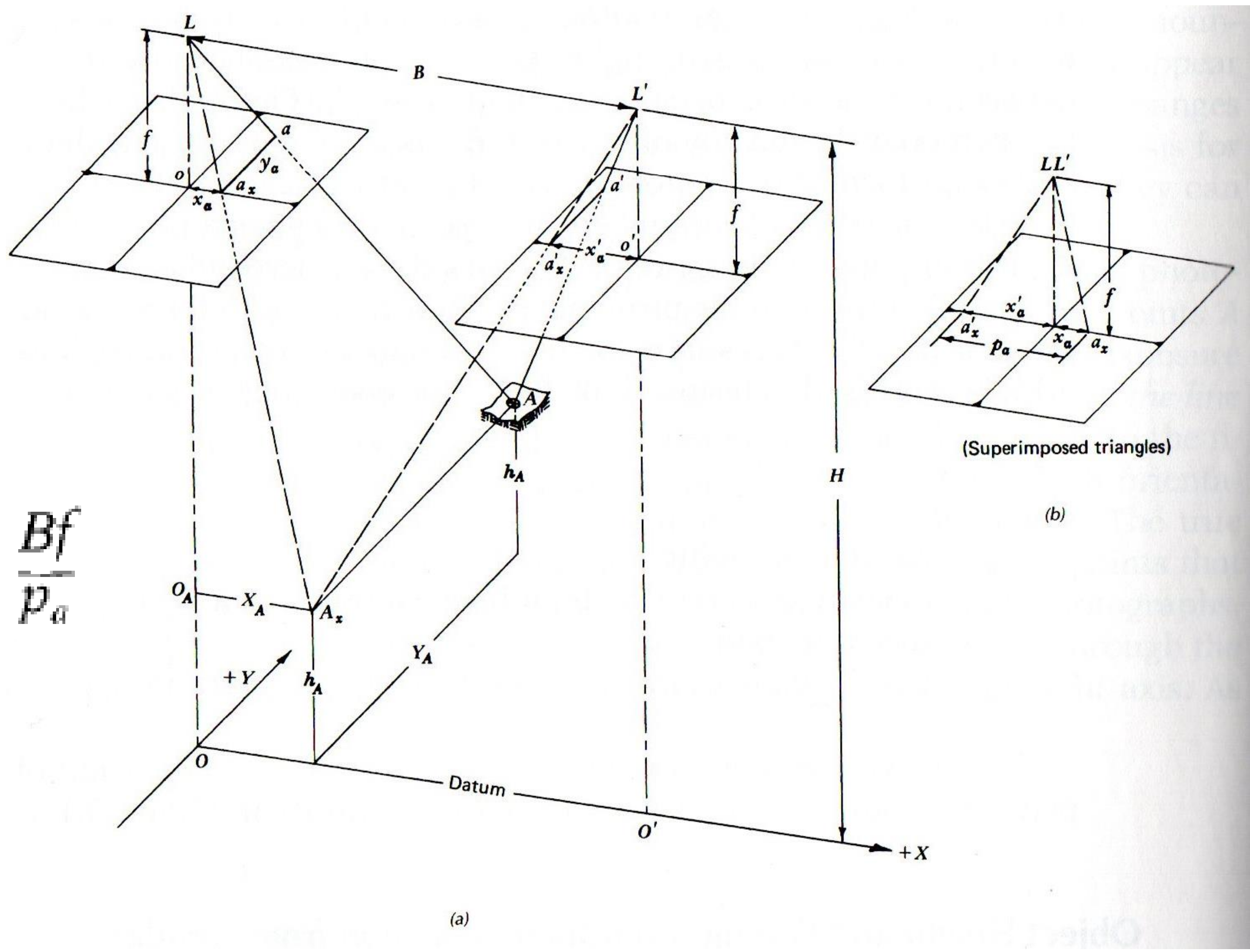
$$\frac{X_A}{H - h_A} = \frac{x_a}{f}$$

$$X_A = \frac{x_a(H - h_A)}{f}$$

- Substituting this equation into the above equation, we get:

$$H - h_A = \frac{Bf}{p_a}$$

$$X_A = B\frac{x_a}{p_a}$$

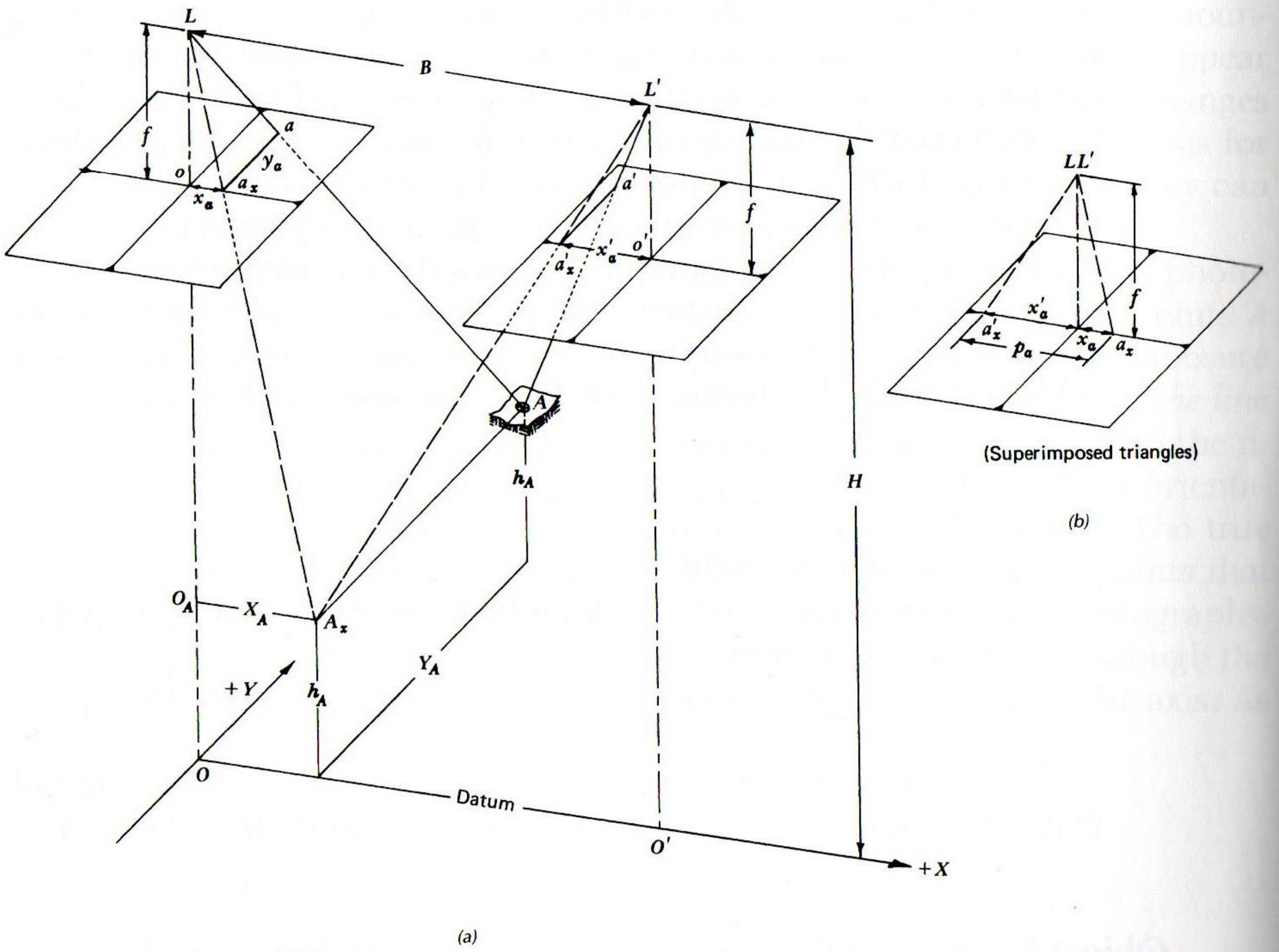


Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Object Height and Ground Coordinate Location from Parallax Measurement

- Using similar derivations, we can get

$$Y_A = B\frac{y_a}{p_a}$$



Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

The Parallax Equations

- In these equations, ***X*** and ***Y*** are the ground coordinates of a point with respect to an arbitrariry coordinate system
- This arbitrary coordinate system's origin is vertically below the left exposure station and with positive *X* in the direction of flight
- ***p*** is the parallax of the point in question
- ***x*** and ***y*** are the photocoordinates of the point on the left-hand photo
- Major assumptions: the photos are truly vertical and taken from the same flying height

$$X_A = B\frac{x_a}{p_a}$$

$$Y_A = B\frac{y_a}{p_a}$$

Example

- The length of line *AB* and the elevation of its end points, *A* and *B*, are to be determined from a stereopair containing images *a* and *b*.
- The camera used to take the photographs has a 152.4-mm lens.
- The flying height was 1,200 m (average for the two photos) and the airbase was 600 m.
- The measured photographic coordinates of points *A* and *B* in the "flight line" coordinate system are:
  - xa = 54.61 mm
  - xb = 98.67 mm
  - ya = 50.80 mm
  - yb = -25.40 mm
  - x'a = -59.45 mm
  - x'b = -27.39 mm.
- Find the length of line *AB* and the elevations of *A* and *B.*
- What is the difference in elevations of *A* and *B*?

Solution

- From the equation: $p_a = x_a - x_a'$

$$p_a = x_a - x_a' = 54.61 - (-59.45) = 114.06 \text{ mm}$$

$$p_b = x_b - x_b' = 98.67 - (-27.39) = 126.06 \text{ mm}$$

- Using the parallax equations:

$$X_A = B\frac{x_a}{p_a} = \frac{600 \times 54.61}{114.06} = 287.27 \text{ m}$$

$$X_B = B\frac{x_b}{p_b} = \frac{600 \times 98.67}{126.06} = 469.63 \text{ m}$$

$$Y_A = B\frac{y_a}{p_a} = \frac{600 \times 50.80}{114.06} = 267.23 \text{ m}$$

$$Y_B = B\frac{y_b}{p_b} = \frac{600 \times (-25.40)}{126.06} = -120.89 \text{ m}$$

Solution (continuation)

Applying the Pythagorean theorem yields

$$AB = [(469.63 - 287.27)^2 + (-120.89 - 267.23)^2]^{1/2} = 428.8 \text{ m}$$

the elevations of A and B are

$$h_A = H - \frac{Bf}{p_a} = 1200 - \frac{600 \times 152.4}{114.06} = 398 \text{ m}$$

$$h_B = H - \frac{Bf}{p_b} = 1200 - \frac{600 \times 152.4}{126.06} = 475 \text{ m}$$

Some Remarks

- In many applications, the difference in elevation between two points is of more immediate interest than is the actual value of the elevation of either point.

- The difference in elevation between two points can be computed as:

$$\Delta h = \frac{\Delta p \, H'}{p_{\text{higher point}}}$$

where

Δh = difference in elevation between two points whose parallax *difference* is Δp

H' = flying height above the lower point

p = parallax of the higher point

Using this approach in our previous example yields

$$\Delta h = \frac{12.00 \times 802}{126.06} = 77 \text{ m}$$

Note this answer agrees with the value computed above.

Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

Reading Assignment

- Read "**Parallax Measurements**" (pp. 161-166 of Lillesand 2004)

QUIZ (10/12/2017; 20 points)

- The length of line *AB* and the elevation of its end points, *A* and *B*, are to be determined from a stereopair containing images *a* and *b*.
- The camera used to take the photographs has a 152.4-mm lens.
- The flying height above Mean Sea Level was 1,300 m.
- The distance between the exposure stations is 500 m.
- The measured photographic coordinates of points *A* and *B* in the "flight line" coordinate system are:
  - x_a = 50.75 mm
  - x_b = 95.60 mm
  - y_a = 50.50 mm
  - y_b = -22.60 mm
  - x'_a = -50.45 mm
  - x'_b = -25.40 mm.
- Find the ground coordinates of *A* and *B* referenced from the exposure station of the left image.
- What is the difference in elevations of *A* and *B*?

Further Reading

- Paine and Kiser, 2012. Aerial Photography and Image Interpretation, 3rd Edition, John Wiley & Sons, Inc. (pp. 44-67)

- Linder, W., 2016. Digital Photogrammetry – A Practical Course, Springer-Verlag Berlin Heidelberg, Germany.

- Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley.

(See Facebook page for the PDF link)