GE 119 – PHOTOGRAMMETRY 2

Topic 1. Review of Basic Concepts and Principles of Photogrammetry

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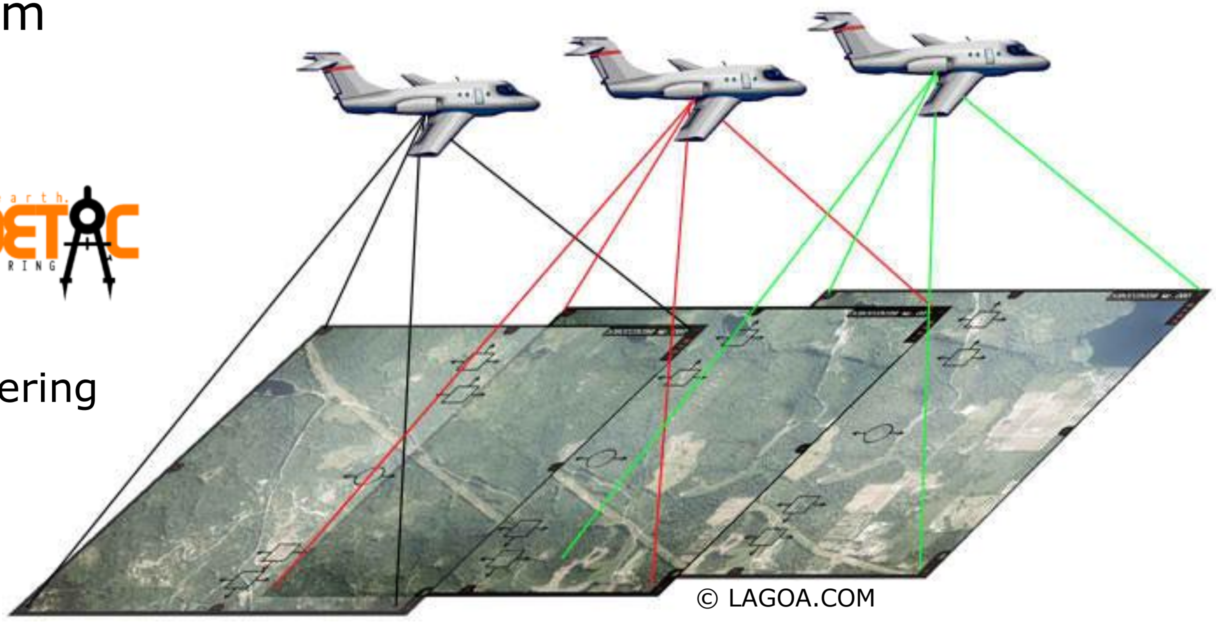


Division of Geodetic Engineering
College of Engineering and
Information Technology
Caraga State University

Outline

- Brief background of Photogrammetry
- Analogue vs. Analytical vs. Digital Photogrammetry
- Monophotogrammetry vs. Stereophotogrammetry
- Relationships of Photogrammetry with GPS/GNSS, Remote Sensing, Cartography and GIS
- Standard Photogrammetric Terms and Definitions
- Photogrammetry Workflow
- Basic geometric characteristics of aerial photographs
- Photographic Scale
- Photo and Object Space Coordinate Systems
- Ground coverage of aerial photographs
- Area measurements
- Relief Displacement in Aerial Photographs
- Flight Planning

Intended Learning Outcomes

- After this lecture, the students must have:
  - Recalled the **basic concepts and principles** of **Photogrammetry**, including standard terms and their definitions, the geometric characteristics of aerial photographs, photographic scale, coordinate systems, and flight planning, among others.
  - Differentiated Photogrammetry from Remote Sensing, GPS/GNSS, Cartography, and GIS.
  - Explained the differences between **analogue, analytical** and **digital** photogrammetry
  - Explained the differences between **monophotogrammetry** and **stereophotogrammetry**
  - Described the different activities involved in photogrammetry
  - Determined scales of aerial photographs through computations and hands-on exercises
  - Solved problems on photographic scale, photo and object space coordinate systems, aerial photo ground coverage, area measurements from aerial photographs, and flight planning

BRIEF BACKGROUND OF PHOTOGRAMMETRY

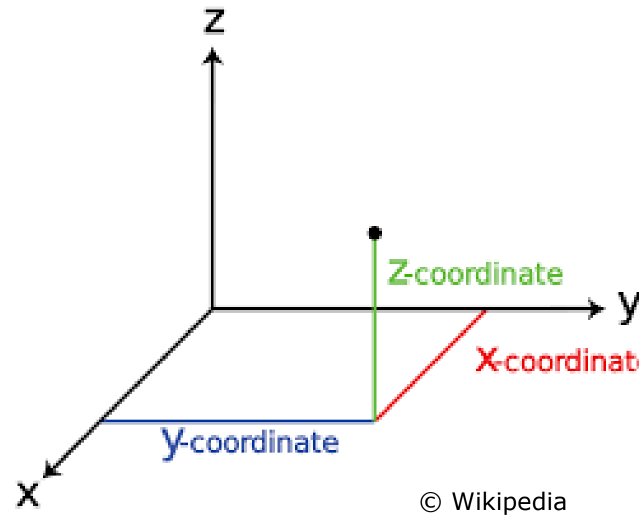
In Geodetic Engineering, where does **Photogrammetry** comes in?

Let’s start with “Surveying/Geodetic Engineering”....

- **Surveying/Geodetic Engineering**: the acquisition, processing, rendering, dissemination and management of ***spatial information*** on or near the surface of the earth*.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

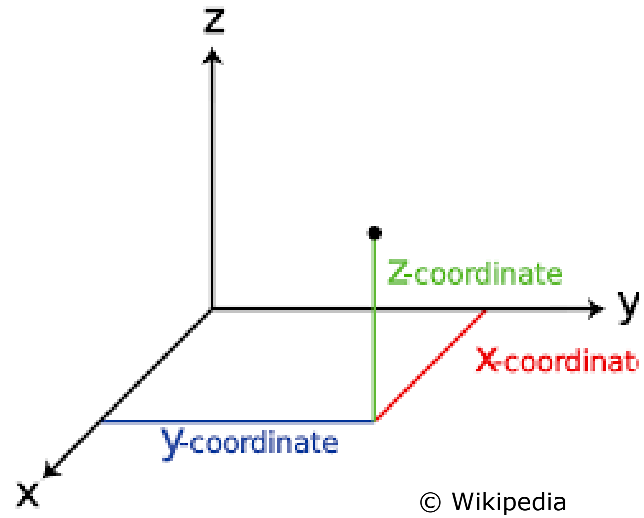
Let's start with "Surveying/Geodetic Engineering"....



- **Spatial Information**:
  - the word '**spatial**' means the location of the information is known in three dimensional (3D) space (i.e., ***x, y, z***)

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Let's start with "Surveying/Geodetic Engineering"....



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- **Spatial Information**:
  - the word '**spatial**' means the location of the information is known in three dimensional (3D) space (i.e., ***x, y, z***)
  - **"the information is geographically referenced in a 3-dimensional coordinate system"***

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Surveyors/Geodetic Engineers:

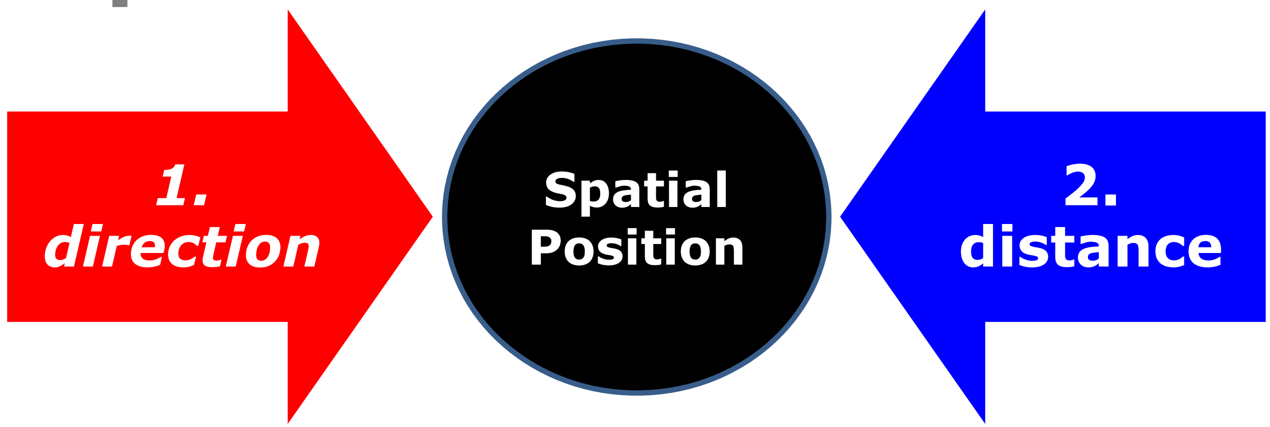
- Locate features, objects and phenomena in three dimensional space
- Combine these data with their attributes; and
- Arrange them in a form that is convenient and functional for utilization by interested parties

"Geomatics"

(short for "Geo-informatics")*

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Fundamental Elements Used to Derive Spatial Position*



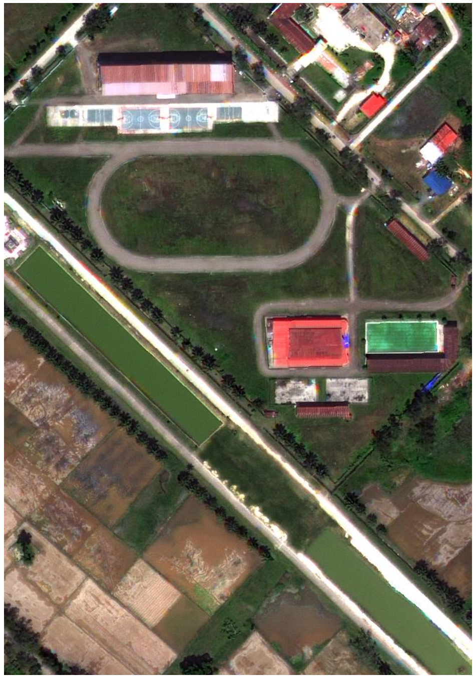
- These elements can be obtained:
  - **By direct observation:**
    - E.g., using a transit, theodolite, a level and a tape
  - **By indirect observation**
    - E.g., using an EDM/Total Station, GPS/GNSS and

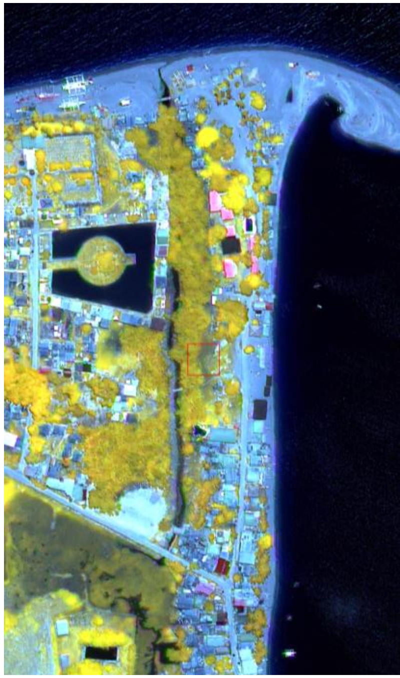
IMAGES

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

IMAGES…

- **Images** = likeness; a representation of reality.
  - Reality = earth surface
- **Can be used for spatial positioning**
- Measurements in images are considered **indirect observations** with respect to the 2 fundamental elements*



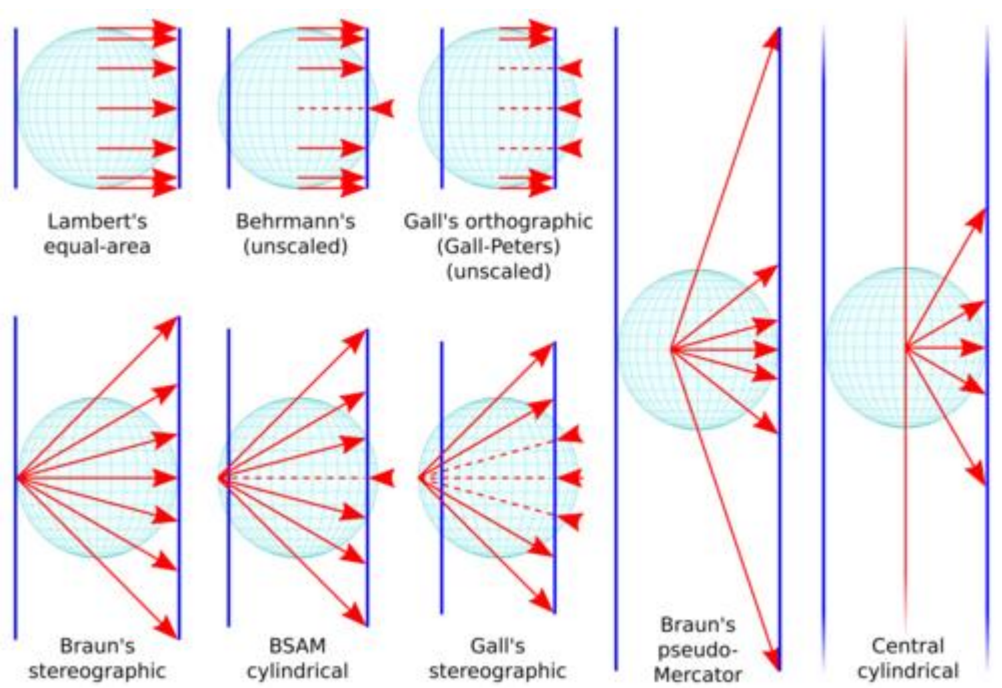


*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Image as a product of 'projection'*

- **'Projection'** = a process or technique of reproducing a spatial object upon a plane or curved surface by straight lines (rays) which originate at the object and are intersected by the surface.
  - If **two points** are joined by a straight line, one point is said to be projected upon the other.

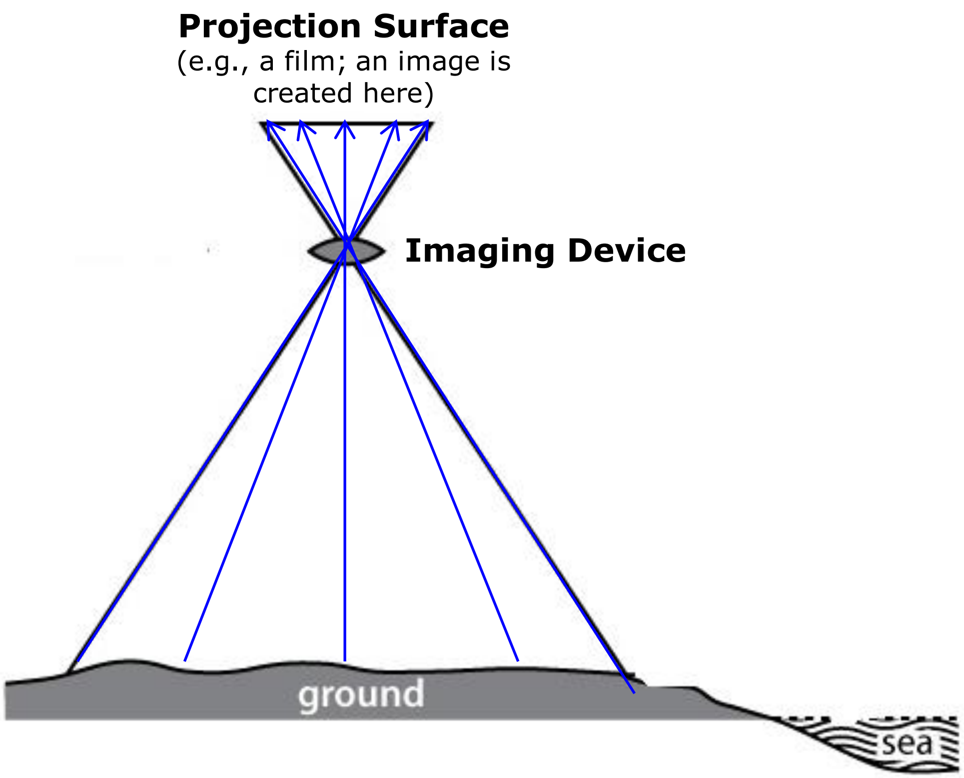
Same principle as used in 'map projection':



*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Image as a product of 'projection'*

- Projection as applied in physical imaging:



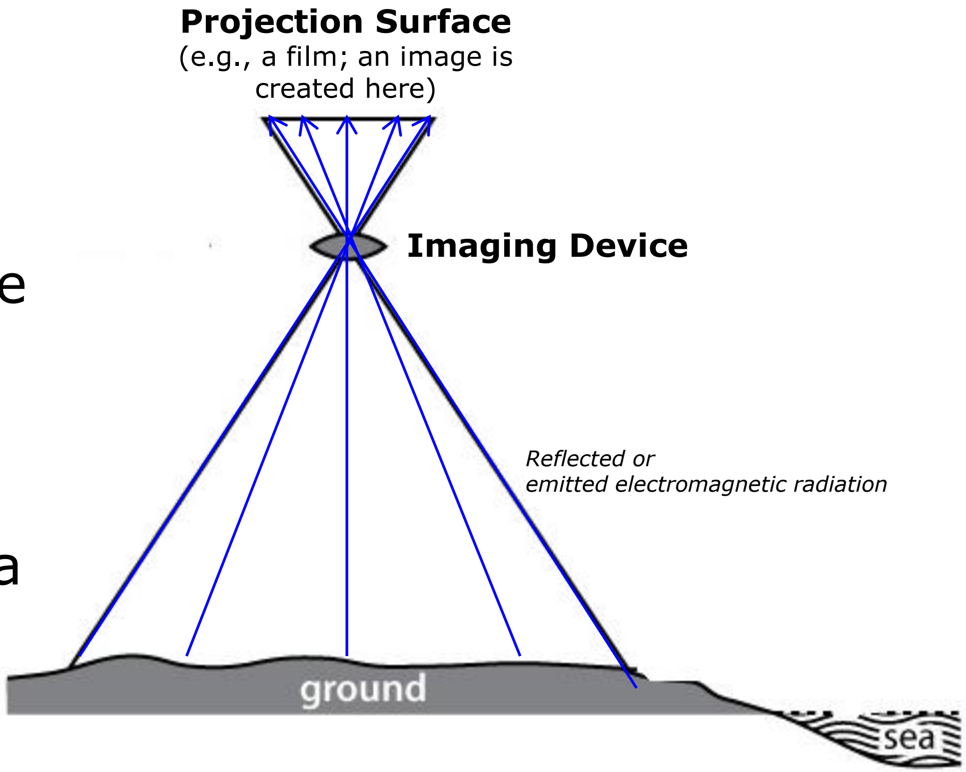
*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Physical Imaging

- In physical imaging, the projecting ray is the electromagnetic or acoustic energy reflected or emitted by an object.

- Imaging devices that is capable of sensing and recording this radiation are often referred to as **sensors**.

- The observation of objects by a sensor occurs from a certain distance without getting into contact with them.
  - This type of data acquisition is referred to as **Remote Sensing**.



*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

From the previous discussion, we learned that:

- Images can be used to get spatial position of objects in the earth surface
  - This is an example of **'indirect' observation**

- Images can be acquired through Remote Sensing

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

What Remotely-sensed Images can provide:

- Three distinct kinds of data:
  - **geometric data** (direction and distance), which indicate the spatial relationship between image and object points and are used to reconstruct spatial positions;
  - **radiometric data** (grey level), which indicate the intensity of the electromagnetic radiation which was reflected or emitted from objects, and received by a sensor. These data are used to identify objects and their qualitative characteristics;
  - **spectral data** (color), which indicate the dominant wavelength of the radiation emanating from objects, and are also used for qualitative analysis.

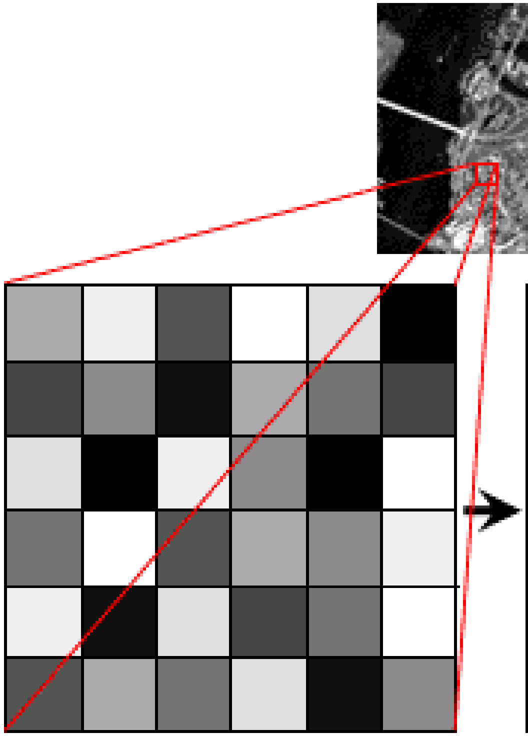
*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Recording of Remotely-sensed Images*

- Images are recorded in either analogue (physical) or digital form.

- **Analogue images** are 'hard copies`
  - the intensity of radiation received by the sensor is visualized in grey levels or in shades of color on photographic paper or film.

- **Digital images** are 'soft copies'
  - the radiance of objects are recorded numerically in small, regularly spaced area elements.
  - These values are stored as a matrix, an element of which is called picture element or pixel



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

Digital Image Representation

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Utilization of Remotely-sensed Images

- Images are utilized in two distinct manner by performing either:
  - **interpretative** or
  - **metric** analysis.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Utilization of Remotely-sensed Images

- **Interpretative analysis**:
  - Qualitative observations are made to detect the presence of certain phenomenon, identify and classify objects and to ascertain their physical condition, state and properties
  - This is what we "IMAGE INTERPRETATION" or "IMAGE ANALYSIS"

This is where the elements of visual image interpretation are utilized.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Buzz Session/Cooperative Learning Activity:

- In the next slide, an image will be provided
- **Together with your seatmate**, discuss what you think are **the two (2) objects indicated in the image.**
- Use the principles and elements of image interpretation
- **DO THIS FOR 5 MINUTES**
- **After 5 minutes,** write your answers with explanations in ¼ sheet of paper. This time, **talking with each other is not allowed**.
  - Time limit = 2 minutes
- Don't forget to write your name and your seatmate's name

Buzz Session Activity: Image Interpretation

Utilization of Remotely-sensed Images

- **Metric** analysis:
  - **quantitative** measurements are made in the image and then geometric information, such as spatial position, distance, area, shape, size, volume, distribution of objects are derived.

- This operation is called….

PHOTOGRAMMETRY!

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Photogrammetry Formal Definition*

The science of obtaining reliable measurements by means of images for the determination of the geometric properties of objects.

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Principal Application of Photogrammetry

- Photogrammetry is mainly used in **TOPOGRAPHIC APPLICATIONS:**
  - To determine the spatial position of the natural and man-made features situated on the earth's surface (topographic applications).

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Other Applications of Photogrammetry

- Photogrammetry is also used as a measuring tool in:
  - architecture,
  - industrial design,
  - deformation studies of structures,
  - accident investigation,
  - medicine etc.
- These operations are referred to as **non-topographic applications**.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Photogrammetry Applications
(Audio/Video Presentation)

https://www.youtube.com/watch?v=SNfcnGfVXw0

Branches of Photogrammetry

- According to the location of the sensor during data acquisition:
  - **Terrestrial photogrammetry**
  - **Aerial photogrammetry**
  - **Space photogrammetry**

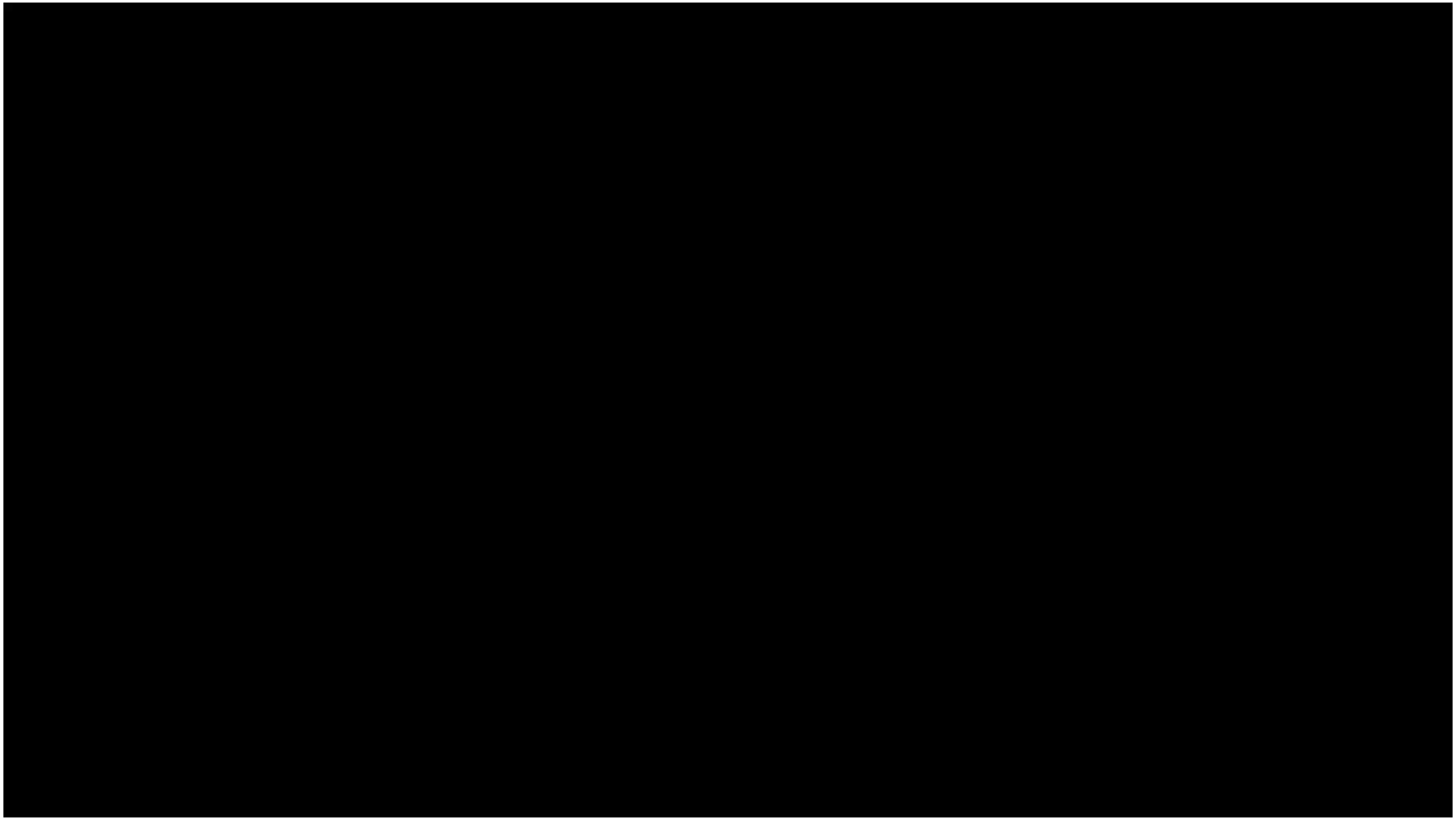
*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Branches of Photogrammetry

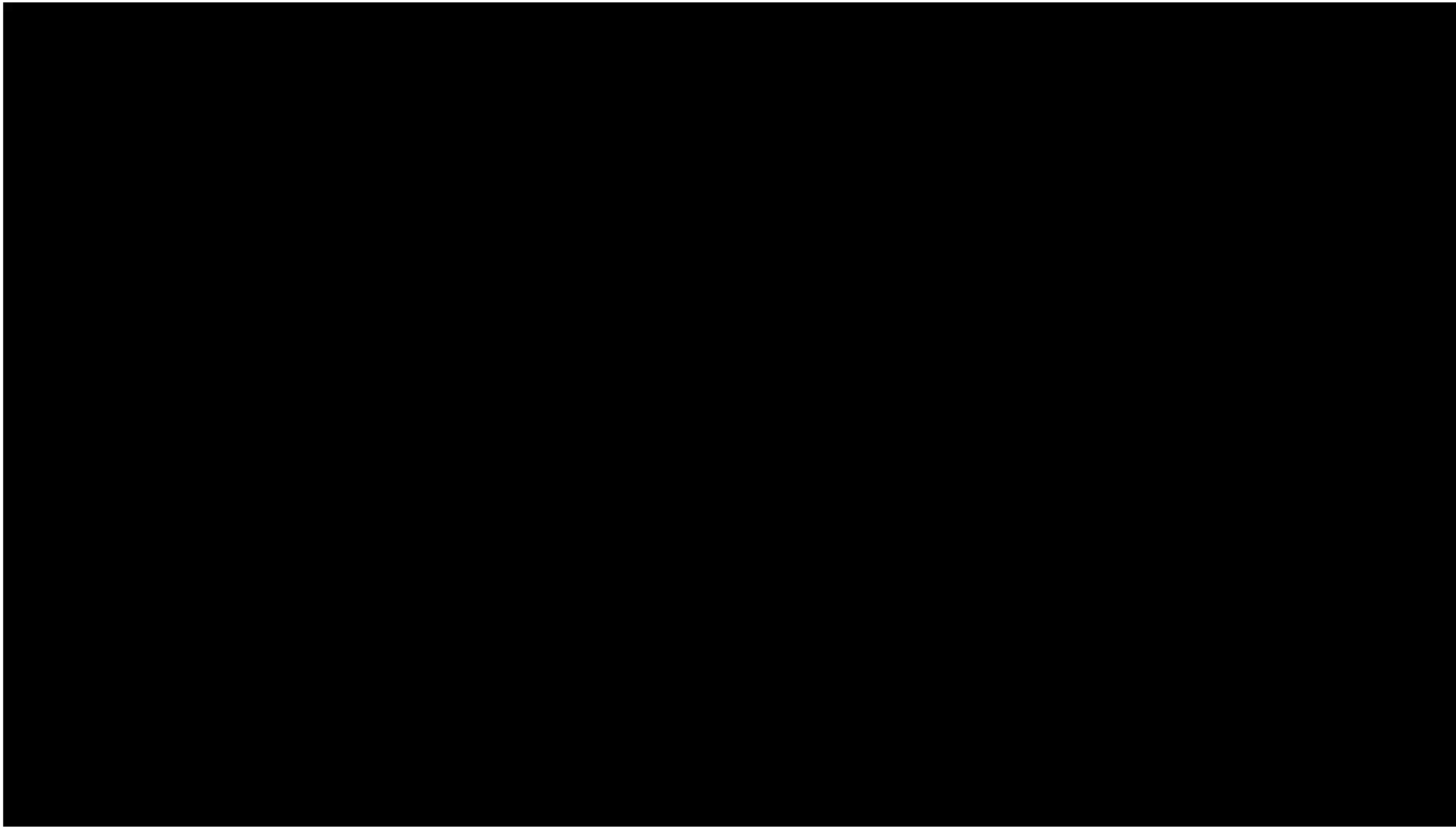
- According to the location of the sensor during data acquisition:
  - **Terrestrial photogrammetry** means that the images are acquired by a ground based stationary sensor.
  - **Aerial photogrammetry** deals with images taken with sensors mounted on airborne platforms.
  - **Space photogrammetry** embraces the processing of images recorded of the earth or of other planets from satellites.
- **Close-range photogrammetry** is a sub-branch of terrestrial photogrammetry implying that the sensor is situated in the close vicinity of the object to be imaged.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Close Range Photogrammetry Application (Audio/Video)



https://www.youtube.com/watch?v=1Egy0nVombc



http://www.youtube.com/watch?v=W_lp2kcBofw

Types of Photogrammetry based on Operations

- Photogrammetry operations -- refers to photogrammetric **measurements and data processing**.

- Two types:
  - Analogue or Instrumental Photogrammetry
  - Analytical Photogrammetry

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Analogue Photogrammetry*

- Employs complex instruments, which physically model the geometric relationship that existed between the image and the object at the time of data acquisition.
- These instruments act as **analogue computers**

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Example of Instrument used in Analogue Photogrammetry (Stereoplotter)

© keywordteam.net

Example of Instrument used in Analogue Photogrammetry (Stereoplotter)

©http://b-29s-over-korea.com/aerial%20photography/aerial%20photography-pg3.html

Example of Instrument used in Analogue Photogrammetry

[© Institute of Photogrammetry and Remote Sensing]

Analytical Photogrammetry

- Photogrammetric operations are performed by mathematical modelling.
- Computers replace some expensive optical and mechanical components
- Resulting devices are analogue/digital hybrids

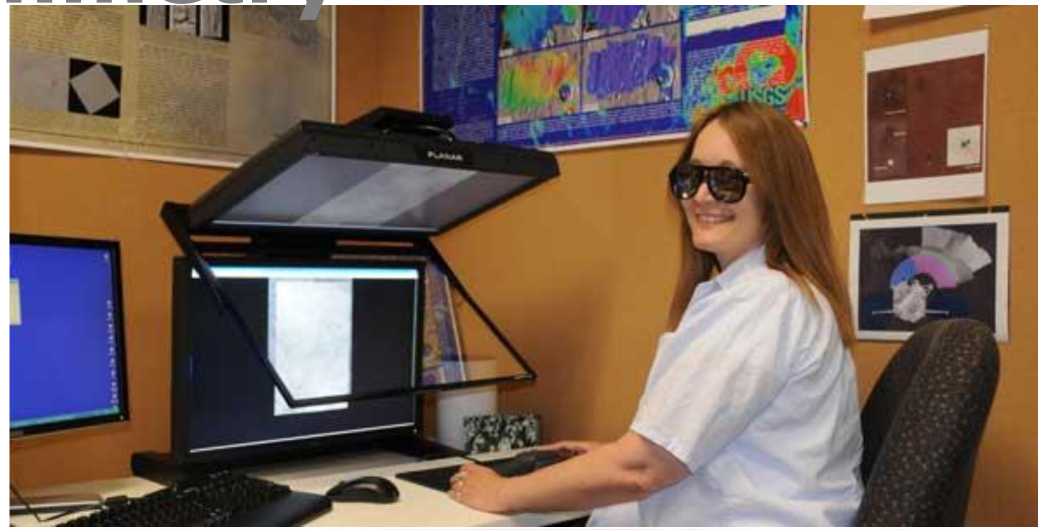
*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

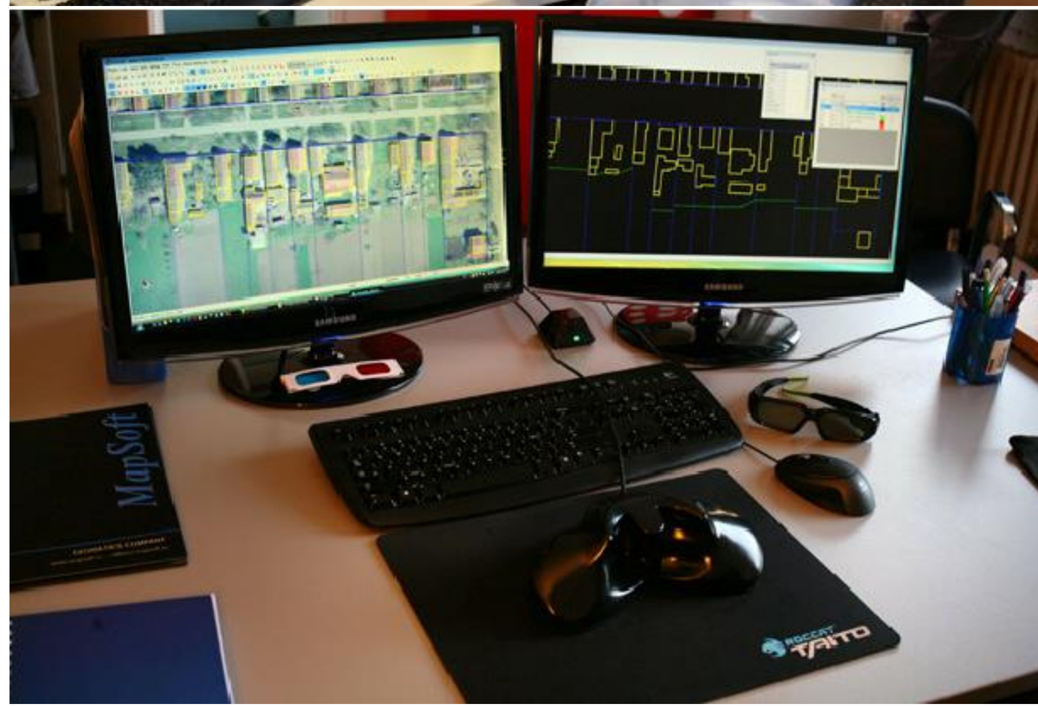
Example of Instrument used in Analytical Photogrammetry

© Wikipedia

Alpha 2000 analytical stereoplotter.

Digital Photogrammetry





- The utilization of **digital images** is a special case in analytical photogrammetry, because of the type of instrumentation used and the wide range of data processing operations that are available compared to working with hard copy images.

- This class is called **digital or soft copy photogrammetry**.

Photogrammetric Instruments through the years

A Vintage Stereo Camera

Stereogram of a Temple

Analogue Photogrammetry
(~ 1960s)

Analytical Photogrammetry
(1970s)

Digital Photogrammetry
(1980s - Present)

- Regardless of the data processing method employed in photogrammetry, the spatial position of points is determined by the fundamental geometric operation of **intersection**.

- Two rays which meet in space produce an intersection and define a point.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Some Notes

- The two types of evaluation processes (interpretative and metric) are not mutually exclusive.
  - Image interpretation may require that some measurements be made to facilitate the interpretation.
  - Conversely, in photogrammetry, a certain amount of interpretation must be performed during mapping to assign attributes to objects .

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Some Remark

- It is evident from the preceding discussion that the objectives of **surveying/Geodetic engineering** can be met equally well by **utilizing images of a scene to be surveyed** rather than making on-site measurements.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Advantages of Photogrammetry

- Photogrammetry has distinct advantages over data acquisition by direct or on-site measurement:

1. An image is a complete, comprehensive record of a scene or situation as it existed at the instant of acquisition.
2. It is a multilevel data set which can provide both quantitative and qualitative information.
3. Data acquisition can be accomplished within a short time over large areas by imaging from the air or space.
4. Processing and analysis of this data can be made at an appropriate time and place, distant from the scene and can be repeated or augmented at will.
5. The direct observation of directions and distances means point-by-point measurement, while on images continuous measurements can be made by tracing or delineating objects.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Limitations

1. The weather and the seasons can place severe restrictions on the primary data acquisition.
   – On the other hand, under favorable conditions, images can. be acquired over a large tract of land within a short period of time from the air ·or from space.
2. It is not feasible to use aerial photography for the survey of small areas.
3. Equipment needed for the acquisition and processing of the data is more expensive and more complex to operate than those used for surveying on site.
4. Photogrammetry is not an entirely self sufficient spatial positioning process. A certain amount of on-site observations are needed to control and verify the analysis.
5. At the current state of the art, direct in situ measurements can provide the highest possible accuracy for determining spatial positions.

*Derenyi, E.E., 1996. Photogrammetry: The Concepts, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. Also available Online at http://www2.unb.ca/gge/Pubs/LN57.pdf

Important Notes to Remember

- The choice of using direct observations or imaging to solve a particular spatial positioning problem should be decided through a pre-analysis in which all requirements, conditions, circumstances are carefully considered.
- As future GEs, we should be ready when this situation arises

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Mono vs. Stereophotogrammetry

- **Mono**photogrammetry
  - obtaining reliable measurements using **single** aerial photographs or images for the determination of the geometric properties of objects.

- **Stereo**photogrammetry
  - obtaining reliable measurements using a **pair or pairs** of aerial photographs or images for the determination of the geometric properties of objects.

RELATIONSHIPS OF PHOTOGRAMMETRY WITH GPS/GNSS, REMOTE SENSING, CARTOGRAPHY AND GIS

Photogram metry

Remote Sensing

How are they inter-related?

GIS

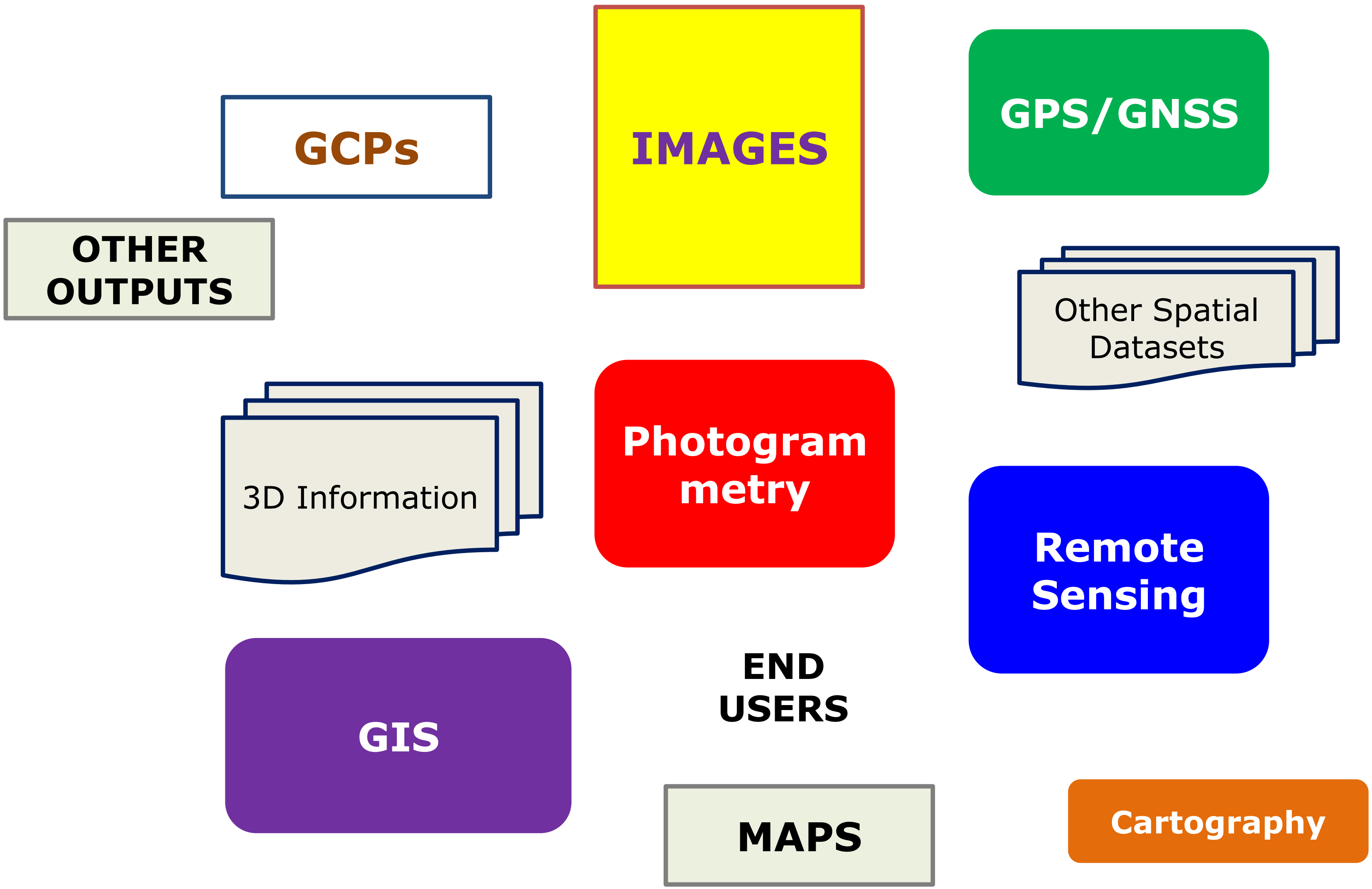
GPS/GNSS

Cartography

Group Discussion/Mini-workshop

- Count off from 1 to 7
- Group yourselves according to your number
- Each group should elect a leader
- Each group will be provided with the following:
  - 1 sheet manila paper
  - 1 marker
- Workshop activity instructions (see next slide)
- After each workshop, the leader will present the group's output

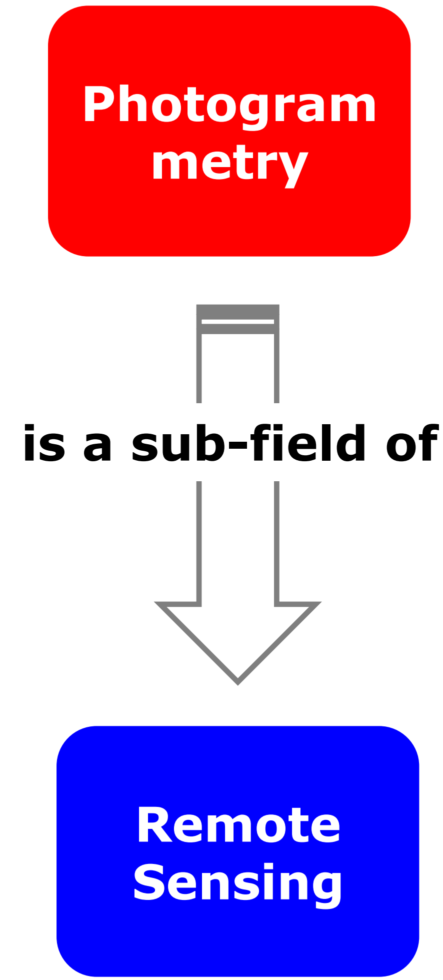
Group Workshop:
Create a Diagram that will show the inter-relationships of Remote Sensing, GNSS, GIS & Photogrammetry based on the following elements:



Remote Sensing & Photogrammetry

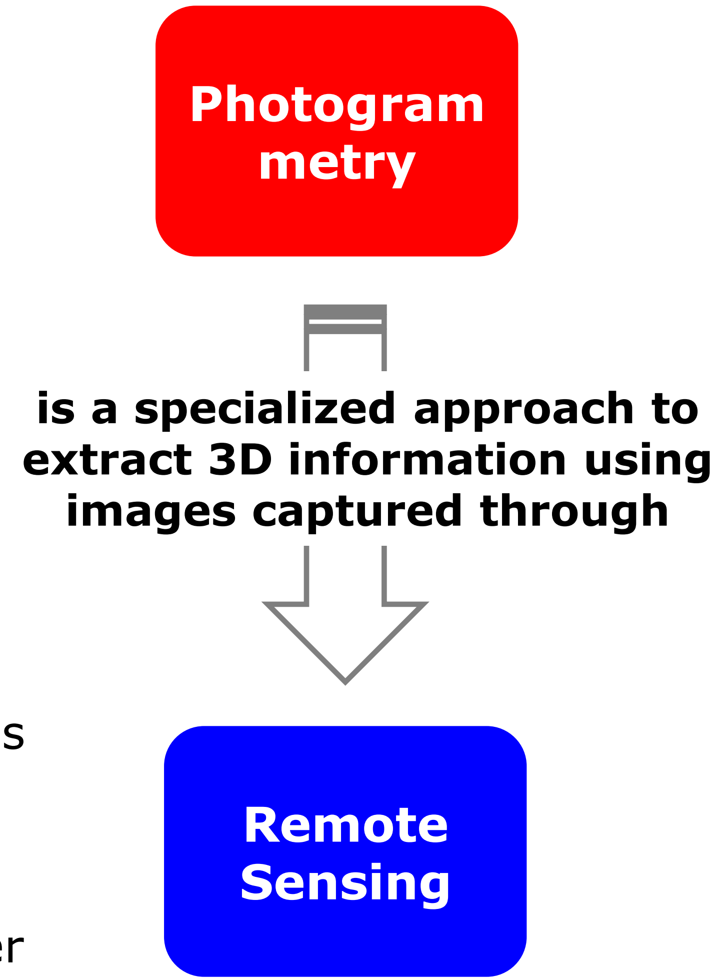
- **Remote Sensing** – the science and art of **obtaining information** about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation.

- **Photogrammetry** - the science of obtaining reliable measurements by means of images for the determination of the geometric properties of objects.



Remote Sensing & Photogrammetry

- Through **Remote Sensing**, images can be captured
  - The type of images vary (e.g., aerial photographs, satellite images)
- From these images, several layers of information can be obtained
- But the methods or approaches of processing these images to extract information **are many**
  - e.g., image interpretation, image enhancement, classification, etc.
- One approach to extract **specific** information is **Photogrammetry**.
  - The specific information we want to extract here are the geometric properties (or 3D information) of objects!
- **Photogrammetry** cannot work without **Remote Sensing**
  - Remote sensing provides images in order for Photogrammetry to extract 3D information



Remote Sensing & Photogrammetry

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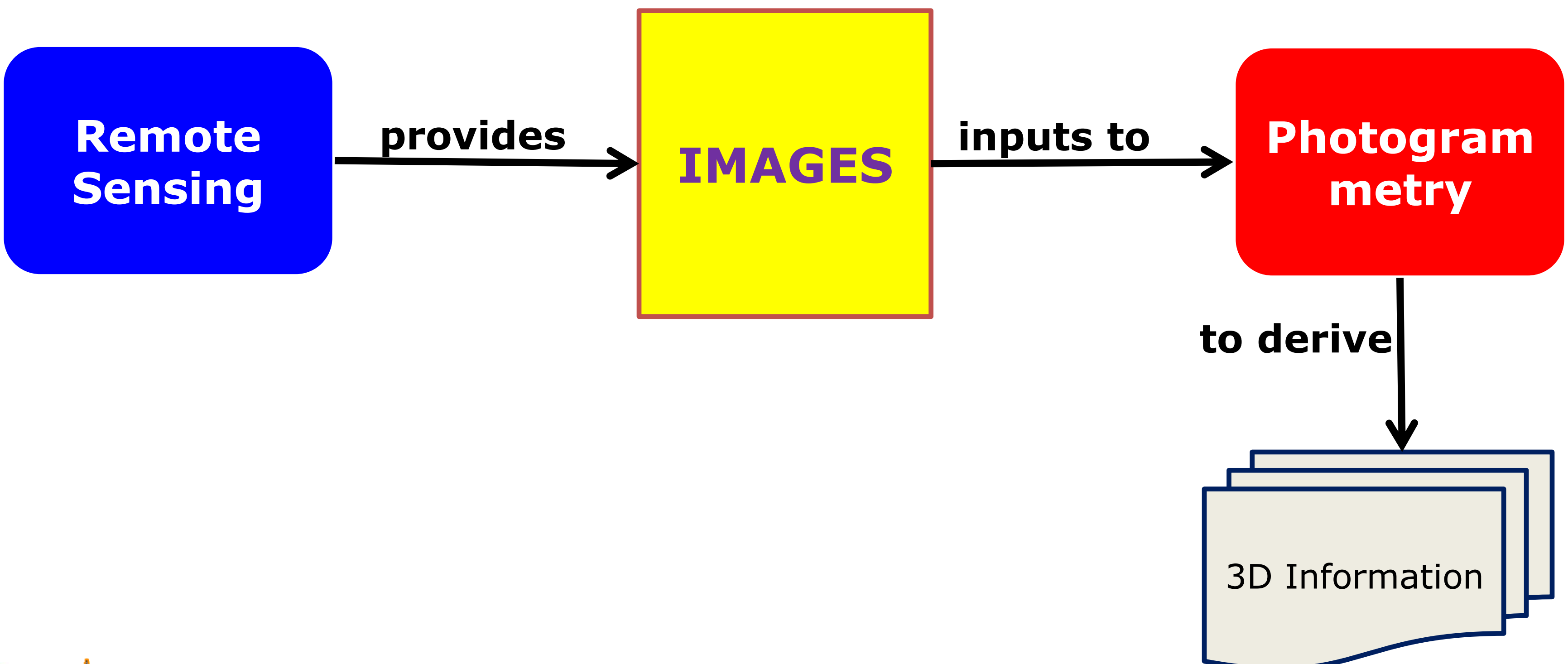
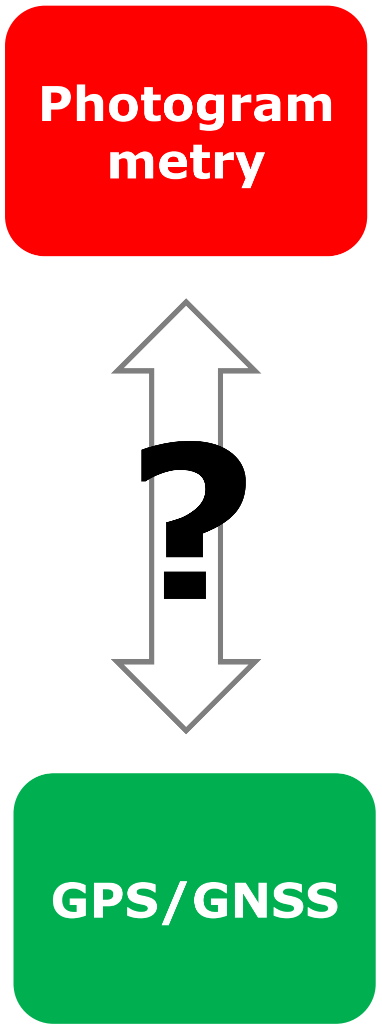


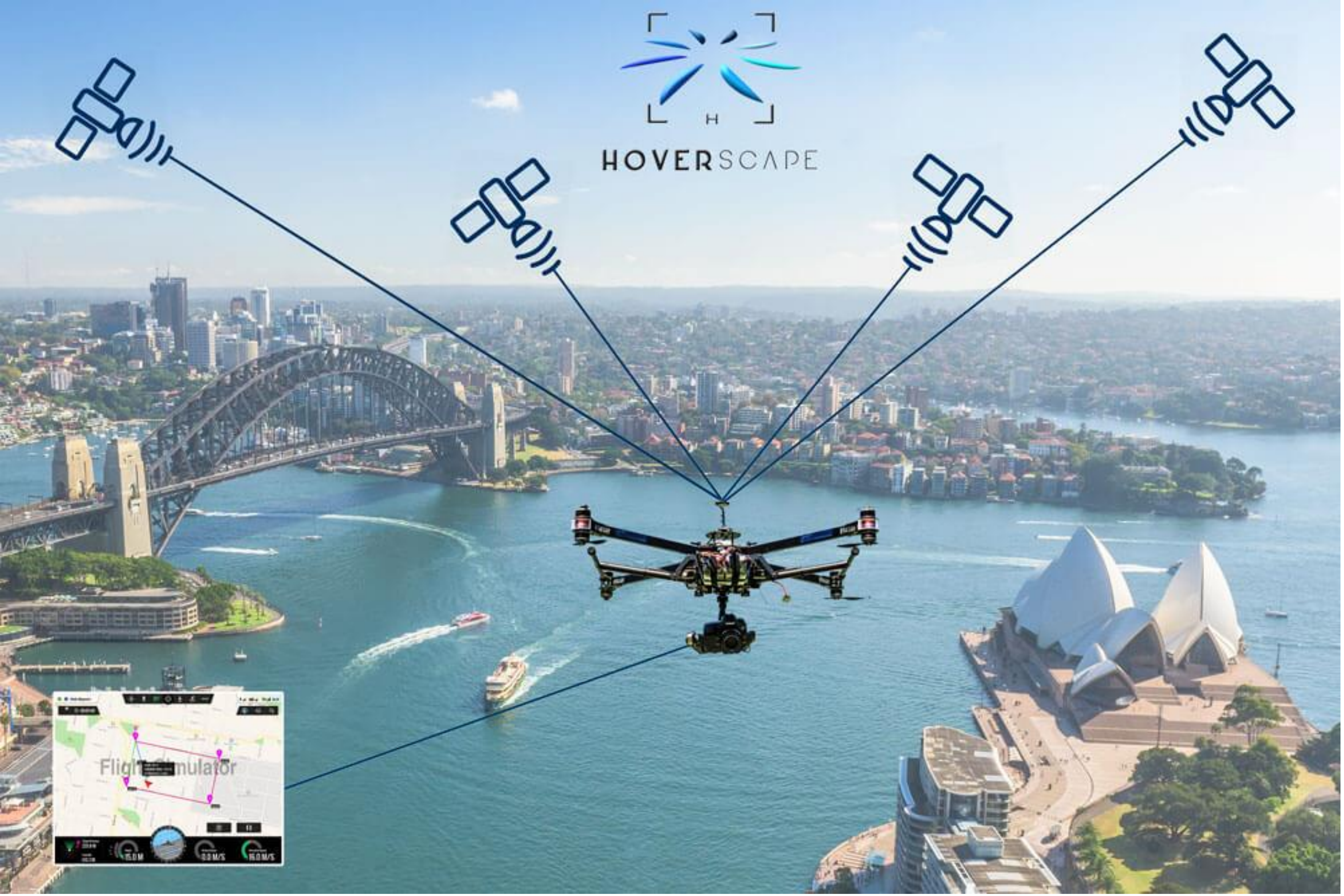
GNSS/GPS & Photogrammetry

- **GNSS**:
  - Global Navigation Satellite System
    - an umbrella term that includes any satellite-based navigation system, including GPS
    - GPS = Global Positioning System
      - GPS is an example of GNSS
  - GNSS is primarily used to establish ground control points/reference control points:
    - During image acquisition
      - For geographic orientation of the sensor
    - During image processing (geometric corrections)



GNSS/GPS & Photogrammetry

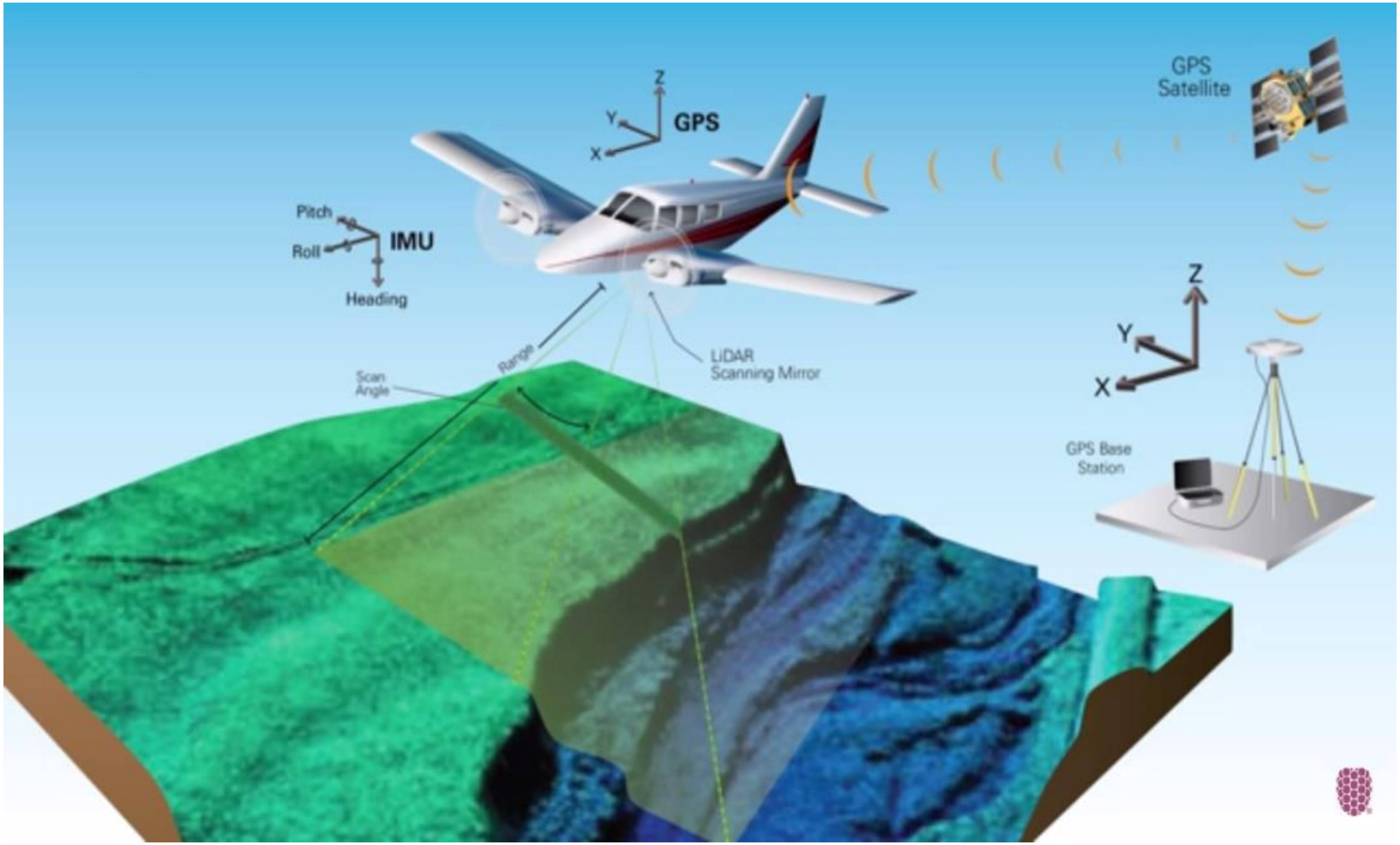
- In Photogrammetry, GNSS is primarily used to establish ground control points/reference control points:
  - During image acquisition
    - For geographic orientation of the sensor
    - Mostly, using Real-Time Kinematic Approaches
  - GCPs as inputs during image processing
    - For geometric correction of images in Photogrammetry


HOVERSCAPE
Flight Simulator

Use of GNSS During Remote Sensing Data Collection (LiDAR Surveys)

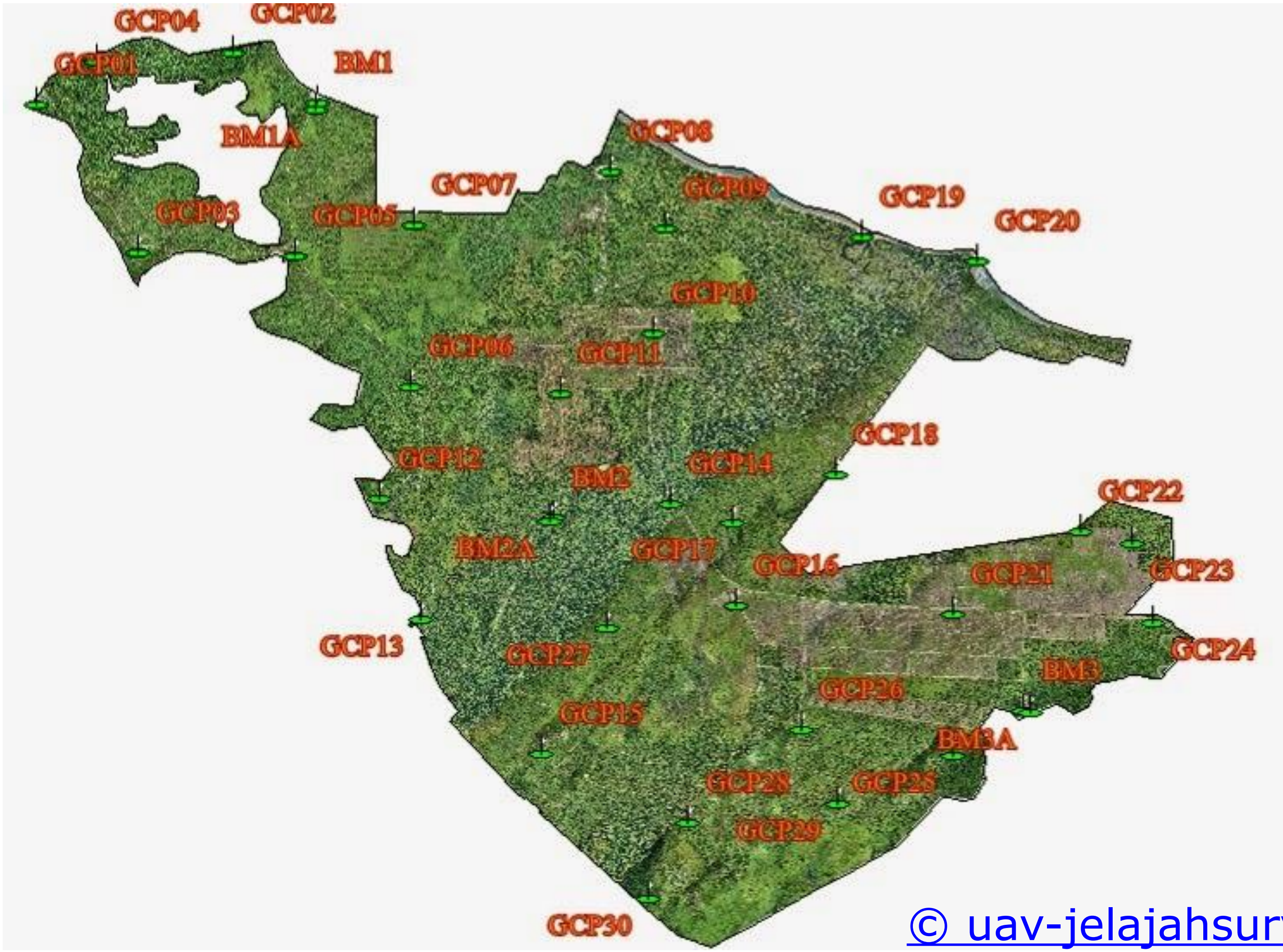
Note: Same principle applies for aerial (digital) image acquisition

Use of GNSS During Remote Sensing Data Collection (LiDAR Surveys)



Note: Same principle applies for aerial (digital) image acquisition

Use of GCPs for Image Orientation in Photogrammetry



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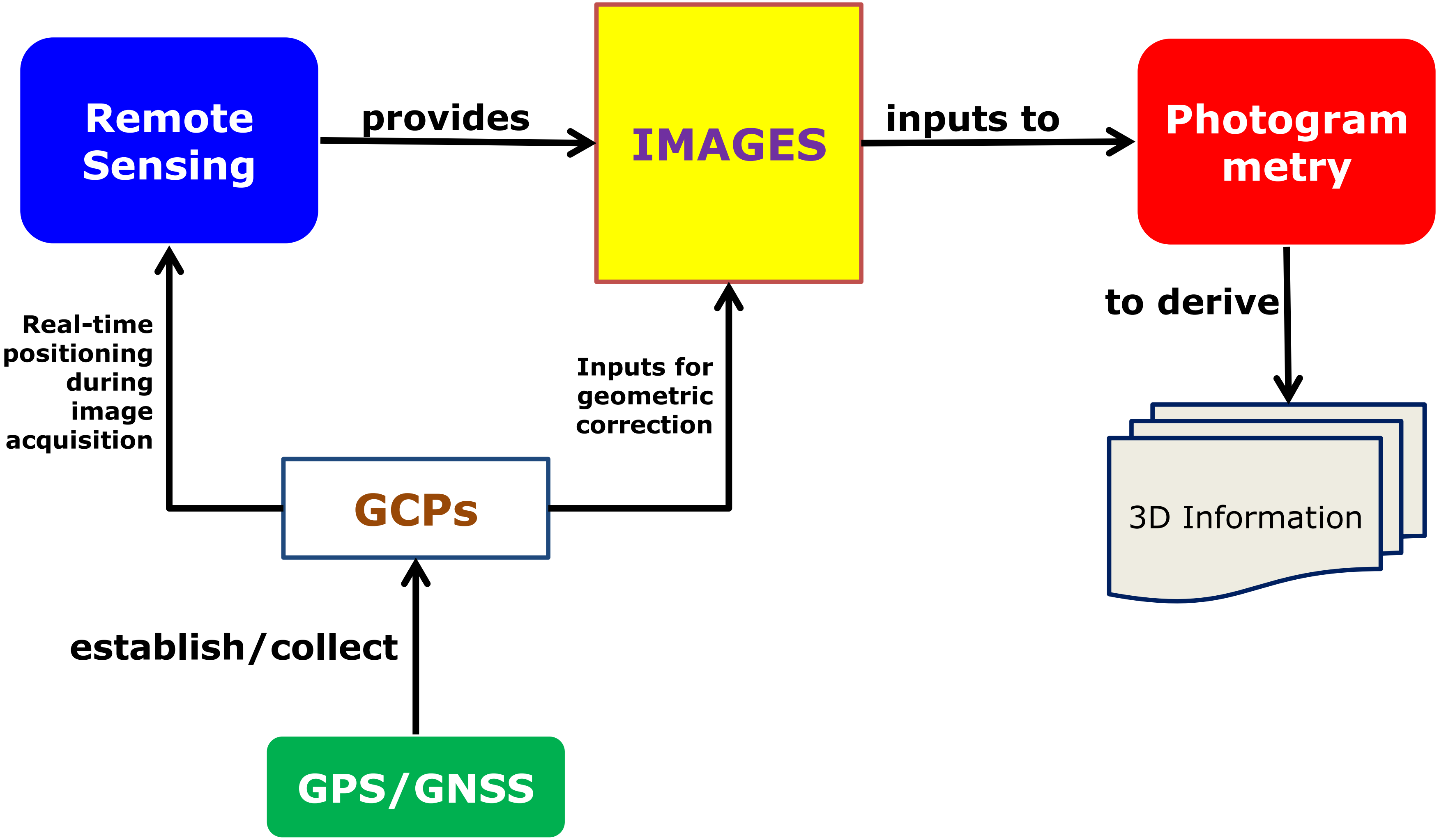
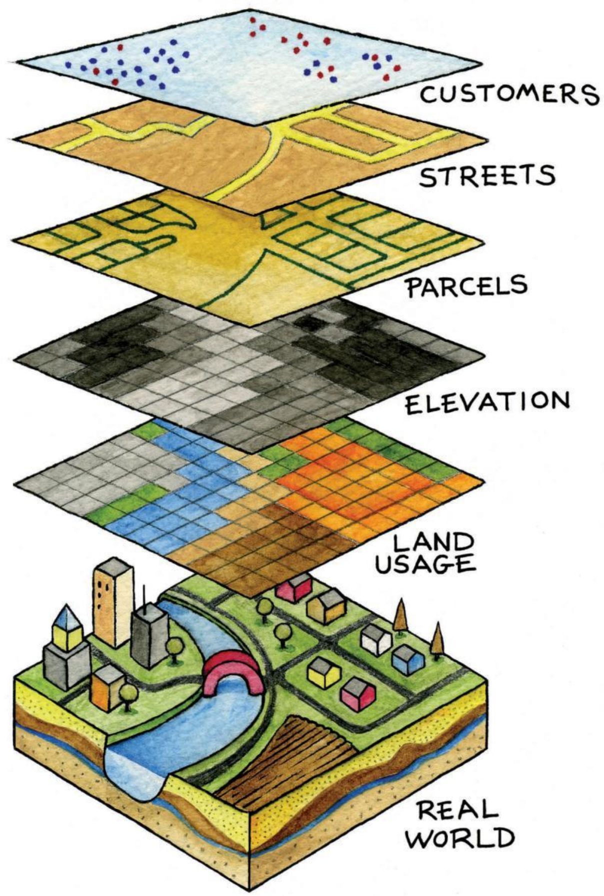
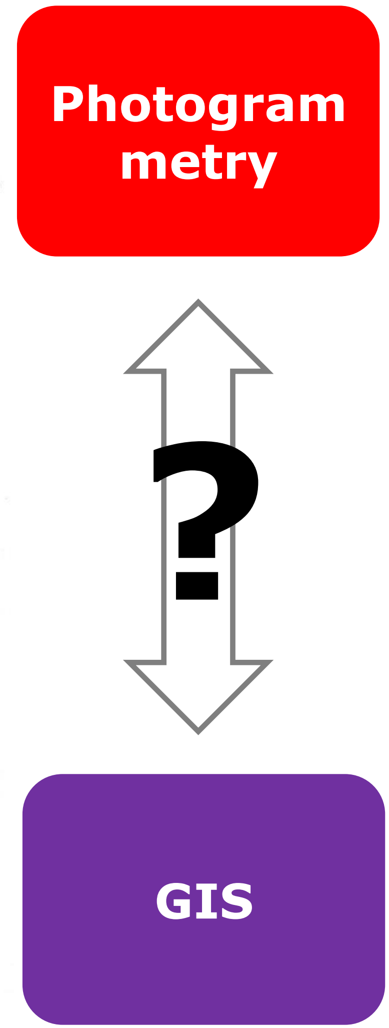
Remote Sensing, GNSS, GIS & Photogrammetry



GIS & Photogrammetry

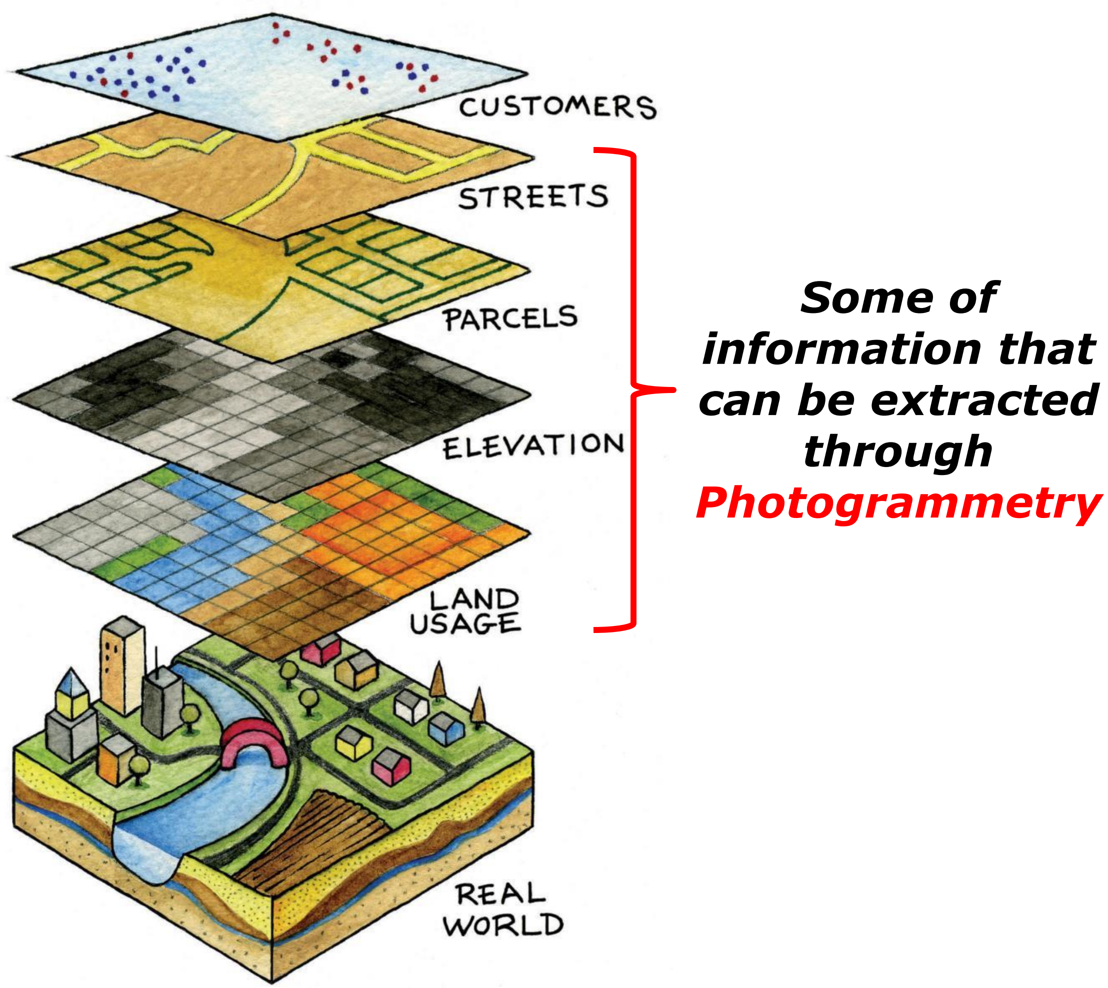
- **GIS**
  - **Geographic Information System**
  - a system designed to capture, store, manipulate, analyze, manage, and present **spatial or geographic data.**



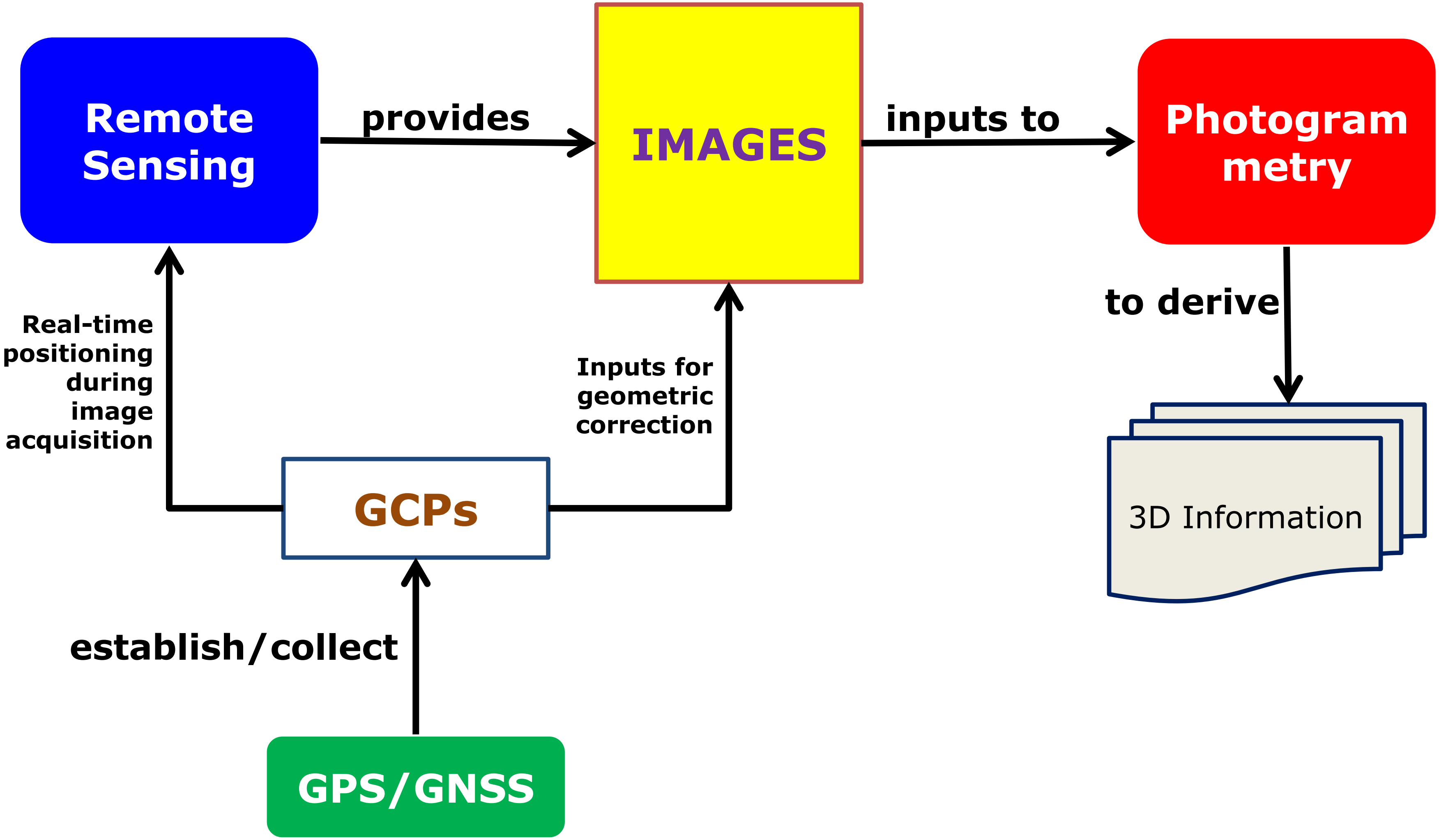


GIS & Photogrammetry

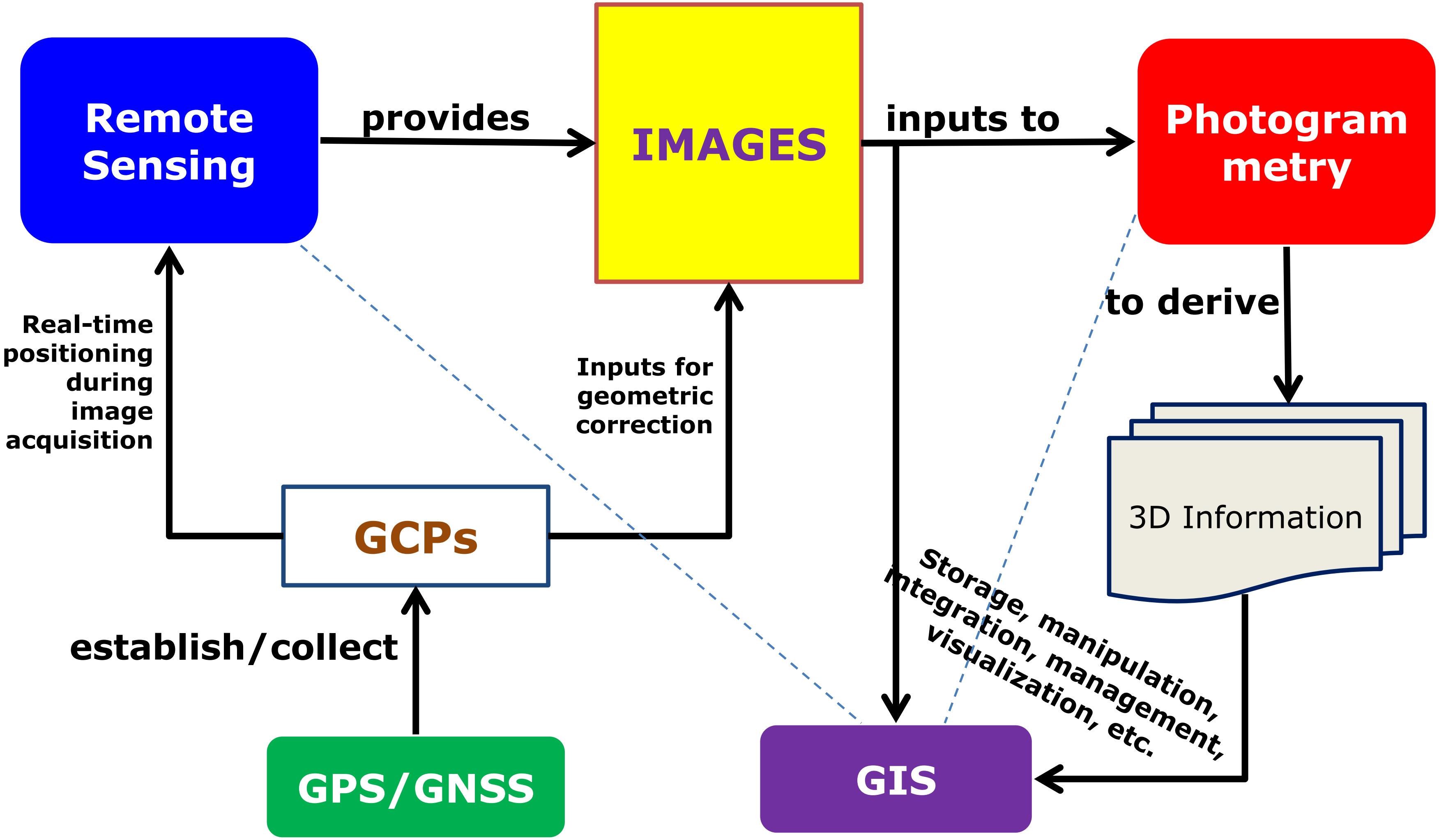
- **GIS** can be used as a system to store the images (acquired by **RS**) and the 3D information extracted from the images through **Photogrammetry**
- These sets of information can be integrated with other spatial datasets
- GIS can also be used as a platform to do RS image processing and Photogrammetric analysis!



Remote Sensing, GNSS & Photogrammetry

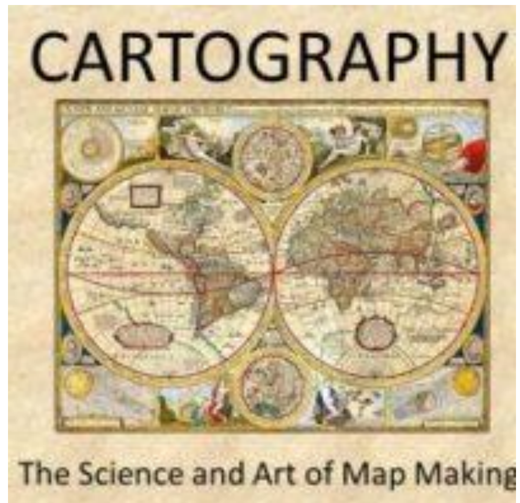


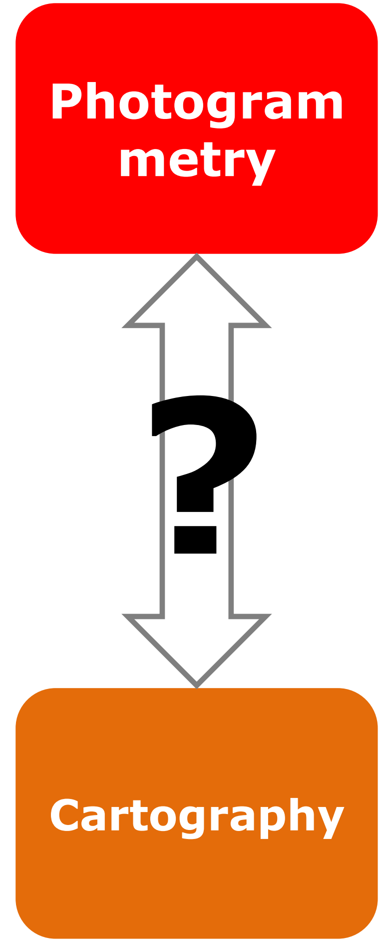
Remote Sensing, GNSS & Photogrammetry



Cartography & Photogrammetry

- **Cartography**
  - The discipline dealing with the conception, production, dissemination and study of maps
    - according to the International Cartographic Association
  - Cartography is also about representation – the map.
  - Cartography is the whole process of mapping.

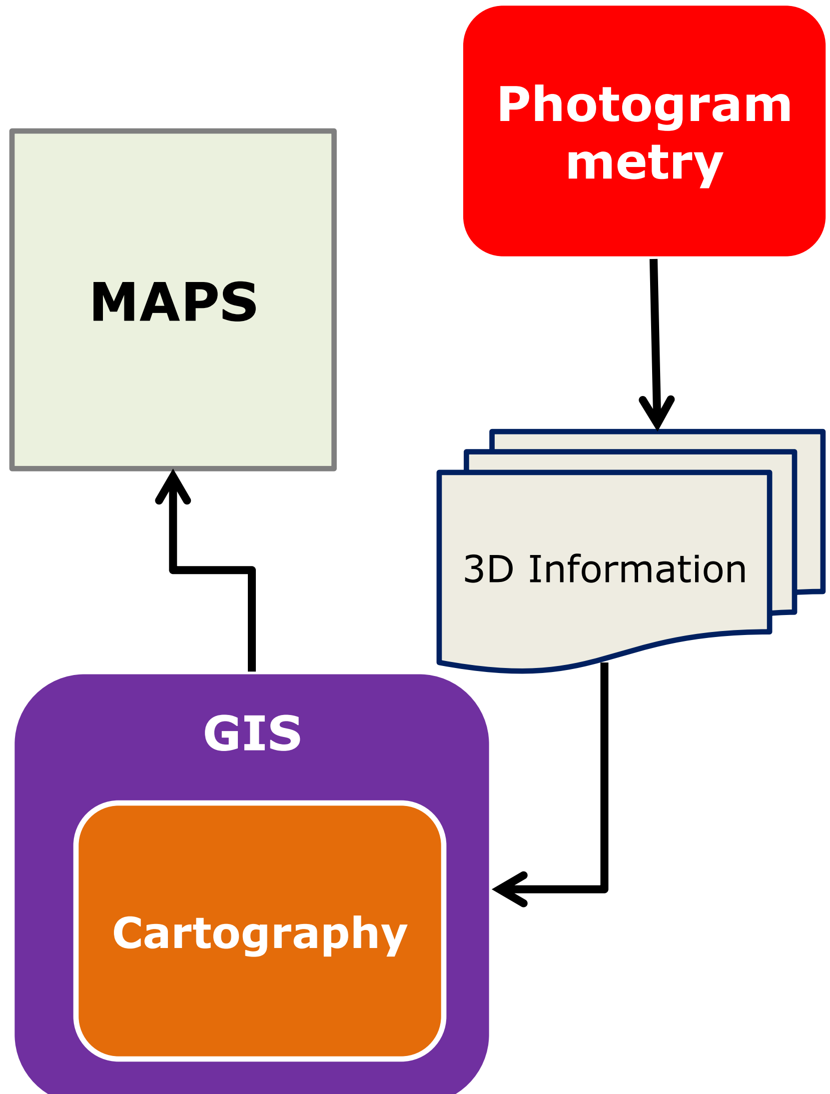




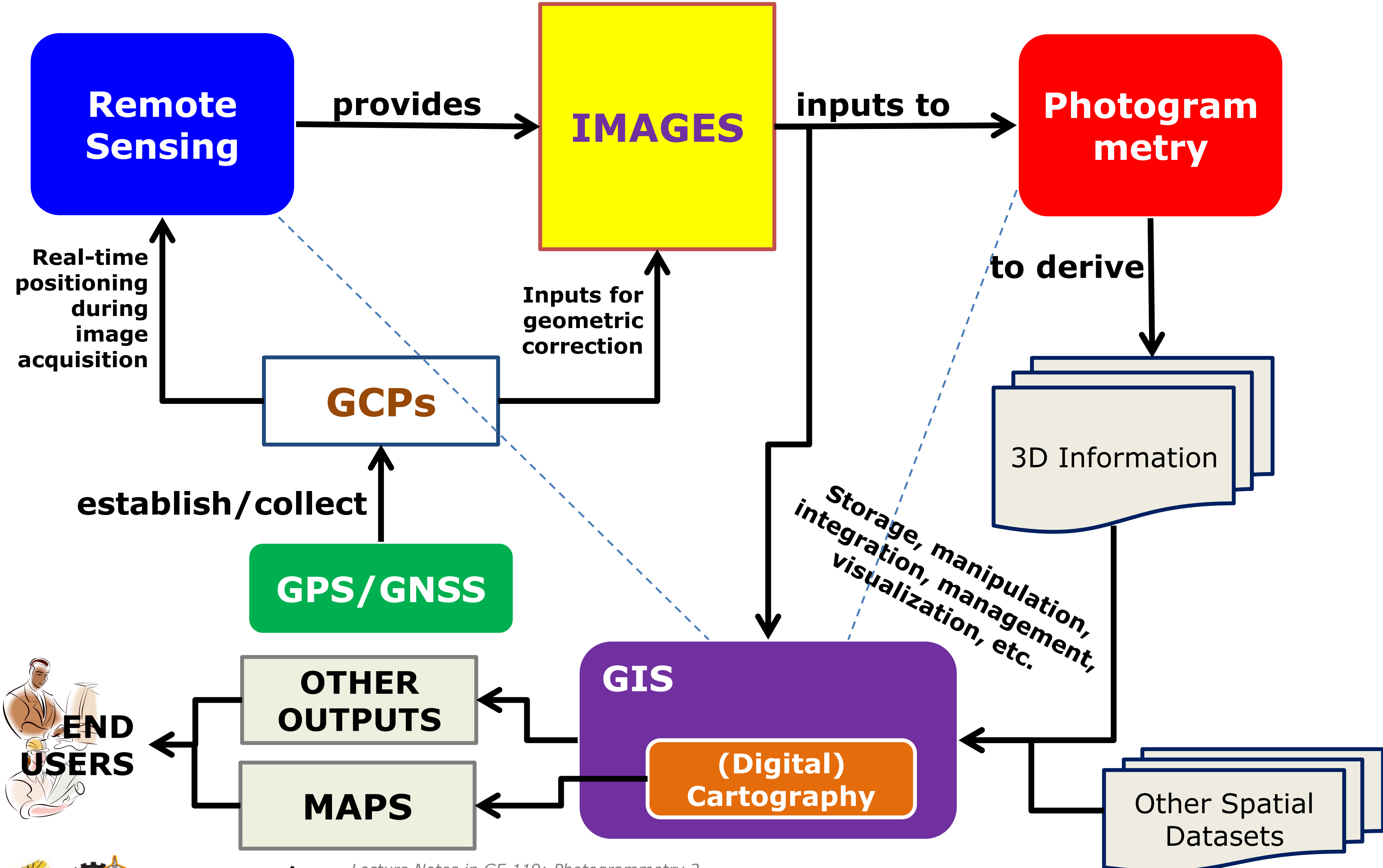
Cartography & Photogrammetry

- Cartography can be used to represent the 3D information extracted from Remote Sensing and Photogrammetry!

- Cartography can be aided by GIS
  - Especially 'Digital Cartography'



Inter-relationships of Remote Sensing, GNSS, GIS & Photogrammetry



STANDARD PHOTOGRAMMETRIC TERMS AND DEFINITIONS

Some standard terms*

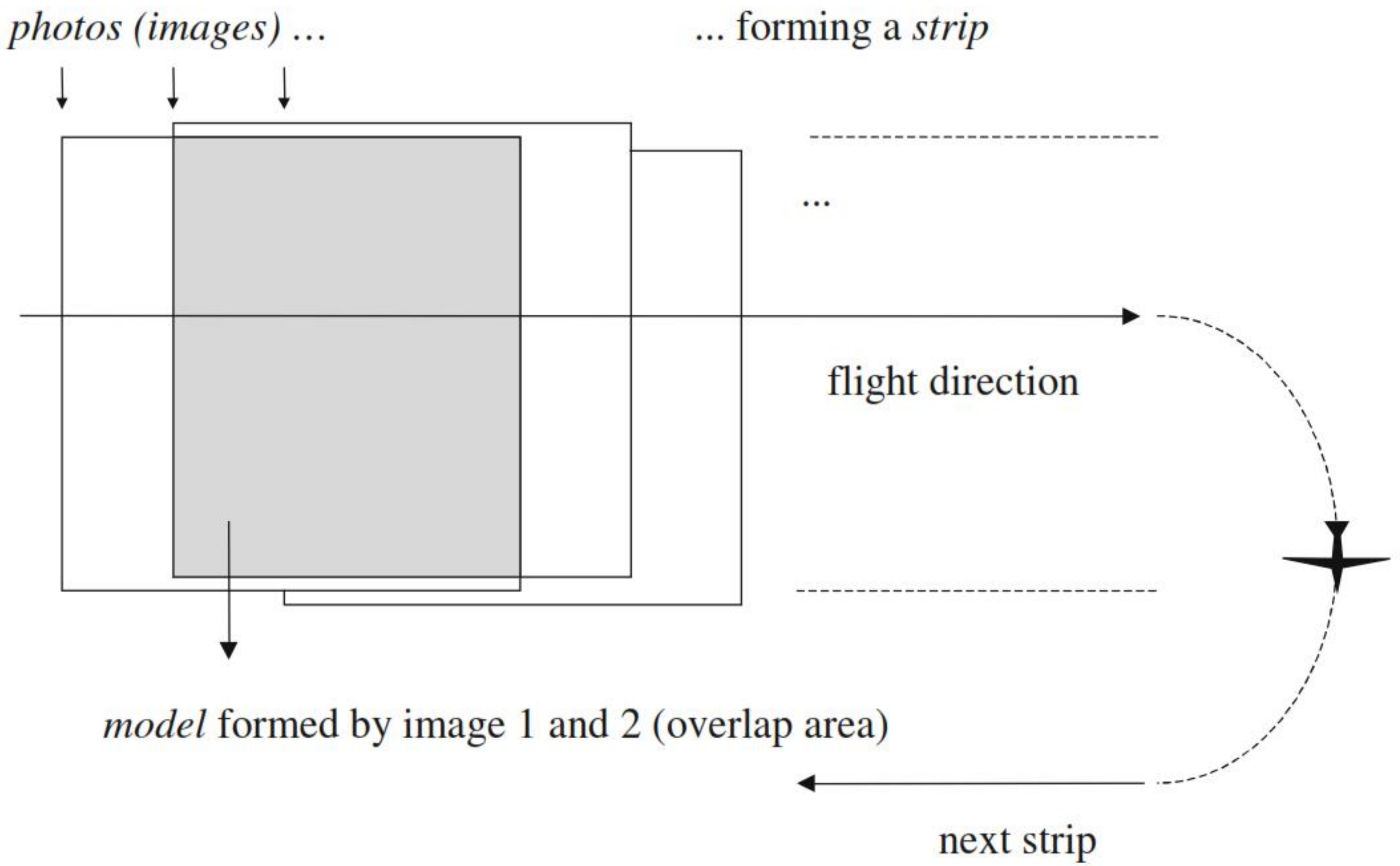
(which we will repeatedly encounter in the next lectures especially in stereophotogrammetry) :

Photo	Image
Model	Strip
Block	Base

* Other equally-important terms will be discussed as we go through the remaining sub-topics.

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

Illustration of some standard terms



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

Definitions of some standard terms

- **Photo** → the original photo (e.g., hard copy aerial photograph)
- **Image** → the photo in digital representation (e.g., a scanned hard copy of the aerial photograph)
- **Model** → two neighboring images within a strip
  - *Also called "stereo model" , "image pair"*
- **Strip** → all overlapping images taken one after another within one flight line
- **Block** → all images of all strips
- **Base** → distance between the projection centers of neighboring images

A Flight Strip

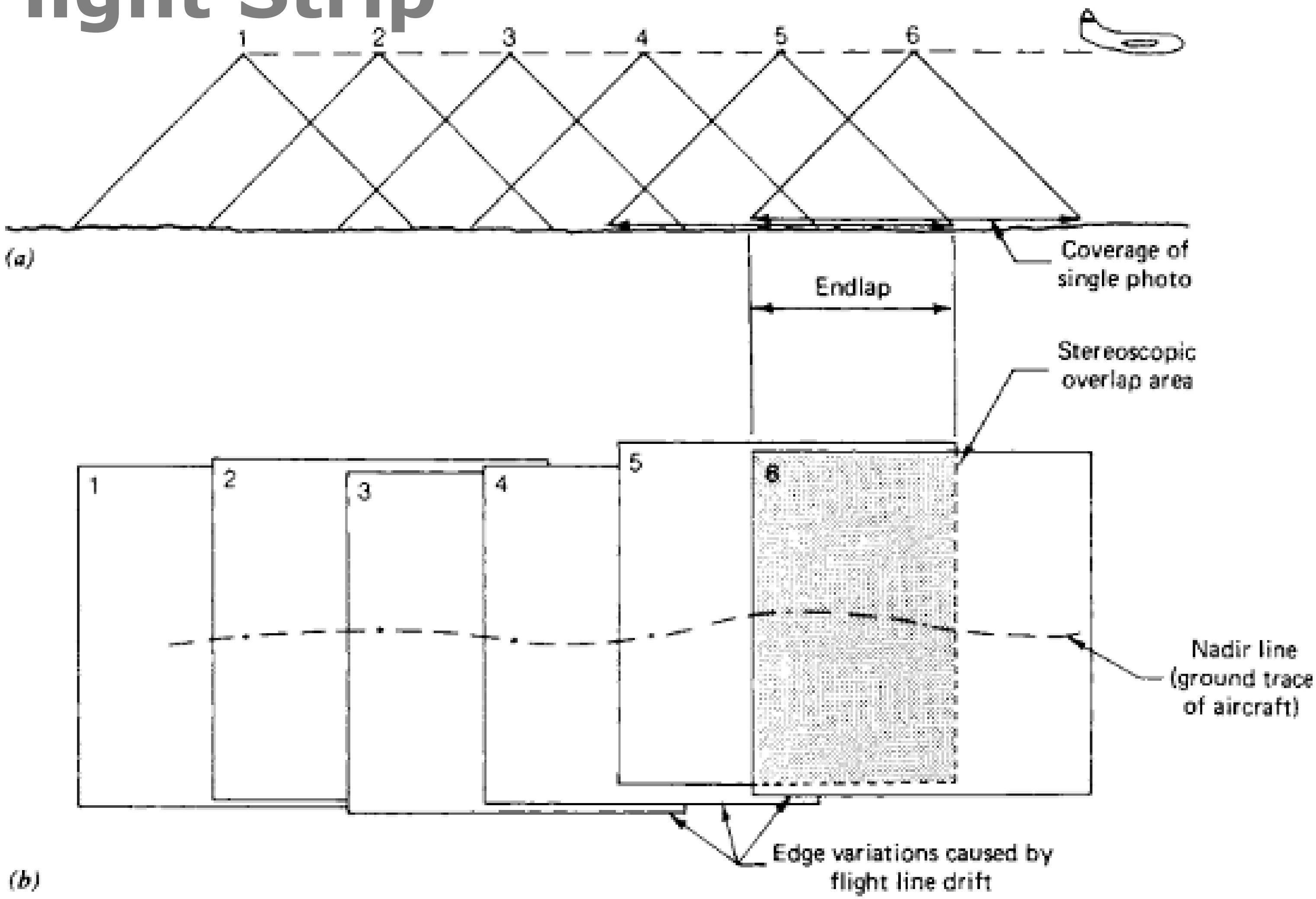


Figure 3.1 Photographic coverage along a flight strip: (a) conditions during exposure; (b) resulting photography.

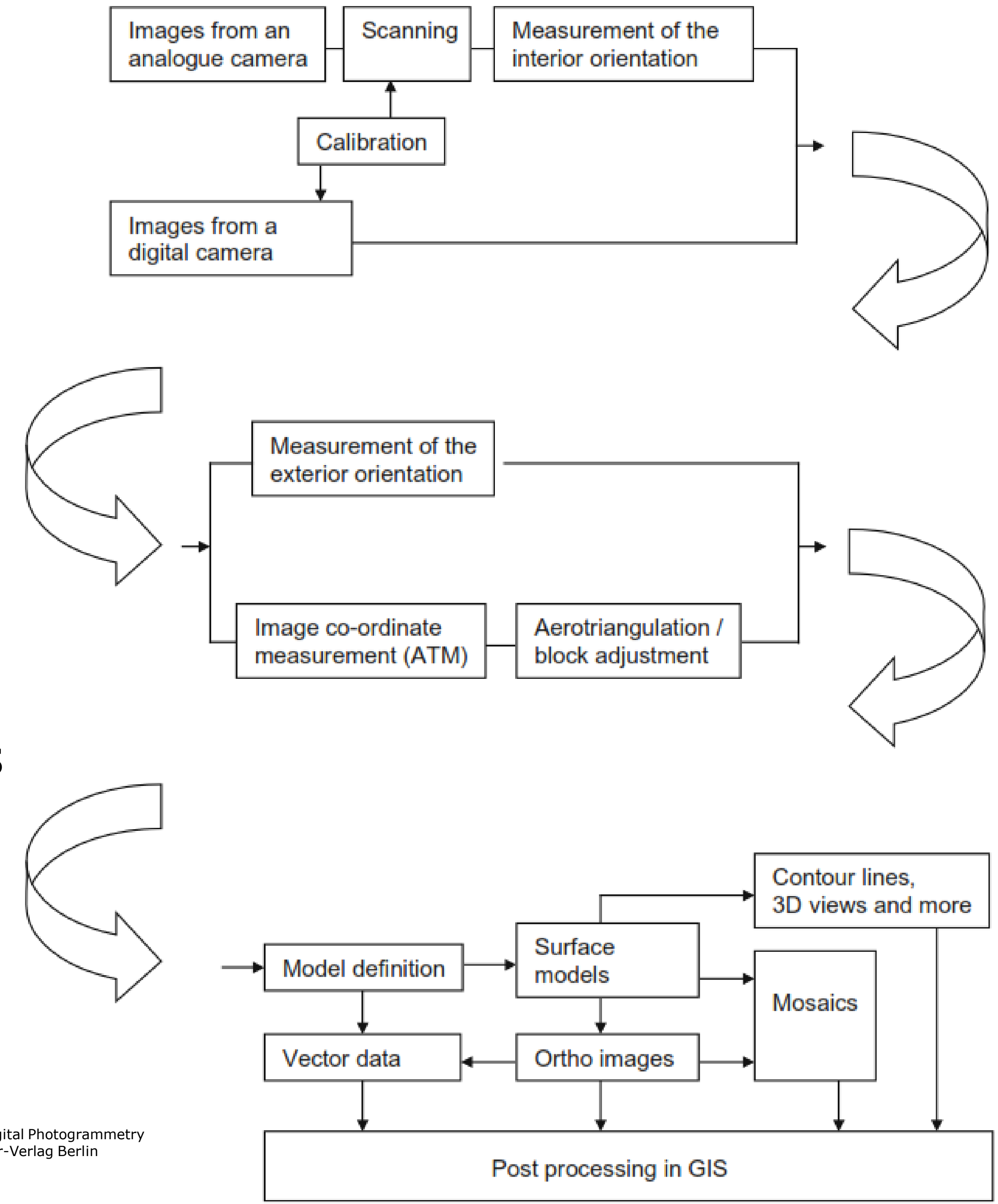
Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

PHOTOGRAMMETRY WORKFLOW

A Typical Workflow in Photogrammetry

Generally:

- Begins with the capture of the images
- Calculation of the orientation parameters of all images that will be used
- Measure co-ordinates
- Create several image products
- Use of results in cartographic or GIS software



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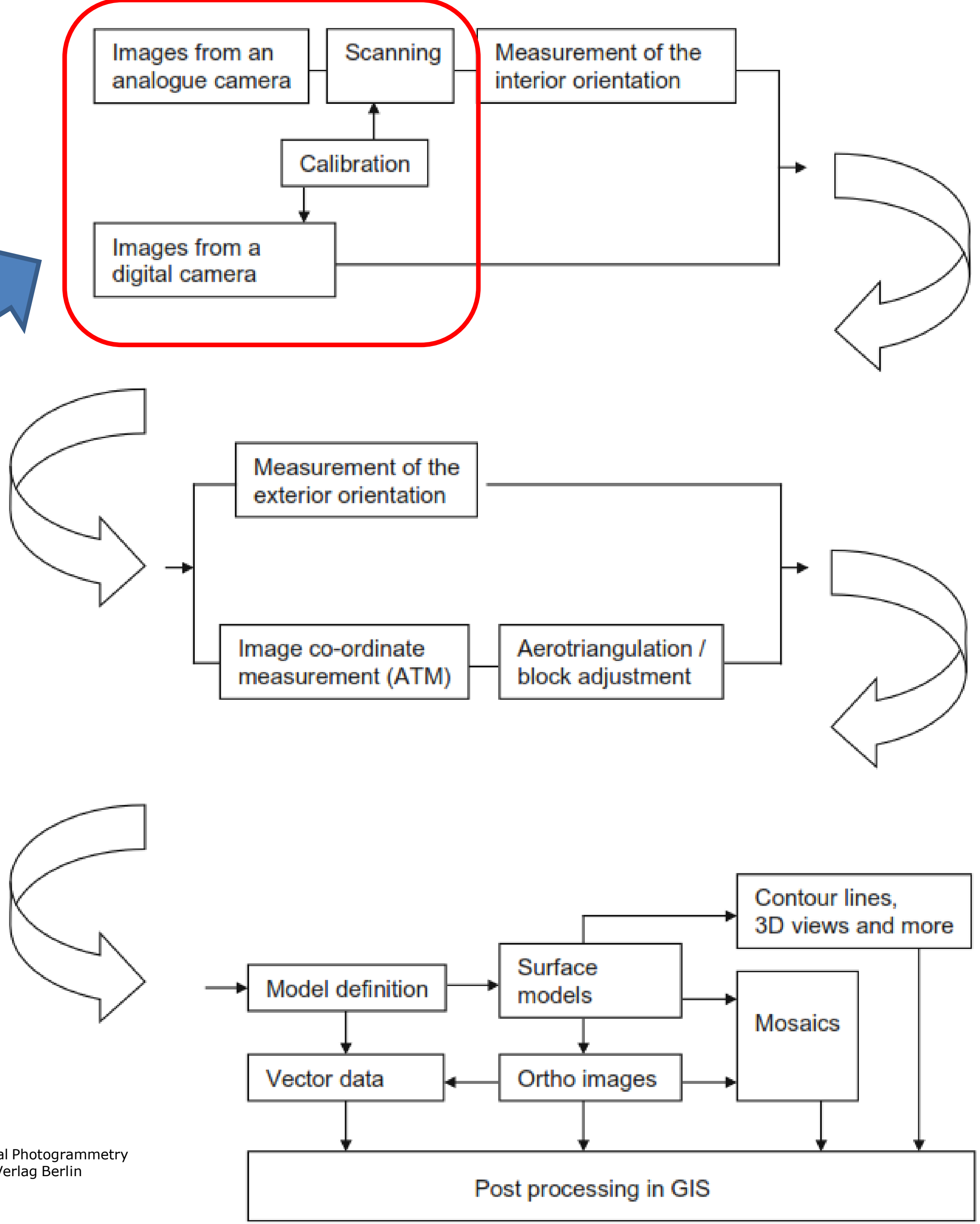

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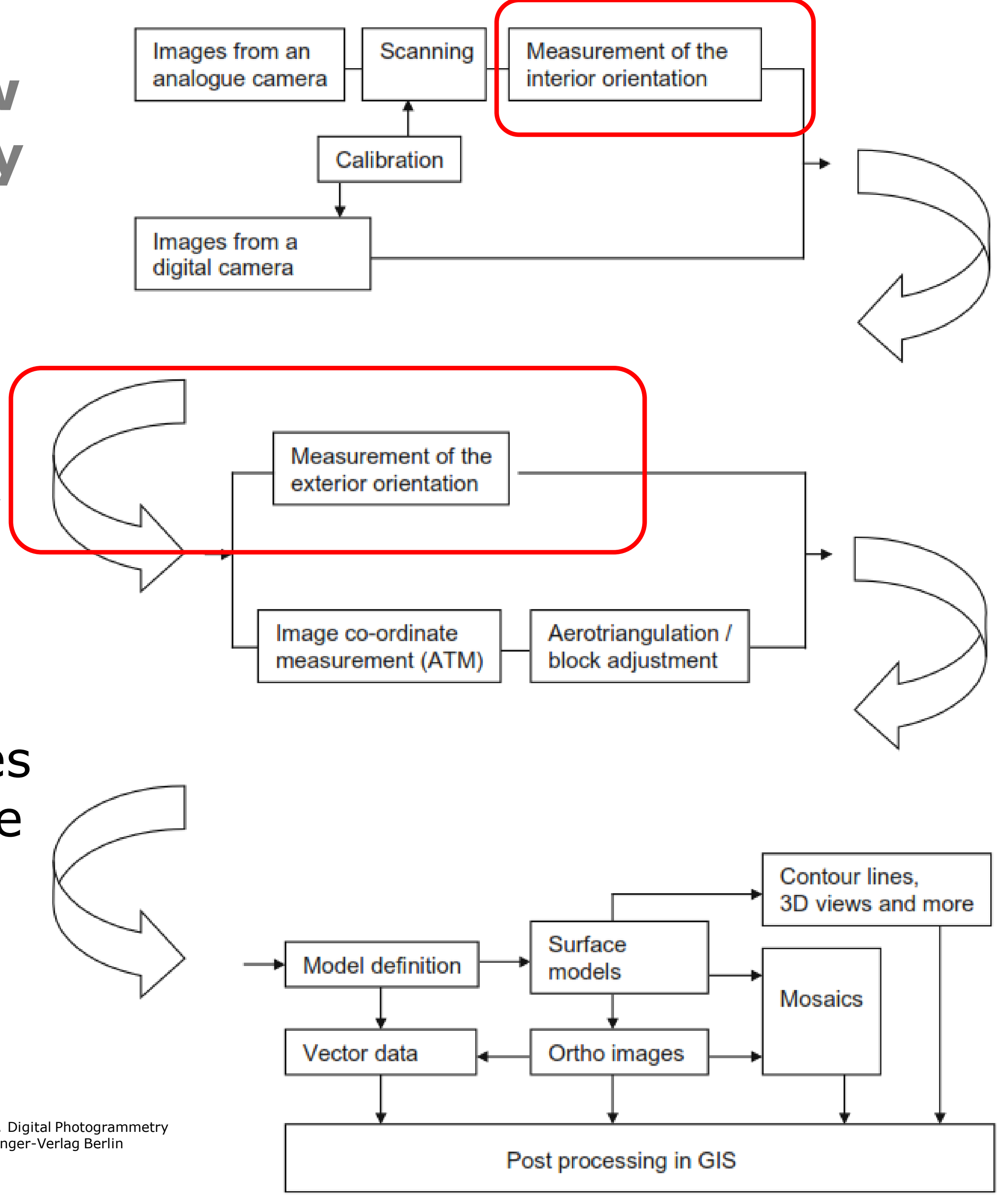

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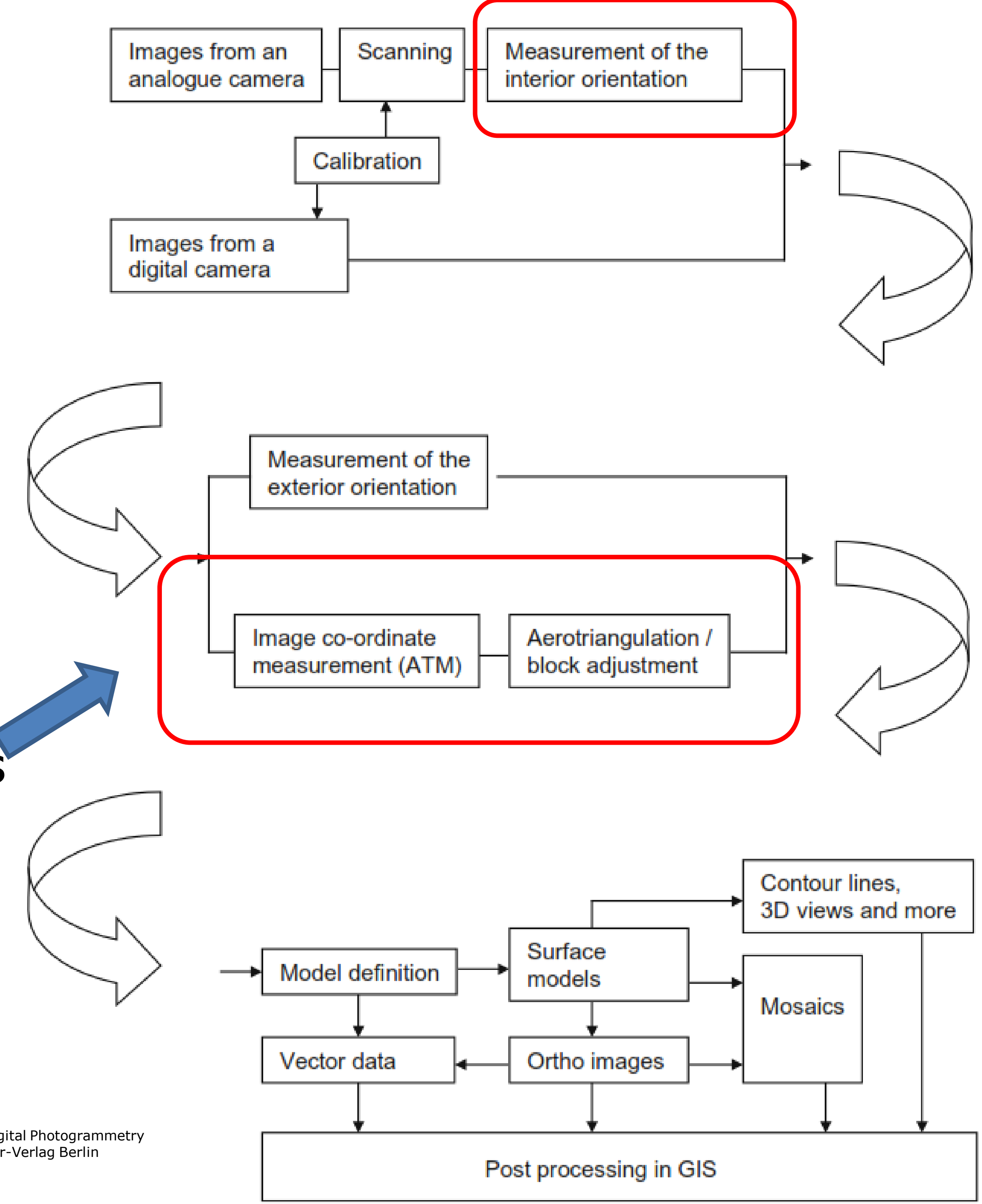

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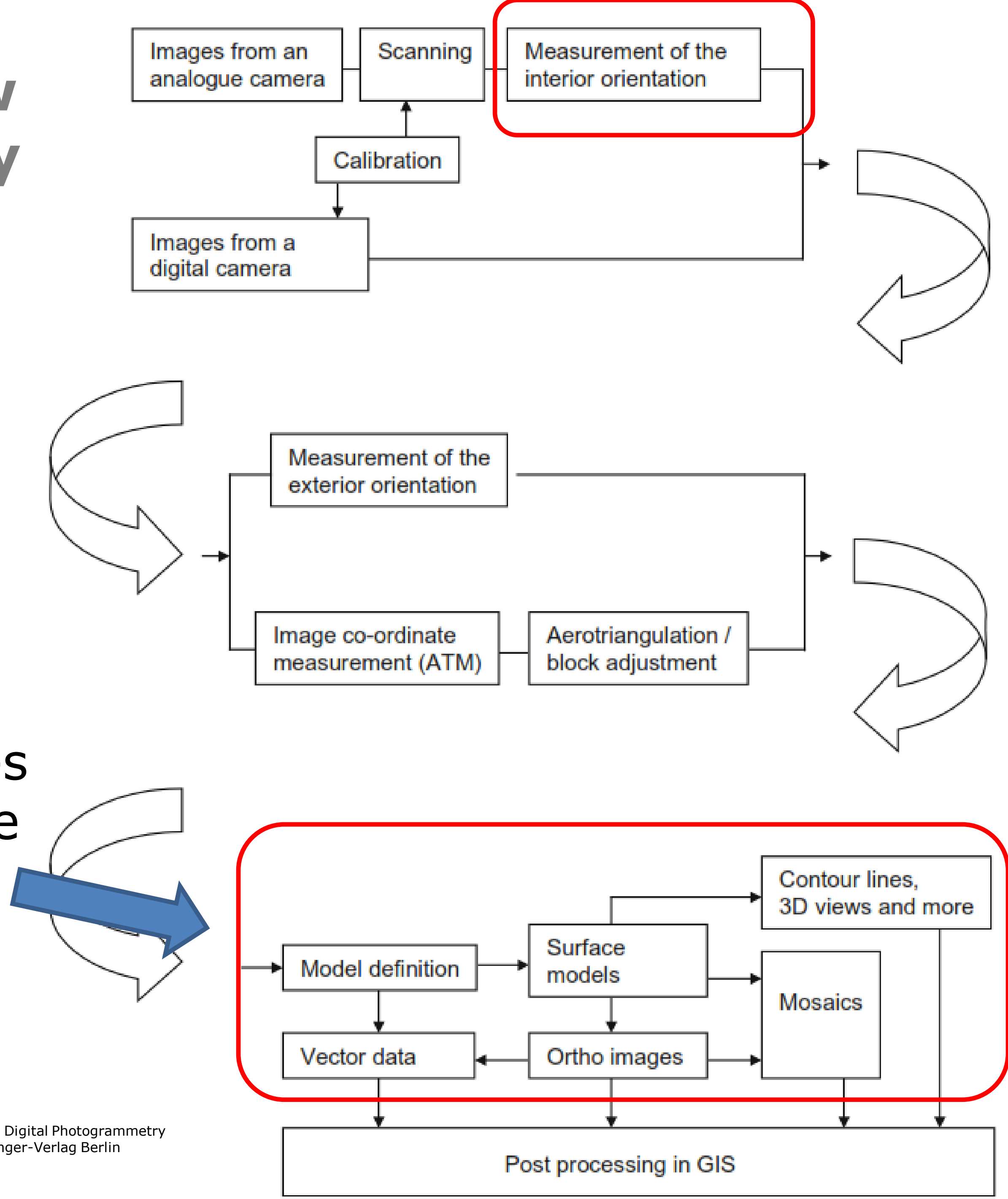

Source: Linder, W., 2016. Digital Photogrammetry – A Practical Course, Springer-Verlag Berlin Heidelberg, Germany.

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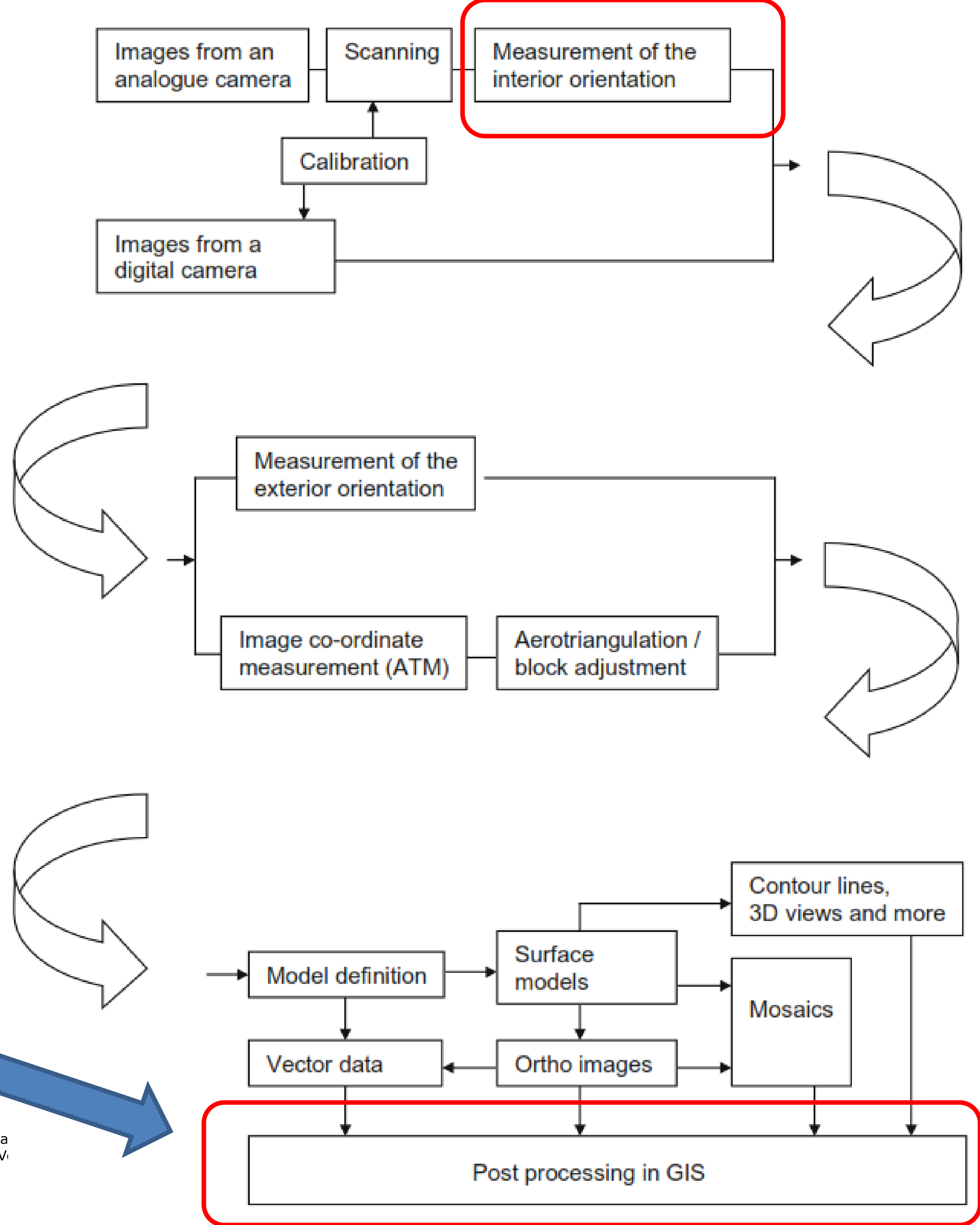
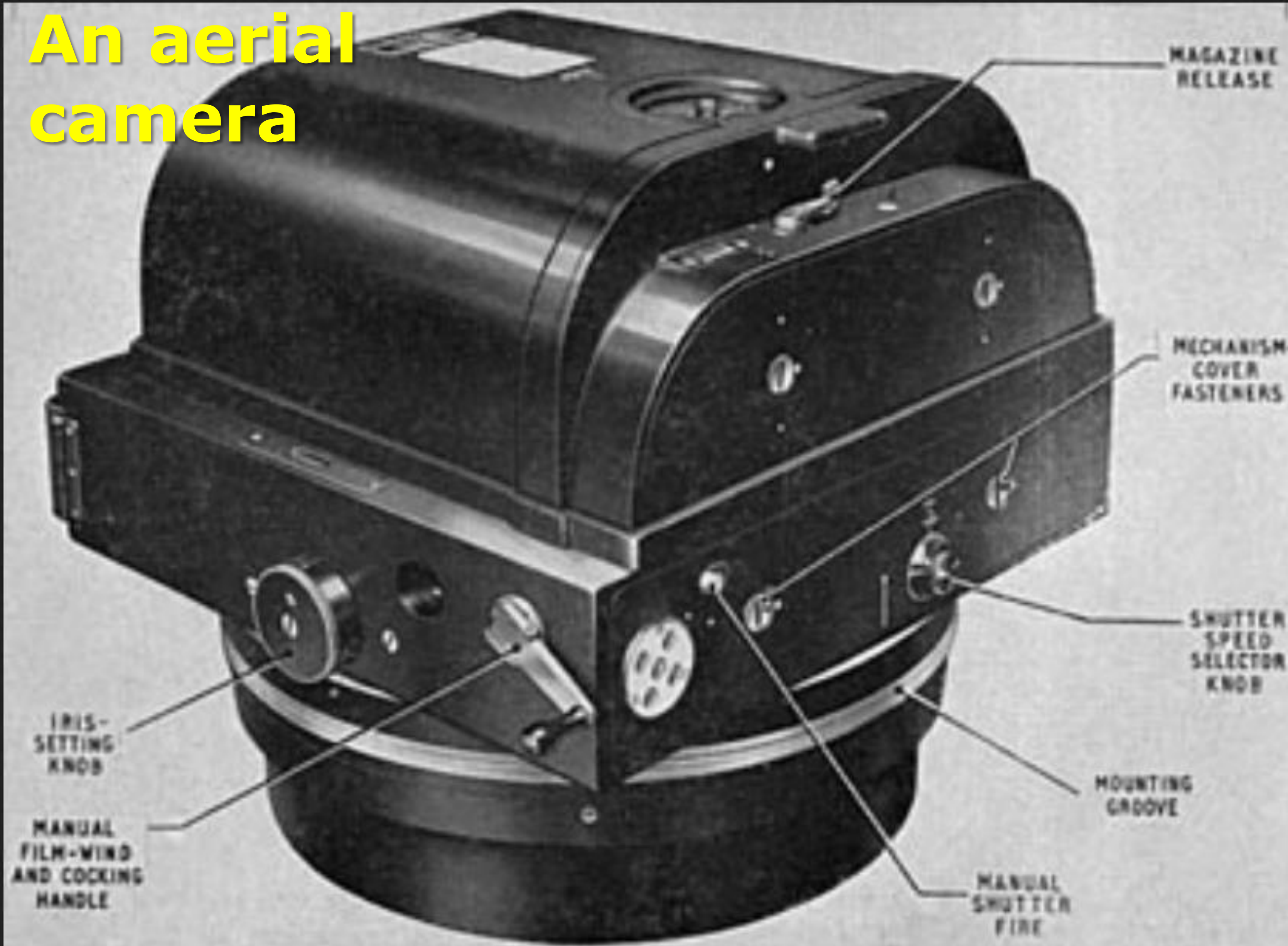


Source: Linder, W., 2016. Digita
– A Practical Course, Springer-V
Heidelberg, Germany.

BASIC GEOMETRIC CHARACTERISTICS OF AERIAL PHOTOGRAPHS

An aerial camera



Source: https://www.airrecce.co.uk/cameras/F49_1.jpg

Diagram of a Single-lens frame (analogue) mapping camera

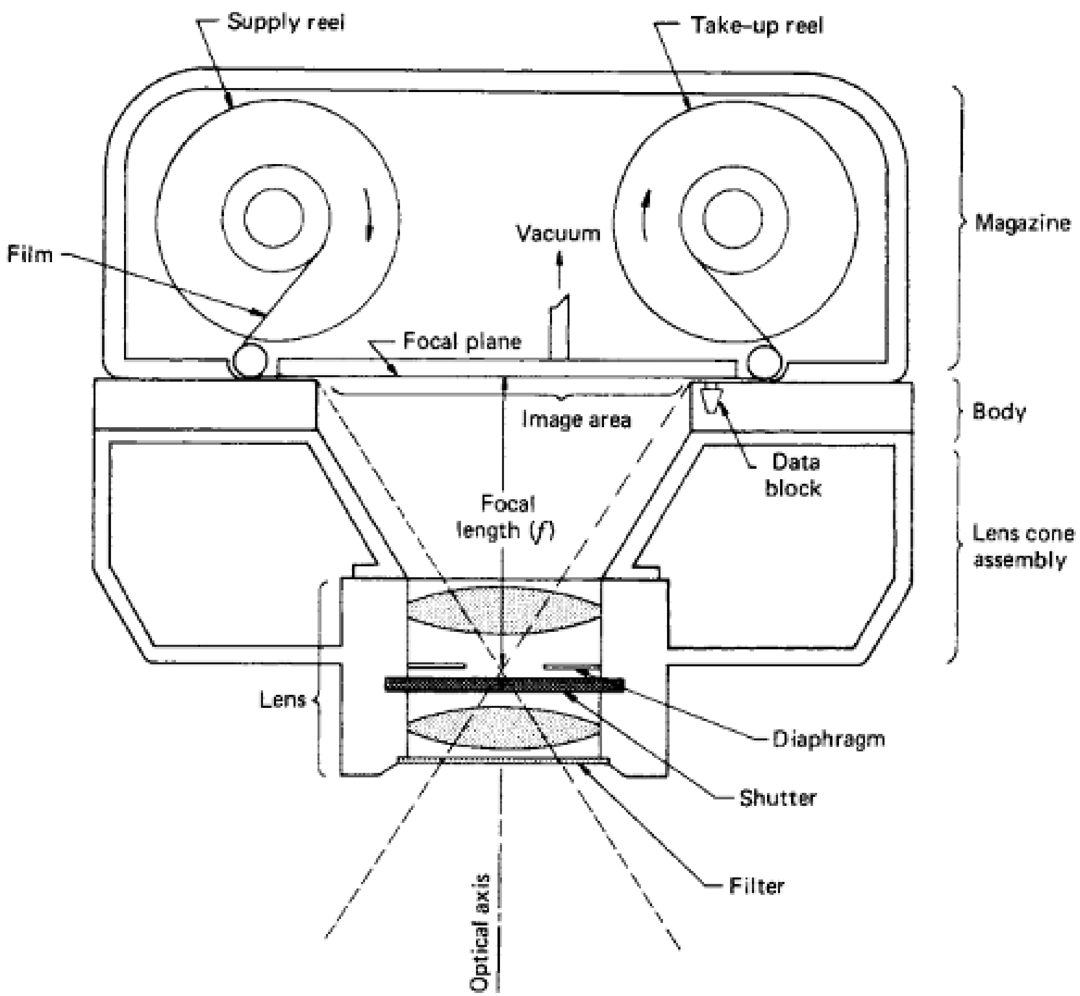


Figure 2.28 Principal components of a single-lens frame mapping camera.

How a photograph is generated from a 'negative' film

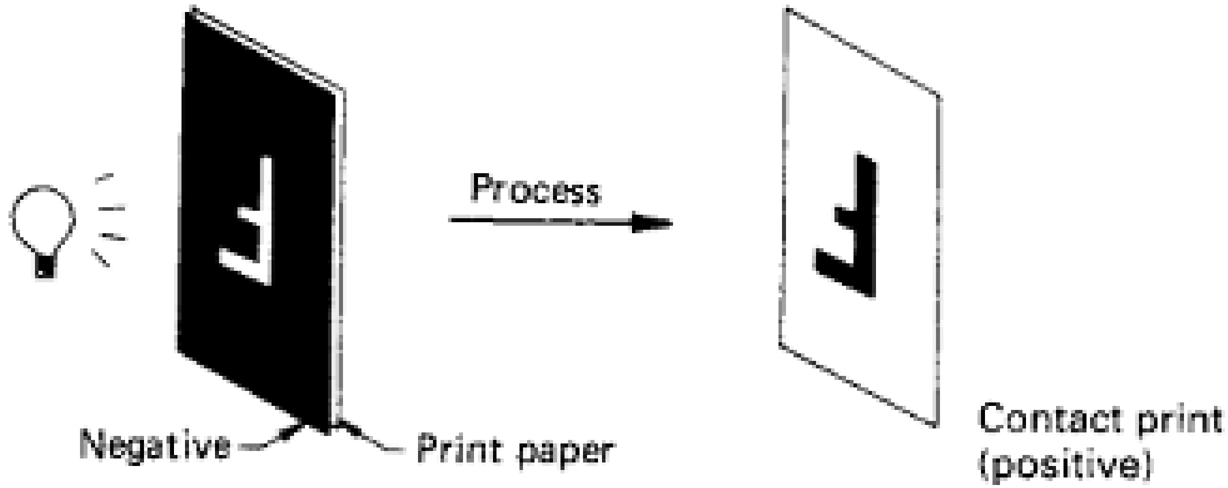
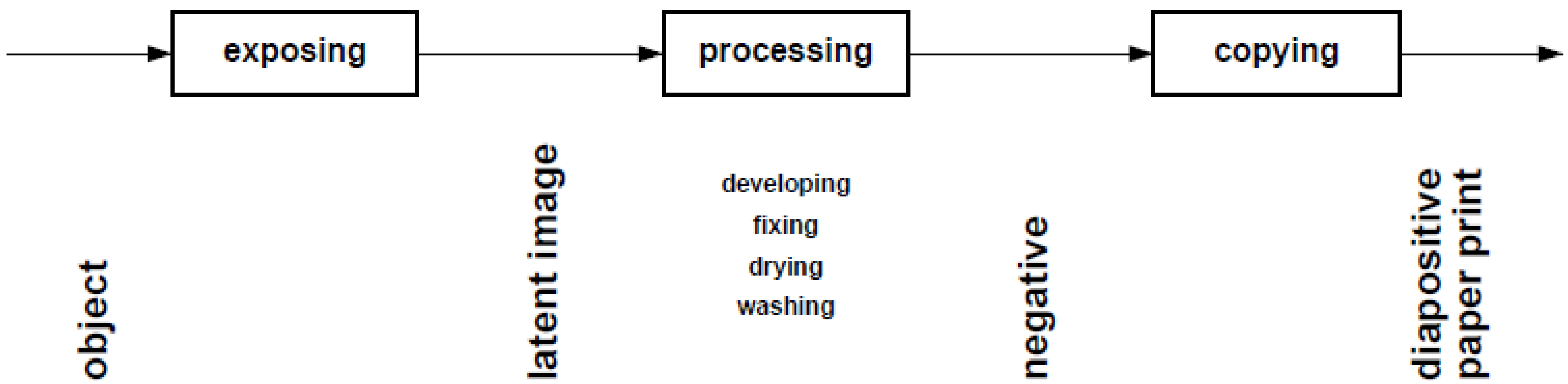


Figure 2.3 Negative-to-positive sequence of photography: (*a*) negative film exposure, (*b*) paper print enlargement, and (*c*) contact printing.

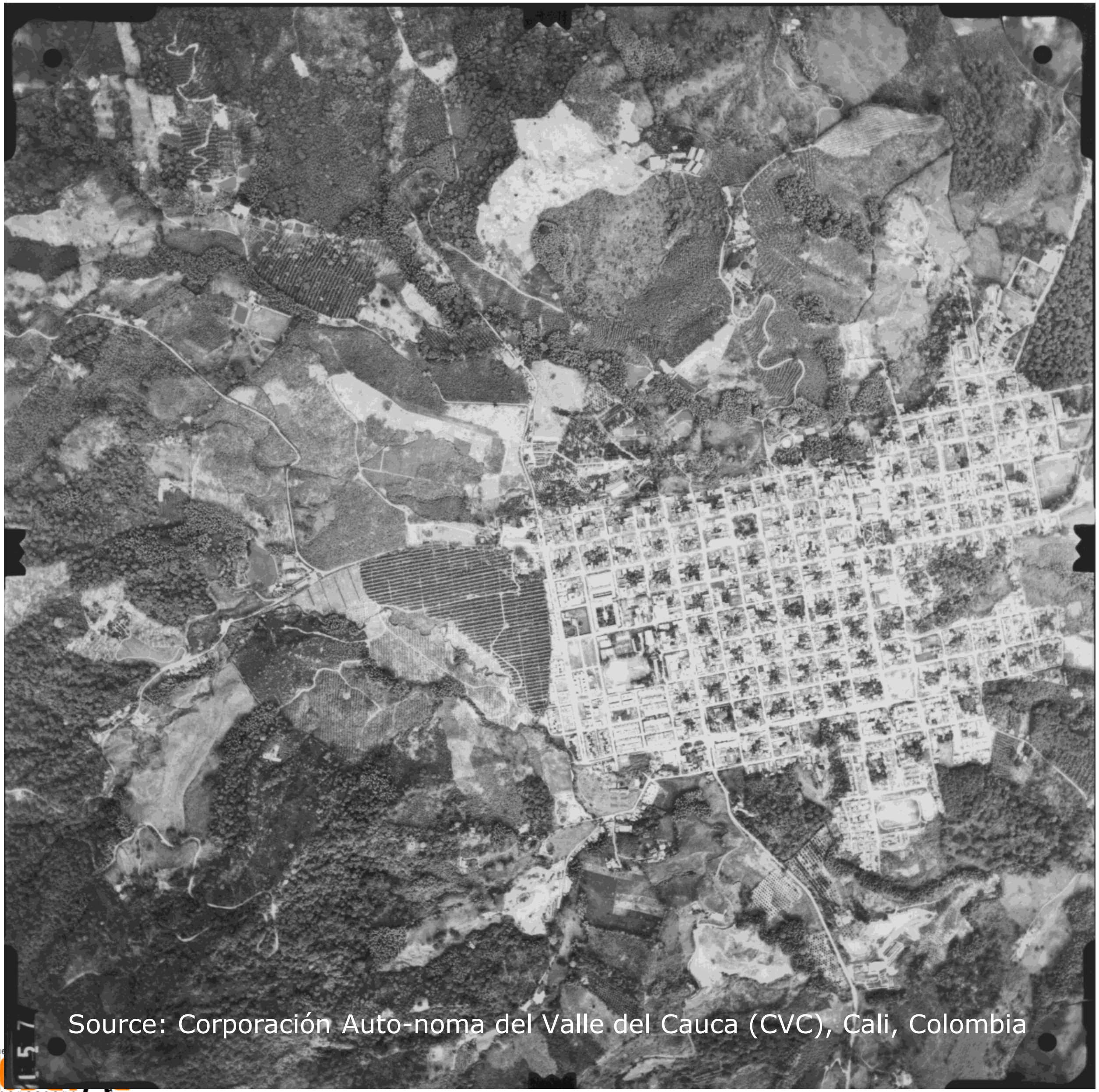
Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

How a photograph is generated from a ‘negative’ film

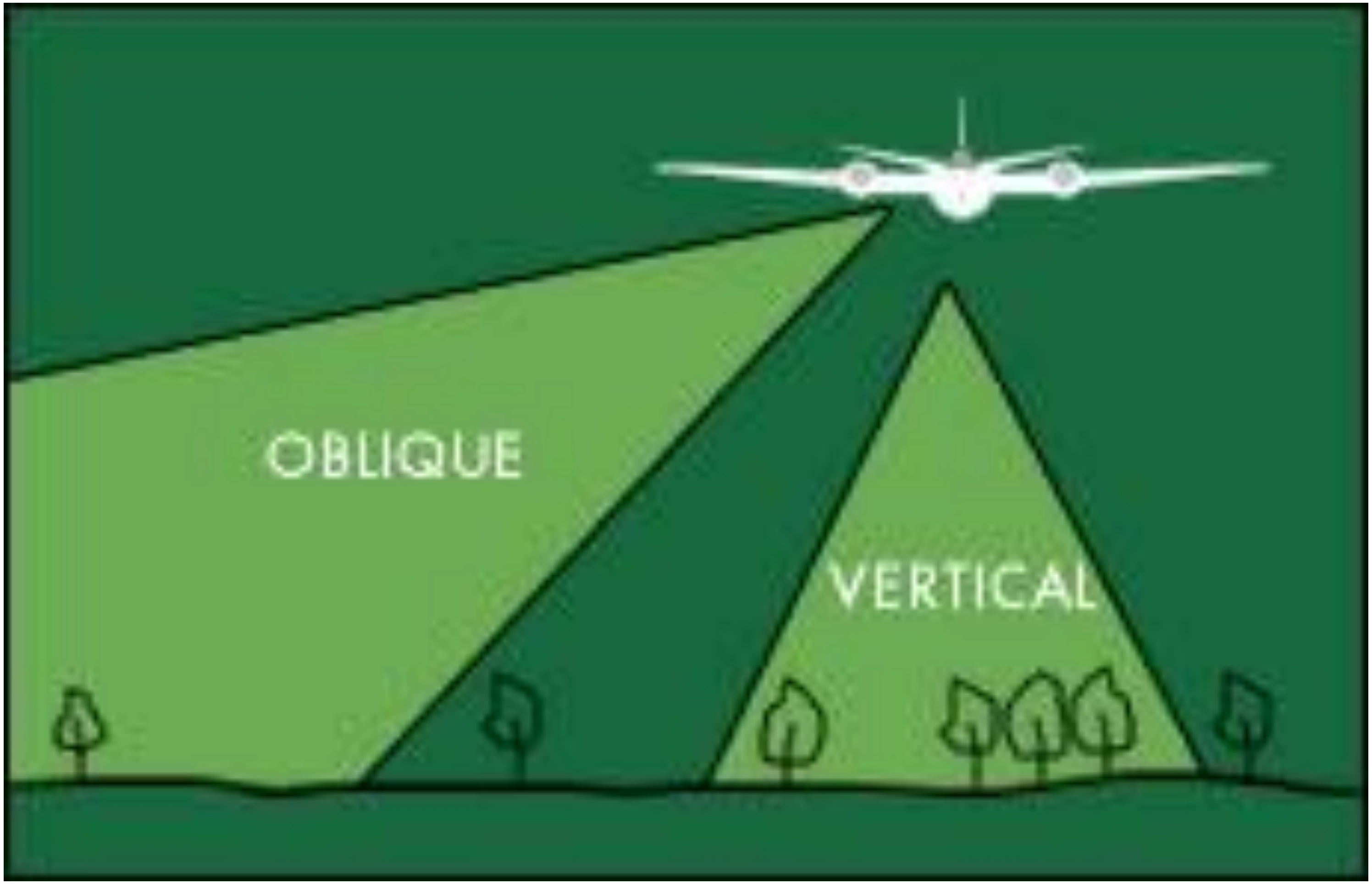


Source: Schenk, 2005. Introduction to Photogrammetry

An Aerial Photograph



Geometric Types of Aerial Photograph



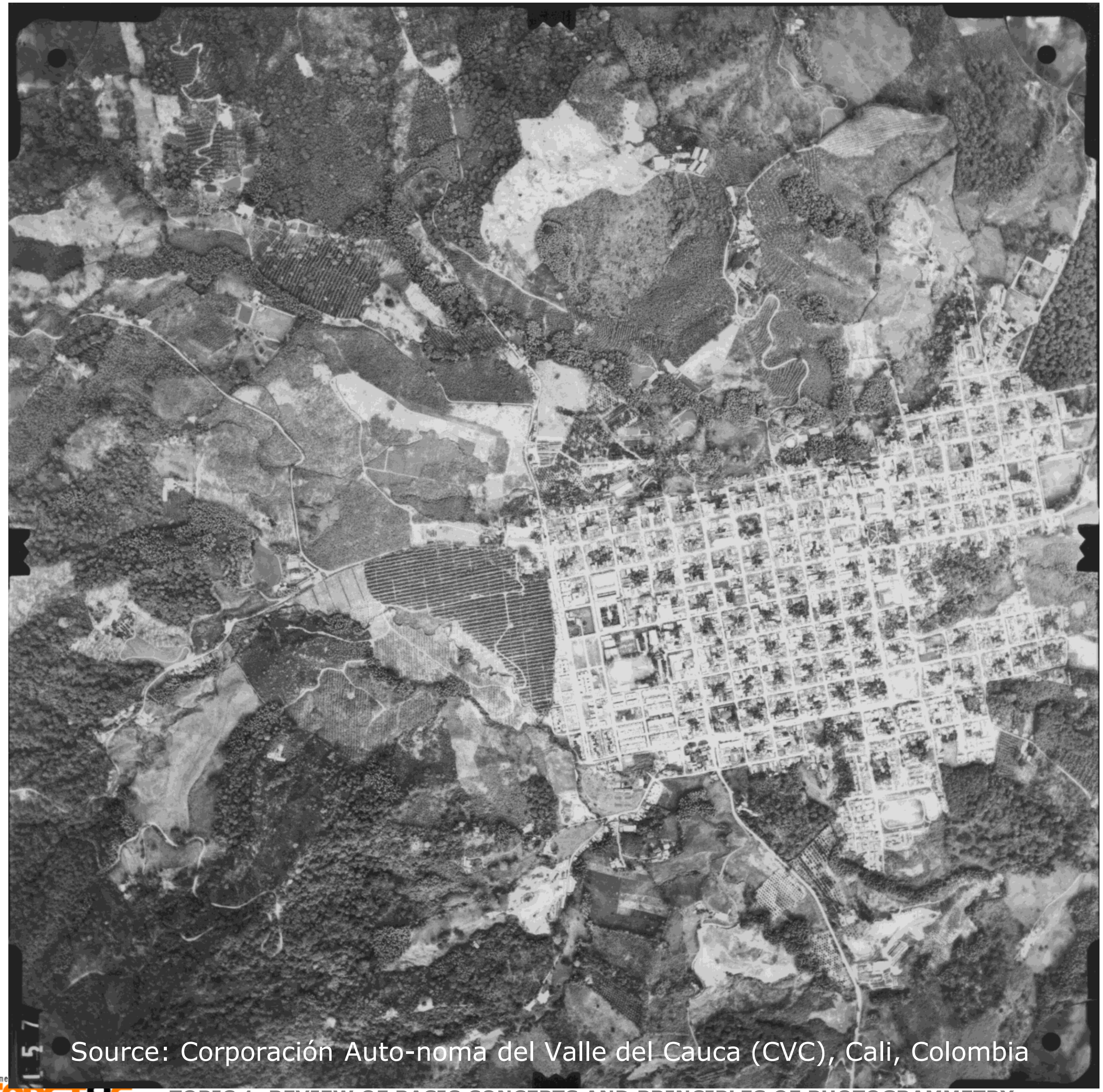
Source: http://ncap.org.uk/sites/default/files/camera_positions2.jpg

Geometric Types of Aerial Photograph

- **Vertical aerial photographs**
  - Those made with the camera axis directed as vertically **as possible**
  - A ‘truly’ vertical aerial photograph is rarely obtainable
    - Why?

Because of **unavoidable** angular rotations, or tilts, caused by the angular altitude of the aircraft at the instant of exposure (i.e., image acquisition)

A Vertical Aerial Photograph



Source: Corporación Auto-noma del Valle del Cauca (CVC), Cali, Colombia

Geometric Types of Aerial Photograph

- **Oblique aerial photographs**
  - Aerial photographs that are taken with an intentional inclination of the camera axis
    - High oblique photographs
    - Low oblique photographs

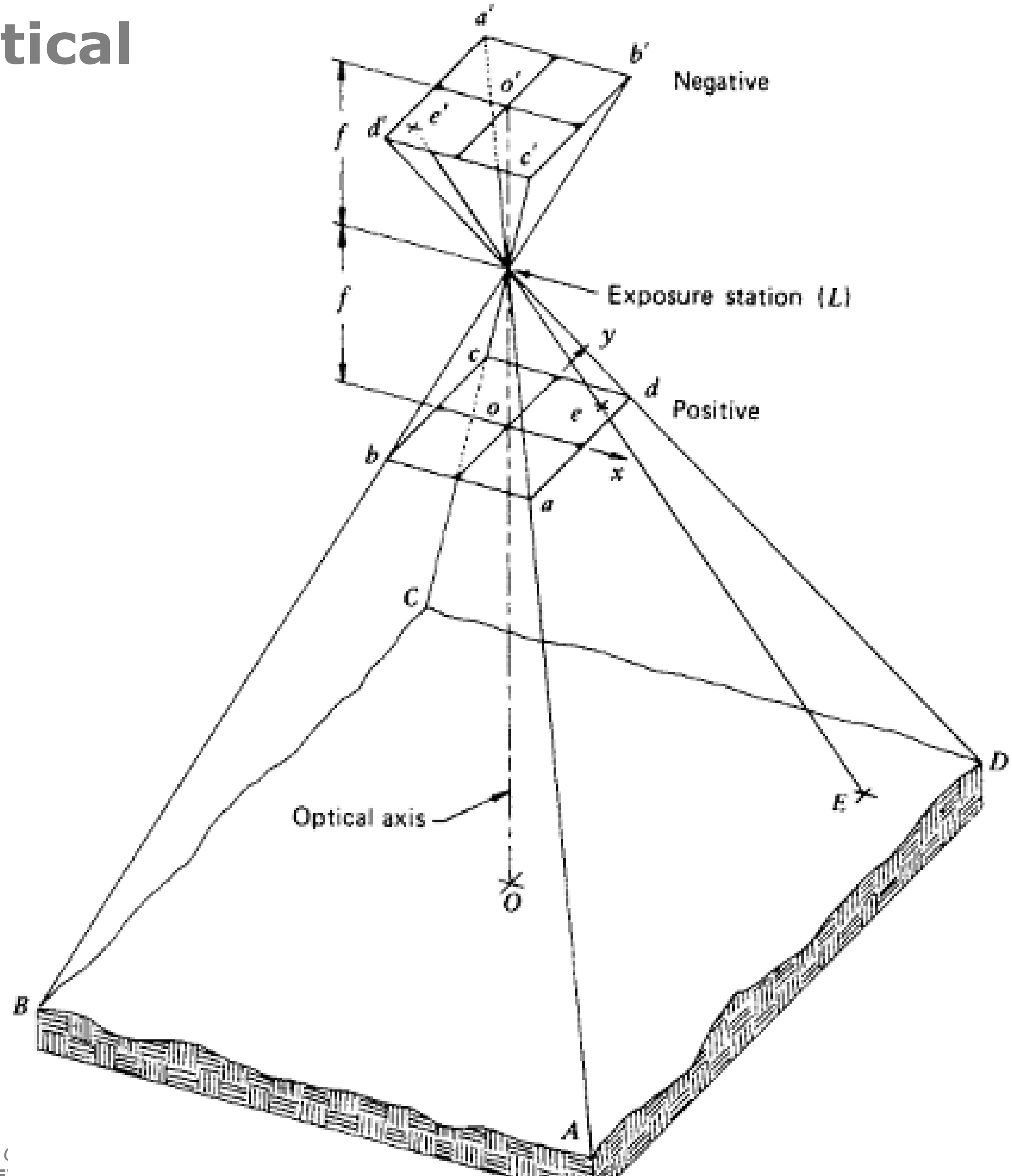
An Oblique Aerial Photograph

Source: http://orapweb.rcahms.gov.uk/coflein/A/AP_2006_2240.jpg

PHOTO AND OBJECT SPACE COORDINATE SYSTEMS

Elements of a vertical photograph

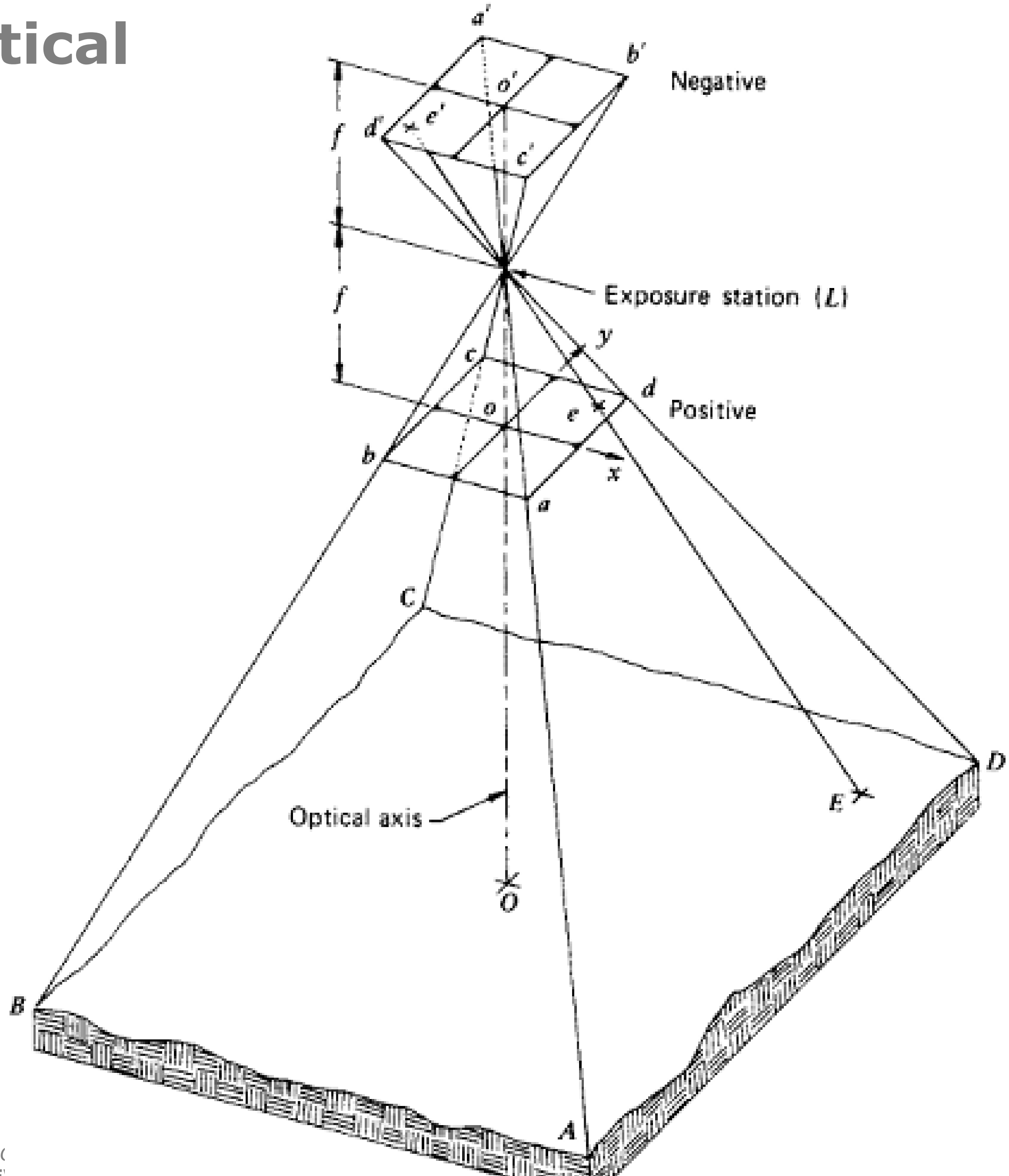
- Light rays from terrain objects are imaged in the plane of the film negative after intersecting at the camera lens exposure station (L)



Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Elements of a vertical photograph

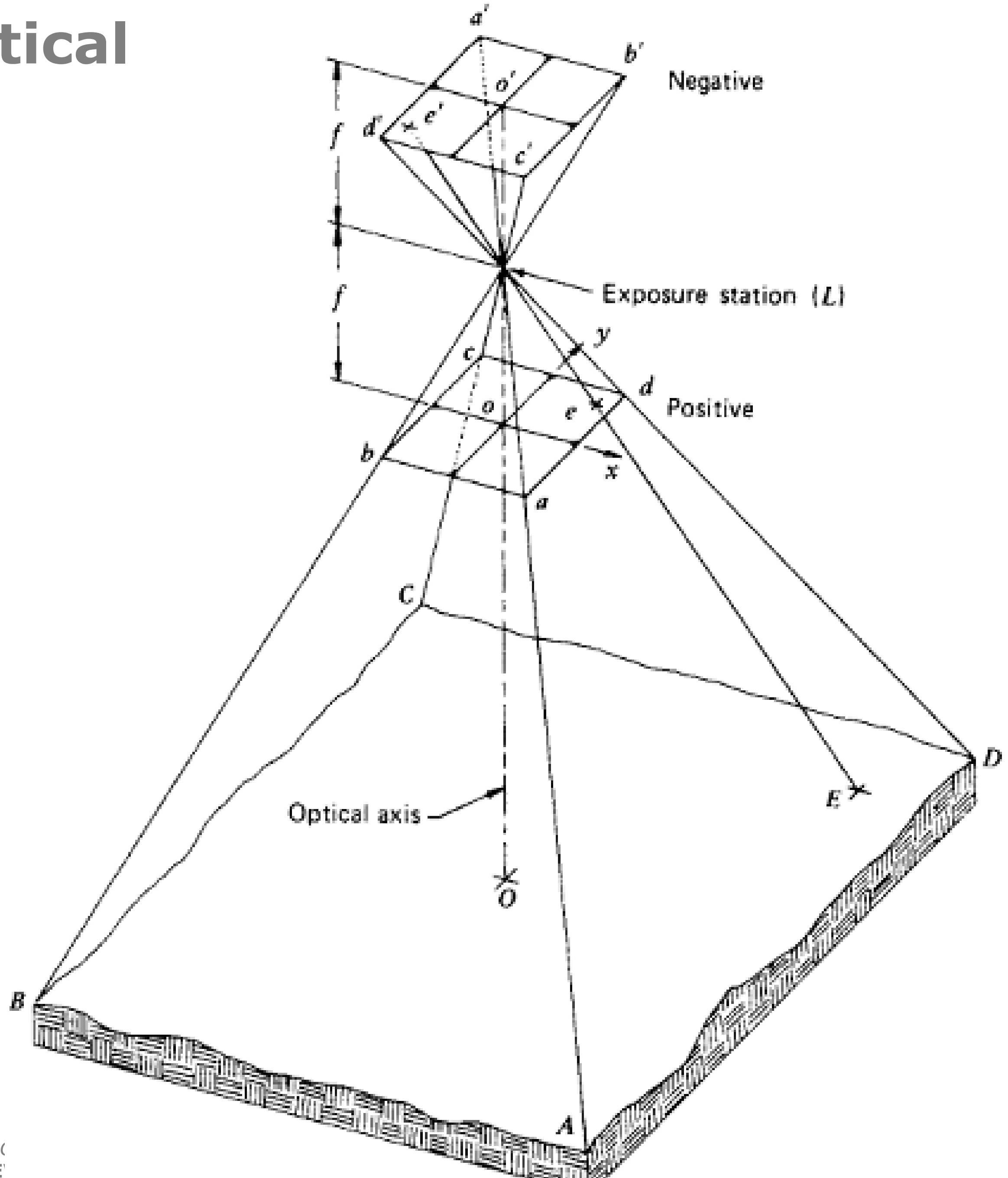
- The negative is located behind the lens at a distance equal to the lens focal length, *f*.



Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Elements of a vertical photograph

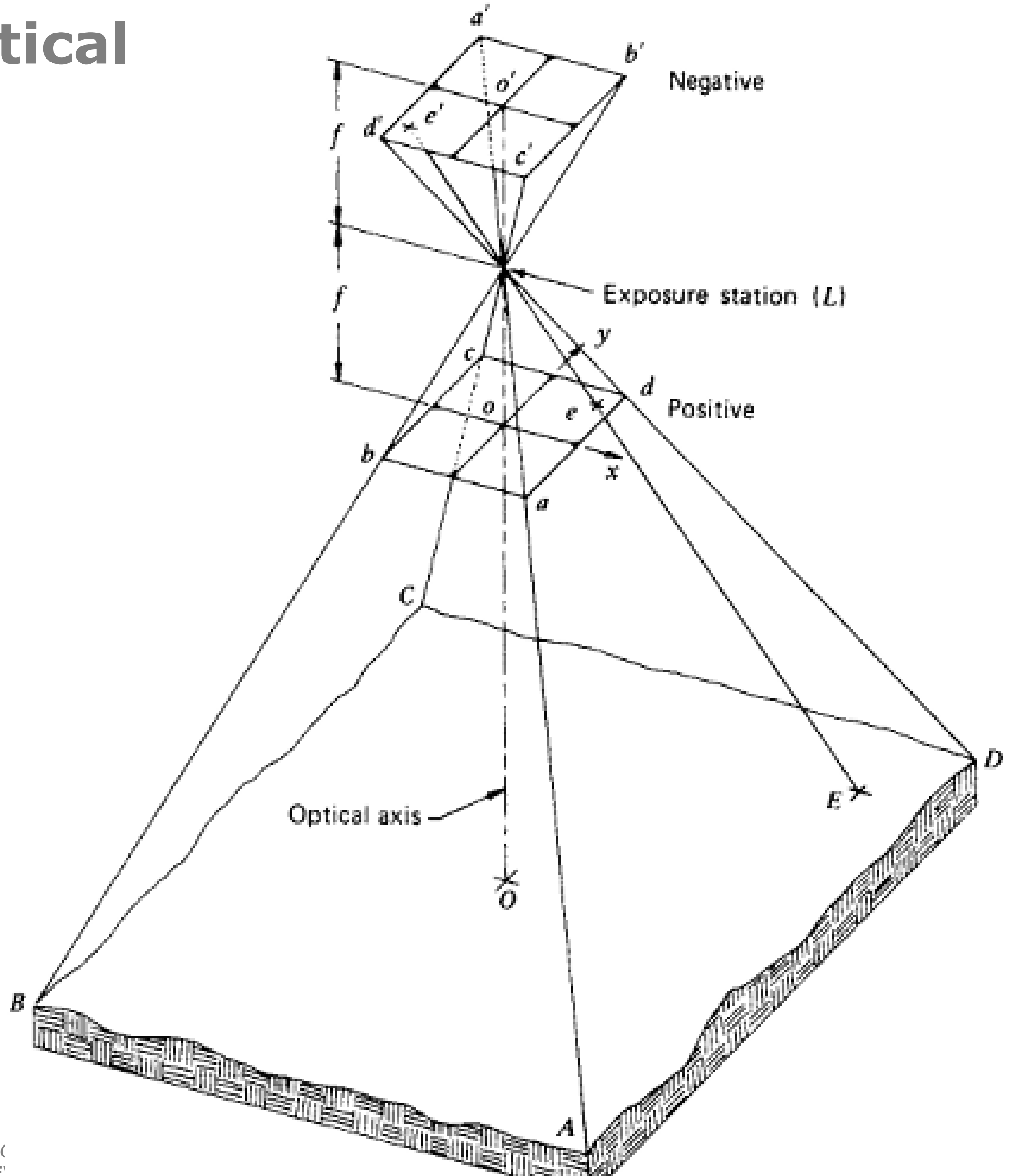
- Positive image positions can be depicted diagrammatically in front of the lens in a plane located at a distance *f*.



Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

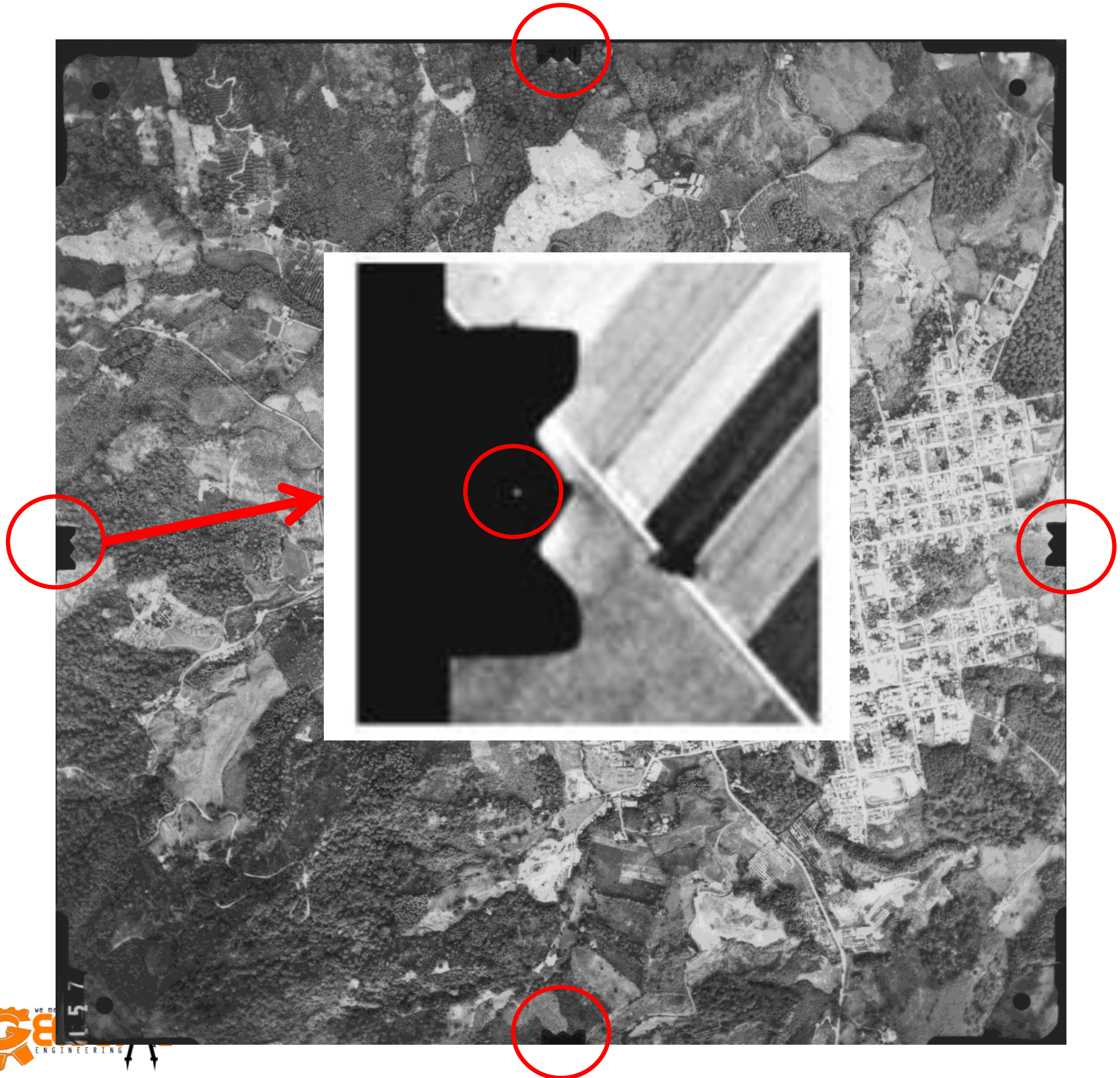
Elements of a vertical photograph

- The (***x,y***) positions of image points are referenced with respect to axes formed by straight lines joining the opposite **fiducial marks** recorded on the positive

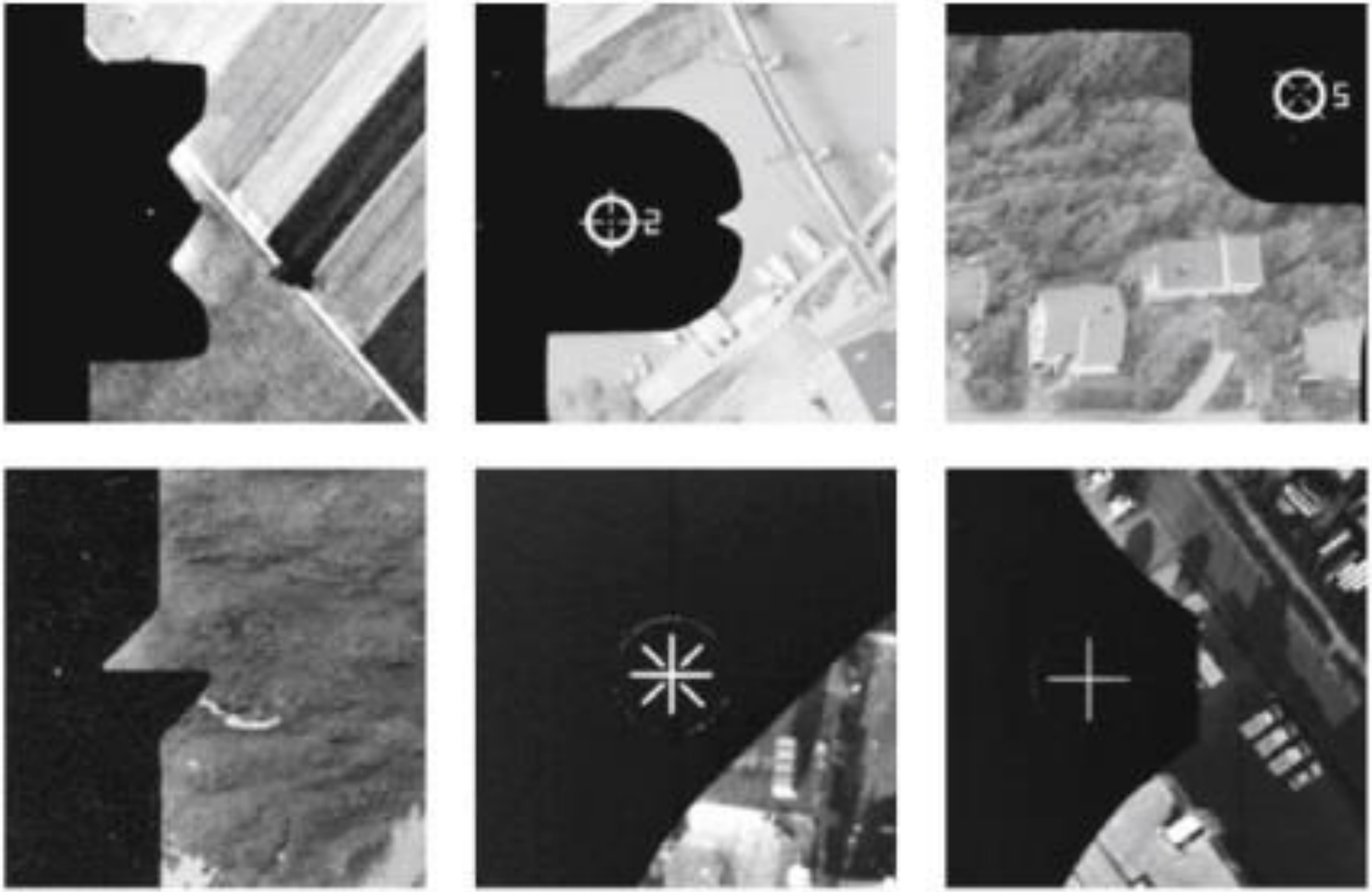


Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Fiducial Marks

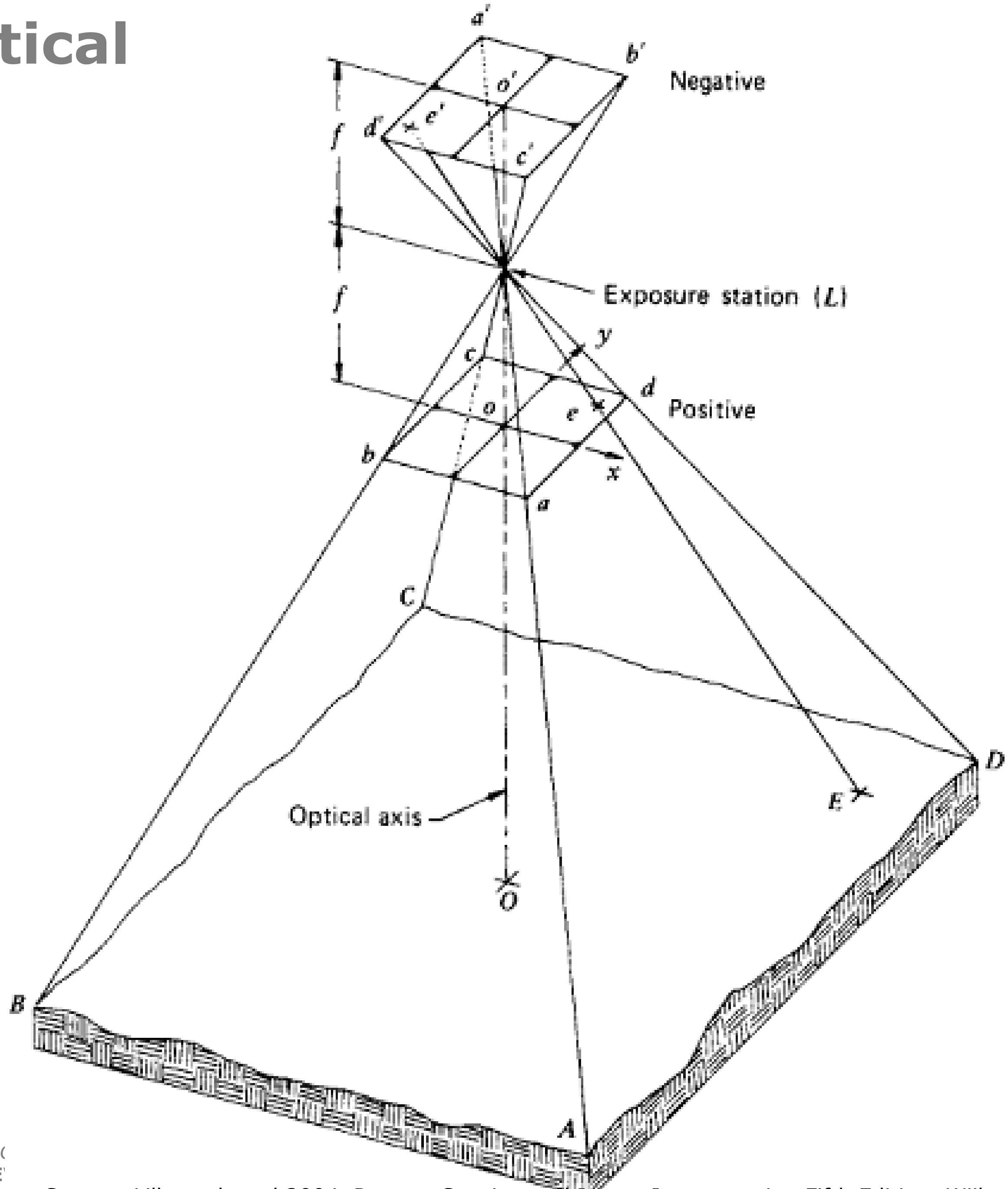


Close-up view of Fiducial Marks

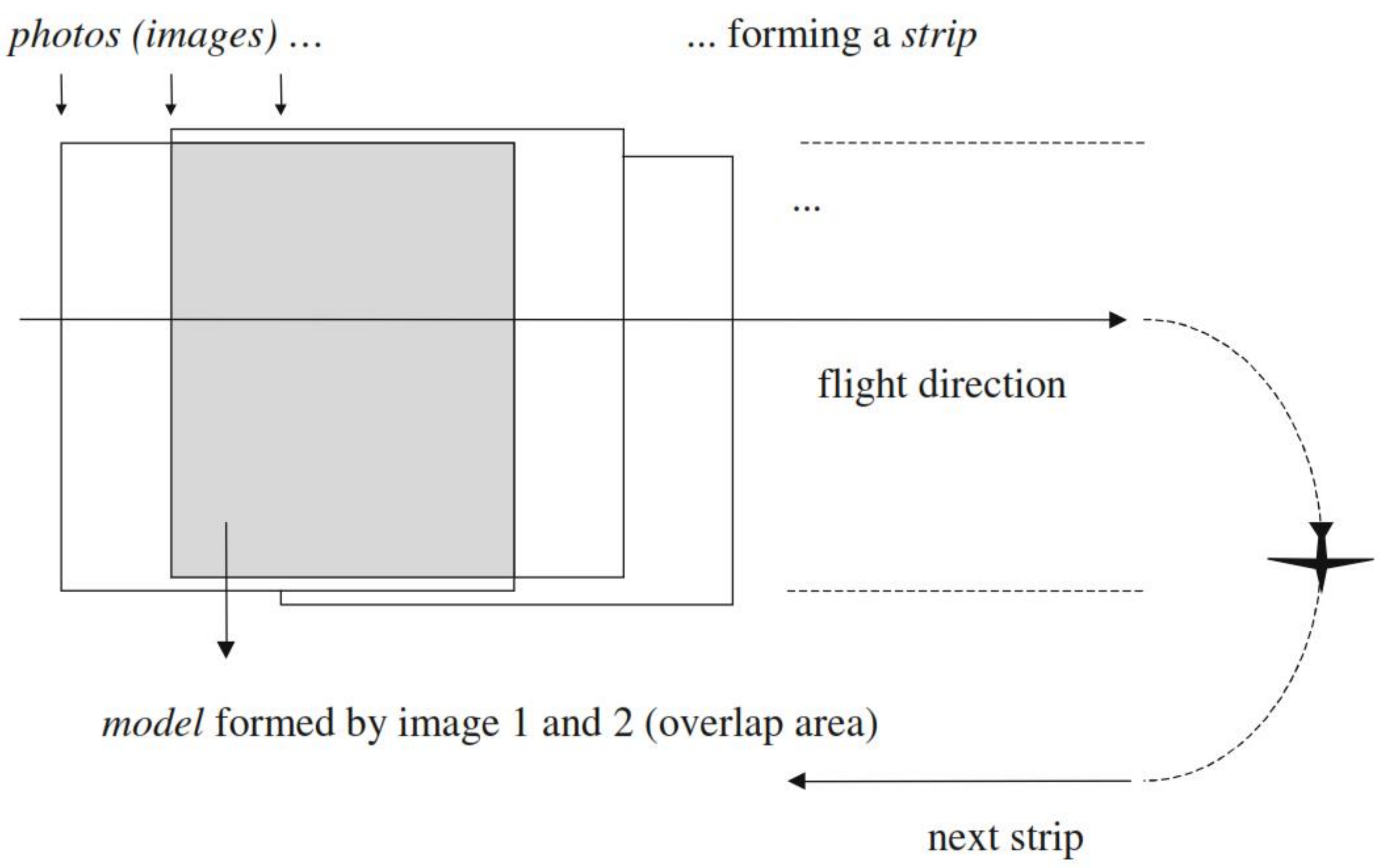


Elements of a vertical photograph

- The x axis is arbitrarily assigned to the fiducial axis most nearly coincident with the line of flight
- Taken as positive in the forward direction of flight

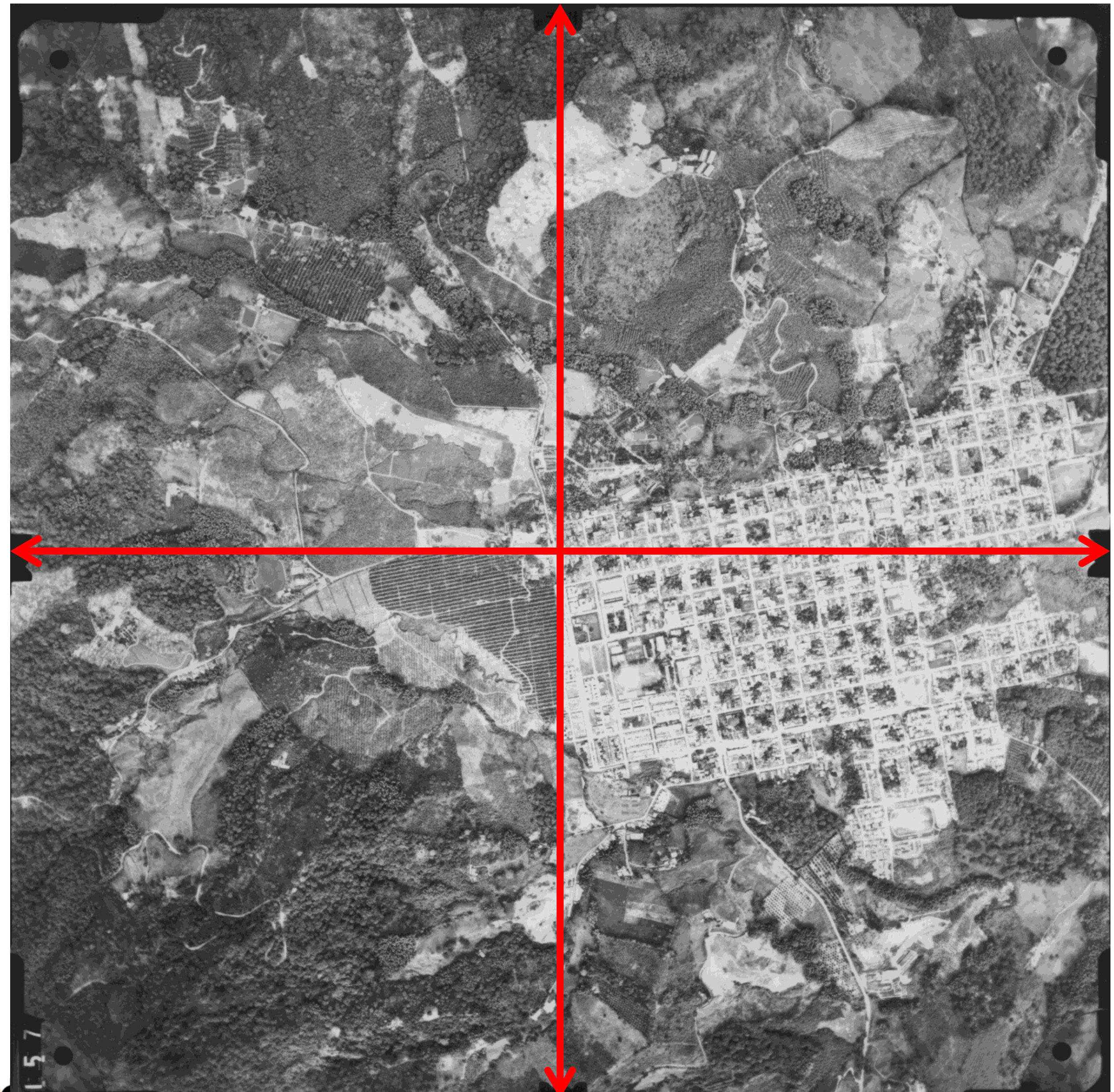


Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.



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

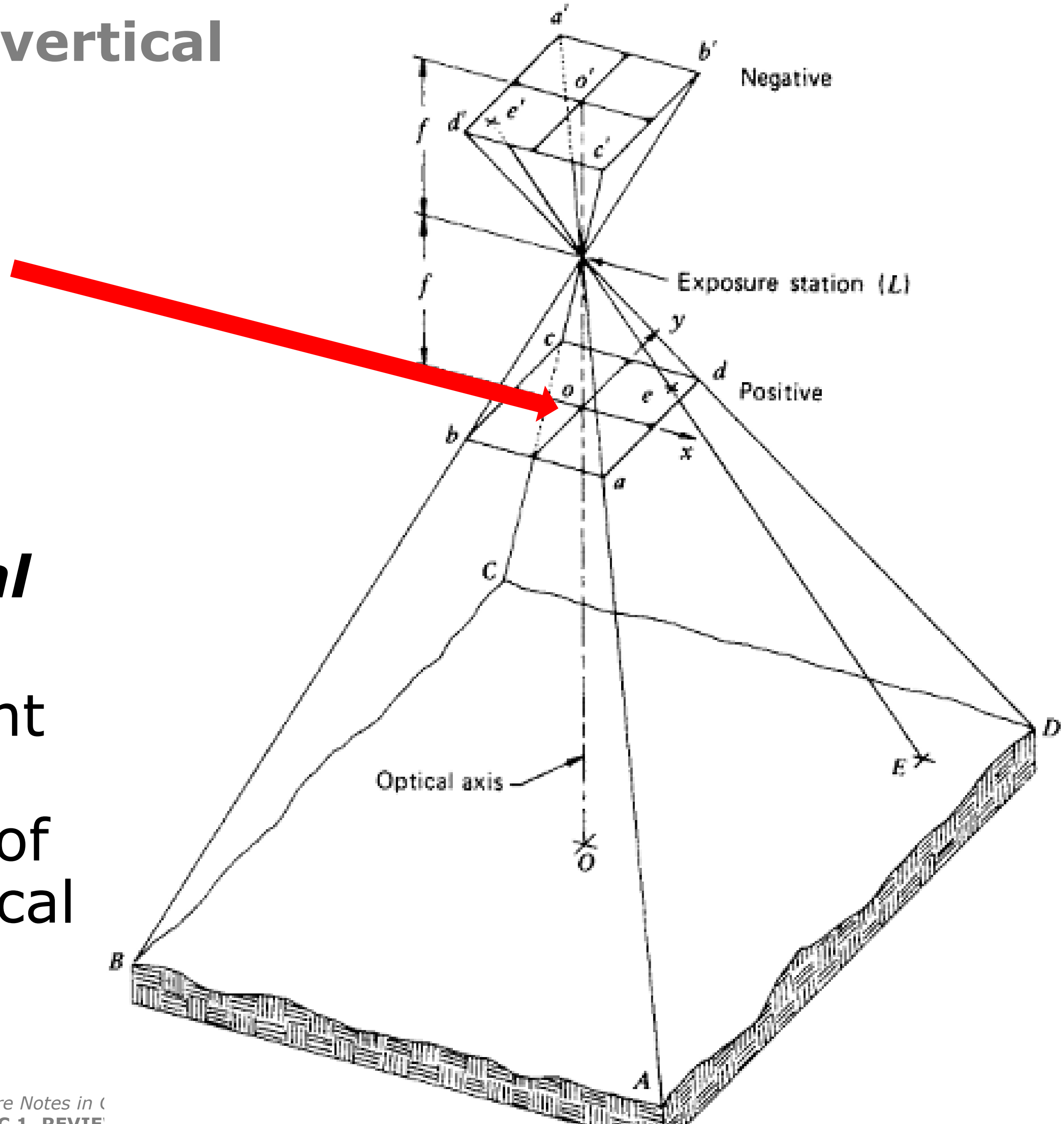
Photo-coordinate Axis



Flight direction

Elements of a vertical photograph

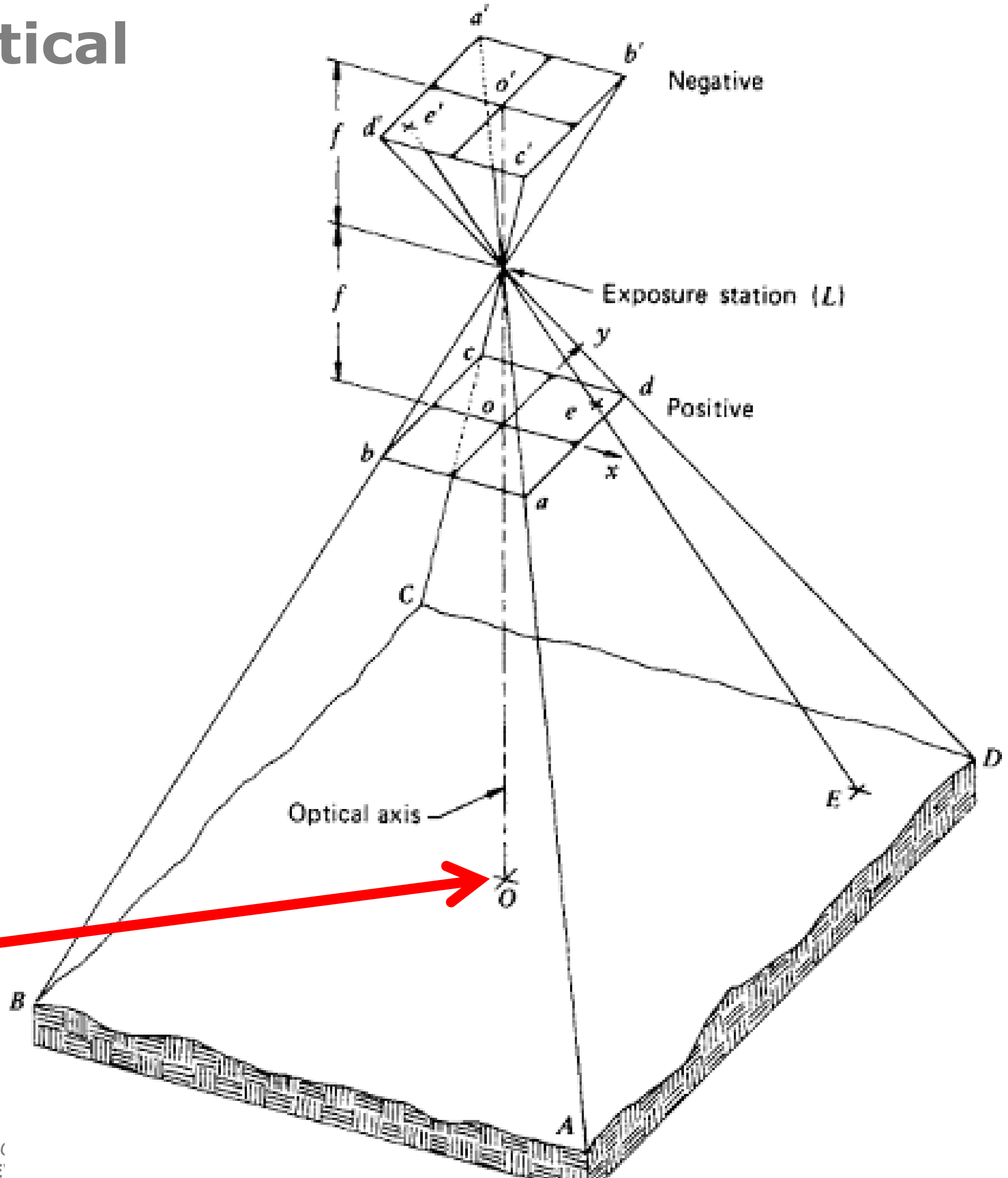
- The photo-coordinate origin, *o*, is assumed to coincide exactly with the ***principal point***
- Principal point = the intersection of the lens optical axis and the film plane.



Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Elements of a vertical photograph

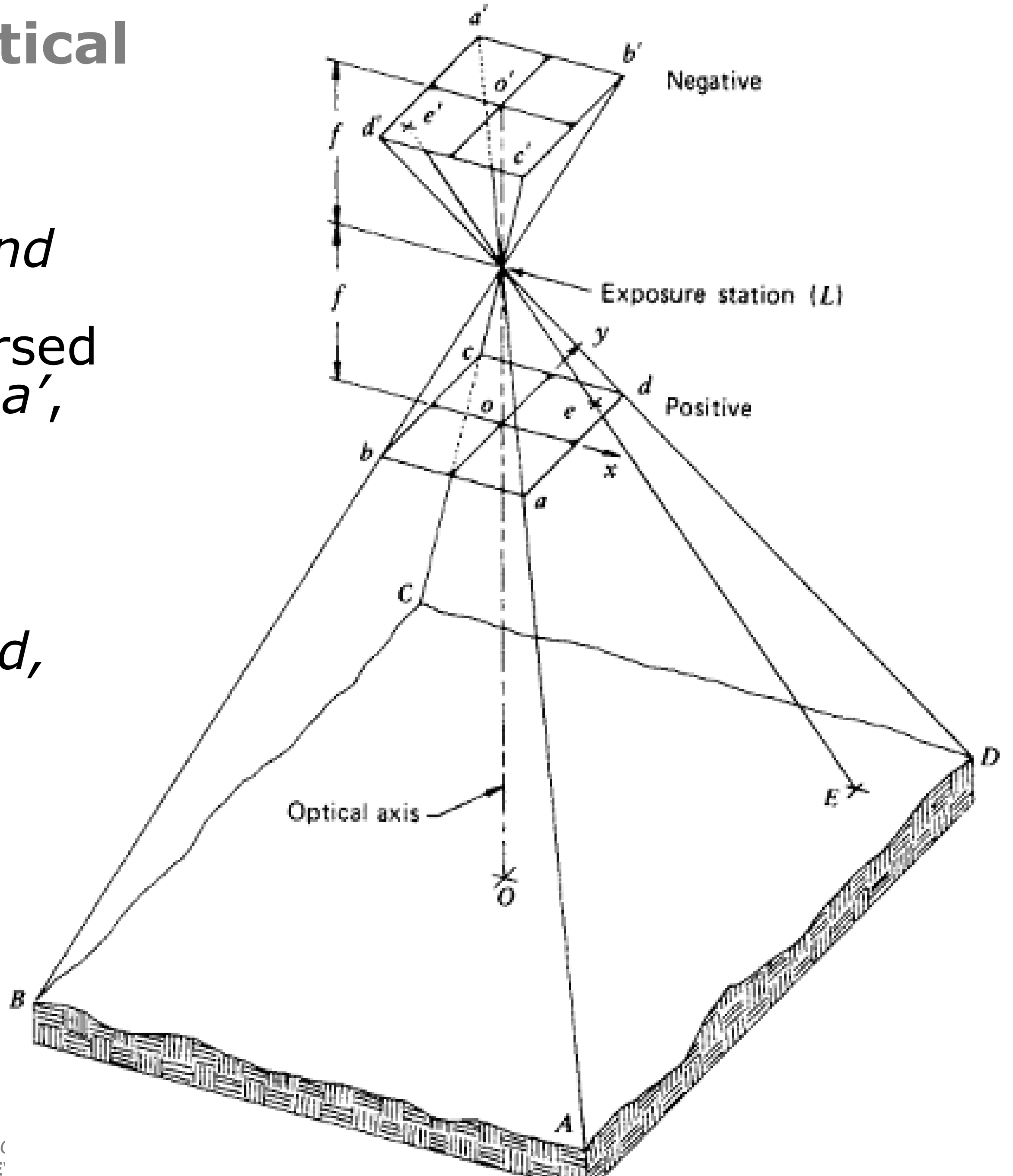
- The point where the prolongation of the optical axis of the camera intersects the terrain is referred to as the ***ground principal point, O.***



Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Elements of a vertical photograph

- Images for terrain points *A, B, C, D and E* appear geometrically reversed on the negative at *a′*, *b′*, *c′*, *d′* and *e′*.
- The points are in proper geometric relationship on the positive at *a, b, c, d,* and e.

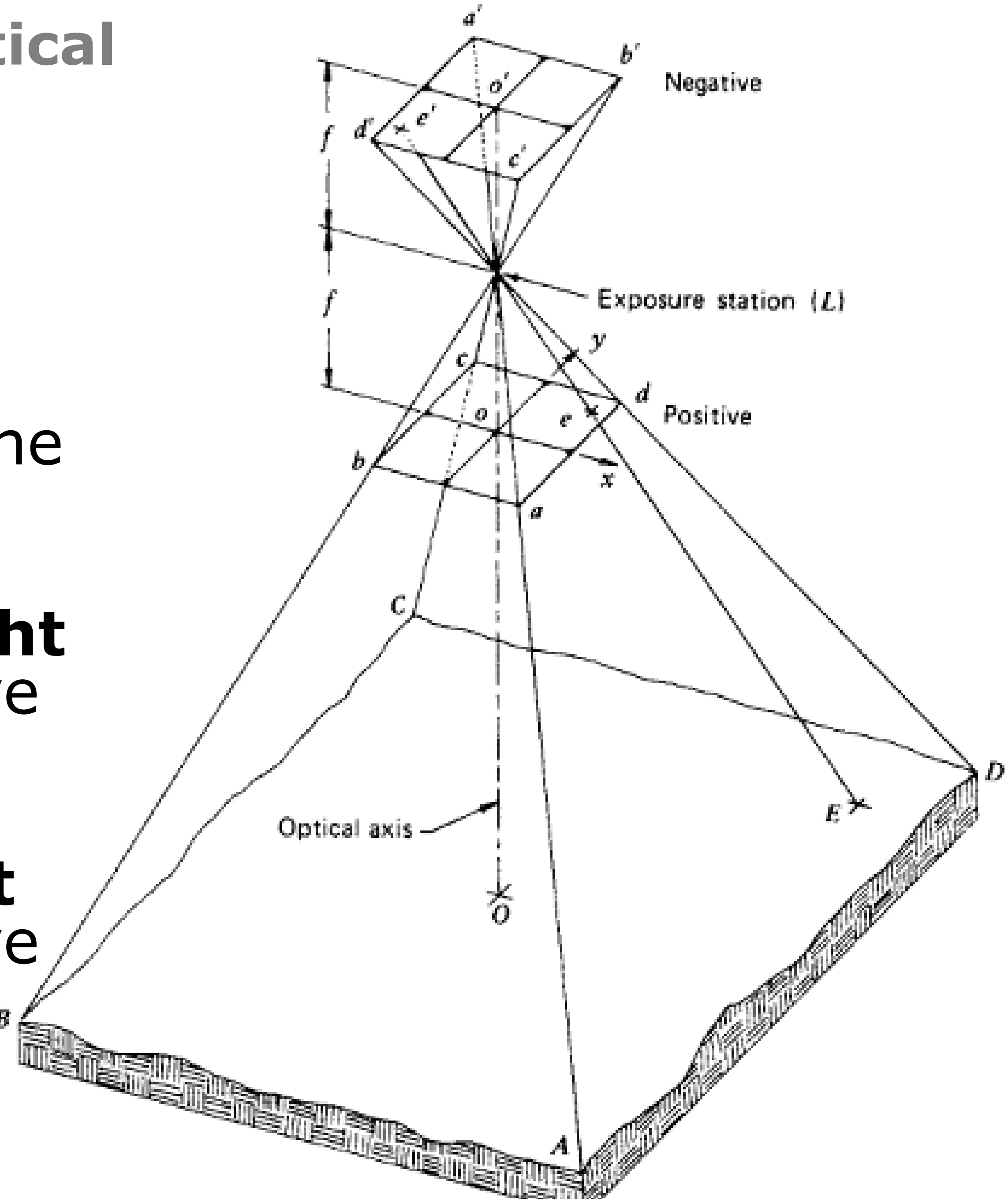


Convention:
- Points on the image (positive plane) are in lowercase letters
- Their corresponding points on the terrain are in uppercase letters

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

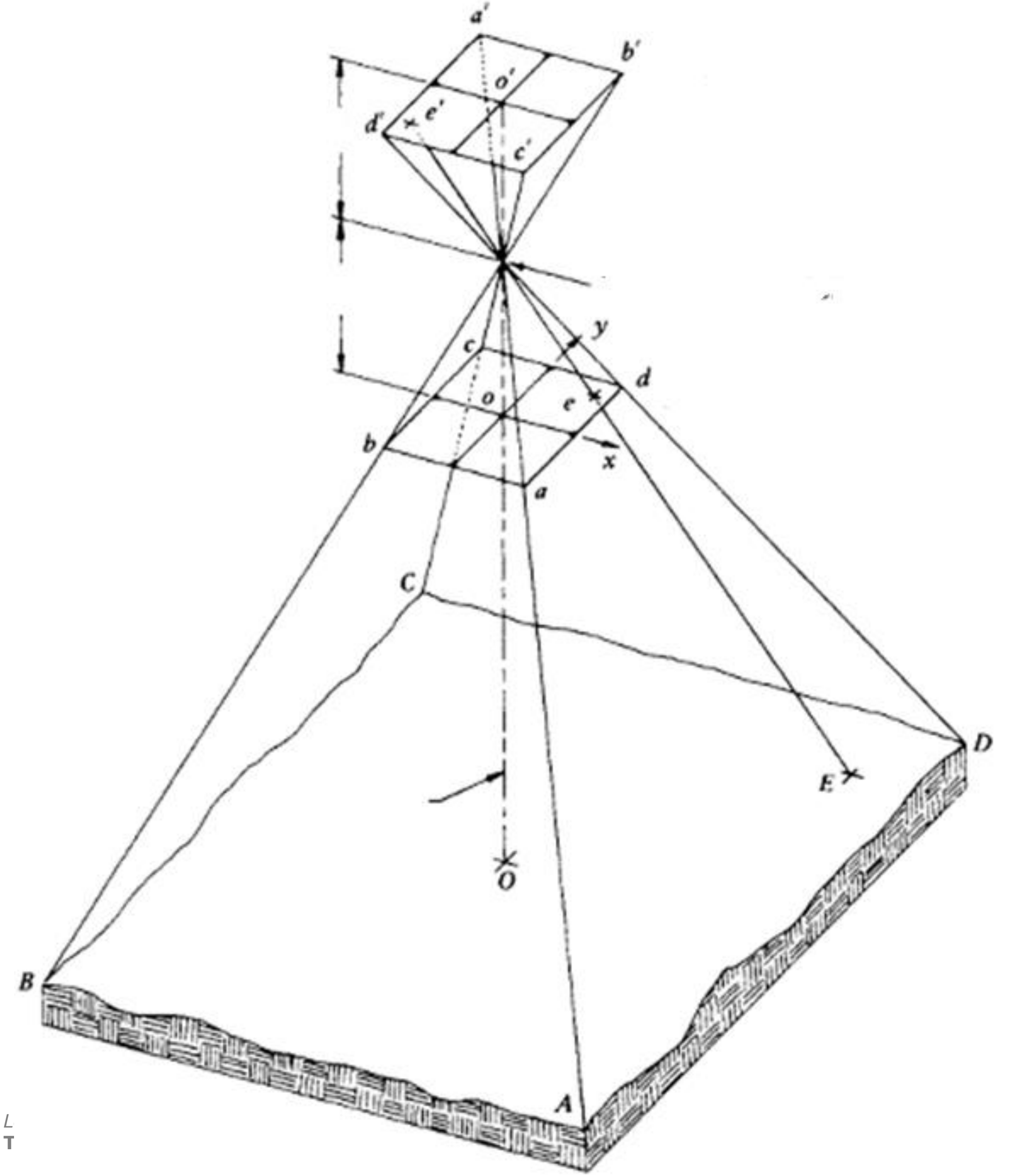
Elements of a vertical photograph

- The *xy* photo-coordinates of a point are the perpendicular distances from the *xy* coordinate axes.
- Points to the **right** of the *y* axis have **positive** *x* coordinates
- Points to the **left** of the *y* axis have **negative** *x* coordinates



Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Review



PHOTOGRAPHIC SCALE

Photographic Scale

- One of the most fundamental and frequently used geometric characteristics of aerial photographs
- A ‘photographic scale’ is an expression that states that one unit of distance on a photograph represents a specific number of units of actual ground distance
- Maybe expressed as:
  - Unit equivalents
  - Representative fractions
  - Ratios

Large Scale versus Small Scale

- Which photograph would have a large scale:
  - A 1:10,000 photo covering several city blocks?
  - A 1:50,000 photo that covers an entire city?

- A convenient way to make scale comparisons is to remember that the same objects are smaller on a “smaller” scale photograph than on a “larger” scale photo.

Determining Photoscale

$$S = \text{photo scale} = \frac{\text{photo distance}}{\text{ground distance}} = \frac{d}{D}$$

Photo Scale Determination Example

- Assume that two road intersections shown on a photograph can be located on a 1:25,000 scale topographic map.
- The measured distance between the intersections is 47.2 mm on the map and 94.3 mm on the photograph.
  a. What is the scale of the photograph?
  b. At that scale, what is the length of a fence line that measures 42.9 mm on the photograph?

Remark: Take note of the significant figures when giving the final answers

Solution

(a) The ground distance between the intersections is determined from the map scale as

$$0.0472 \text{ m} \times \frac{25{,}000}{1} = 1180 \text{ m}$$

By direct ratio, the photo scale is

$$S = \frac{0.0943 \text{ m}}{1180 \text{ m}} = \frac{1}{12{,}513} \quad or \quad 1:12{,}500$$

(Note that because only three significant, or meaningful, figures were present in the original measurements, only three significant figures are indicated in the final result.)

(b) The ground length of the 42.9-mm fence line is

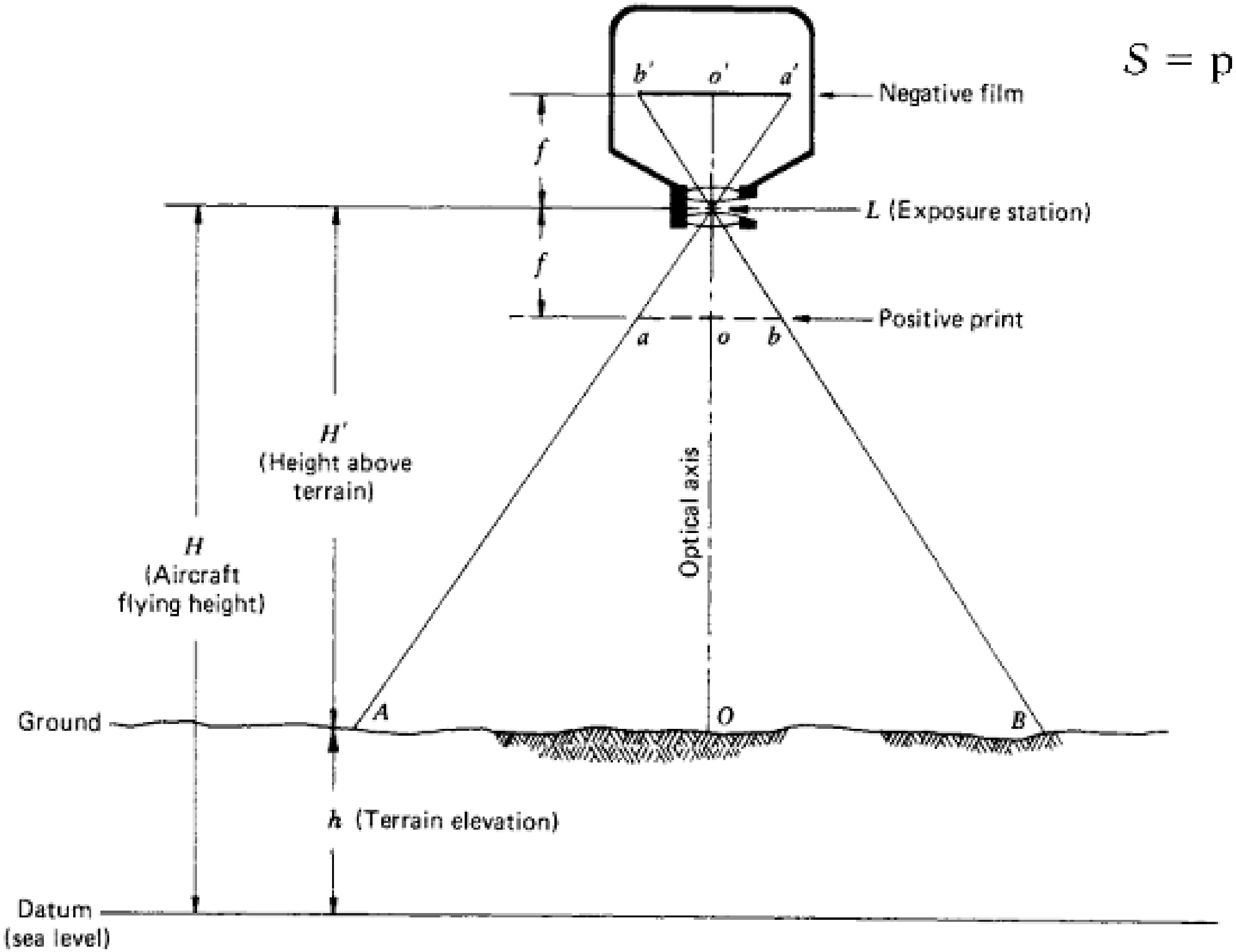
$$D = \frac{d}{S} = 0.0429 \text{ m} \div \frac{1}{12{,}500} = 536.25 \text{ m} \quad \text{or} \quad 536 \text{ m}$$

Scale of Vertical Aerial Photographs Over Flat Terrain

- Scale is a function of:
  - the focal length of camera used to acquire (f)
  - flying height above ground (H’)

$$\text{Scale} = \frac{\text{camera focal length}}{\text{flying height above terrain}} = \frac{f}{H'}$$

Scale of Vertical Aerial Photographs Over Flat Terrain



$$S = \text{photo scale} = \frac{\text{photo distance}}{\text{ground distance}}$$

$$S = \frac{\overline{ao}}{\overline{AO}} = \frac{f}{H'}$$

$$H' = H - h$$

$$S = \frac{f}{H - h}$$

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Example

- A camera with a 152-mm-focal-length lens is used to take a vertical photograph from a flying height of 2780 m above mean sea level. If the terrain is flat at an elevation of 500 m, what is the scale of the photograph?

$$\text{Scale} = \frac{f}{H - h} = \frac{0.152\ \text{m}}{2780\ \text{m} - 500\ \text{m}} = \frac{1}{15{,}000} \quad \text{or} \quad 1:15{,}000$$

Example

Assume a vertical photograph was taken at a flying height of 5000 m above sea level using a camera with a 152-mm-focal-length lens. (a) Determine the photo scale at points *A* and *B*, which lie at elevations of 1200 and 1960 m. (b) What ground distance corresponds to a 20.1-mm photo distance measured at each of these elevations?

Solution

(a) By Eq. 3.4,

$$S_A = \frac{f}{H - h_A} = \frac{0.152 \text{ m}}{5000 \text{ m} - 1200 \text{ m}} = \frac{1}{25{,}000} \quad \text{or} \quad 1:25{,}000$$

$$S_B = \frac{f}{H - h_B} = \frac{0.152 \text{ m}}{5000 \text{ m} - 1960 \text{ m}} = \frac{1}{20{,}000} \quad \text{or} \quad 1:20{,}000$$

(b) The ground distance corresponding to a 20.1-mm photo distance is

$$D_A = \frac{d}{S_A} = 0.0201 \text{ m} \div \frac{1}{25{,}000} = 502.5 \text{ m} \quad \text{or} \quad 502 \text{ m}$$

$$D_B = \frac{d}{S_B} = 0.0201 \text{ m} \div \frac{1}{20{,}000} = 402 \text{ m}$$

Some Notes:

- The formula $S = f/(H - h)$ indicates that photo scale is function of terrain elevation (h)
  - For flat level terrain, Scale is constant throughout the photograph
  - For terrain with varying elevations, Scale is not constant:
    - Photographs taken over terrain with varying elevation will exhibit a continuous range of scales associated with the variations in terrain elevation.
- Often it is convenient to compute an average scale for an entire photograph:

$$S_{average} = f/(H - h_{average})$$

GROUND COVERAGE OF AERIAL PHOTOGRAPHS

Ground Coverage of Aerial Photographs

- Ground coverage is a function of camera format size
  - Camera format size = size of the aerial photo when printed
  - Commonly used format sizes:230-mm x 230-mm
    - About 17.5 times the ground area coverage of an image of equal scale taken with a camera having a 55 x 55 mm format
    - About 61 times the ground area coverage of an image of equal scale take with a camera having a 24 x 36 mm format

Ground Coverage of Aerial Photographs

- Ground coverage of a photograph obtained with any given format is a function of focal length (f) and flying height above terrain (H')
- For a constant flying height, the width of the ground area covered by a photo varies inversely with focal length
  - Photos taken with shorter focal length lenses have larger areas of coverage (and smaller scales) than those taken with longer focal length lenses
- For any given focal length lens, the width of the ground area covered by a photo varies directly with flying height above terrain
  - Image scale varies inversely with flying height

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  - Image scale varies inversely with flying height

AREA MEASUREMENTS FROM AERIAL PHOTOGRAPHS

Manual Area Measurement

- Accuracy of measurement is affected by:
  - Measuring device (e.g., a ruler)
  - Degree of image scale variation due to varying terrain elevation/relief in the terrain, and tilt in photography
- Accurate measurements maybe made on vertical photos of areas of low relief
- Simple scales maybe used to measure the area of simply shaped objects

Example

- A rectangular agricultural field measures 8.65 cm long and 5.13 cm wide on a vertical photograph having a scale of 1:20,000. Find the area of the field at ground level.

Solution

$$\text{Ground length} = \text{photo length} \times \frac{1}{S} = 0.0865 \text{ m} \times 20{,}000 = 1730 \text{ m}$$

$$\text{Ground width} = \text{photo width} \times \frac{1}{S} = 0.0513 \times 20{,}000 = 1026 \text{ m}$$

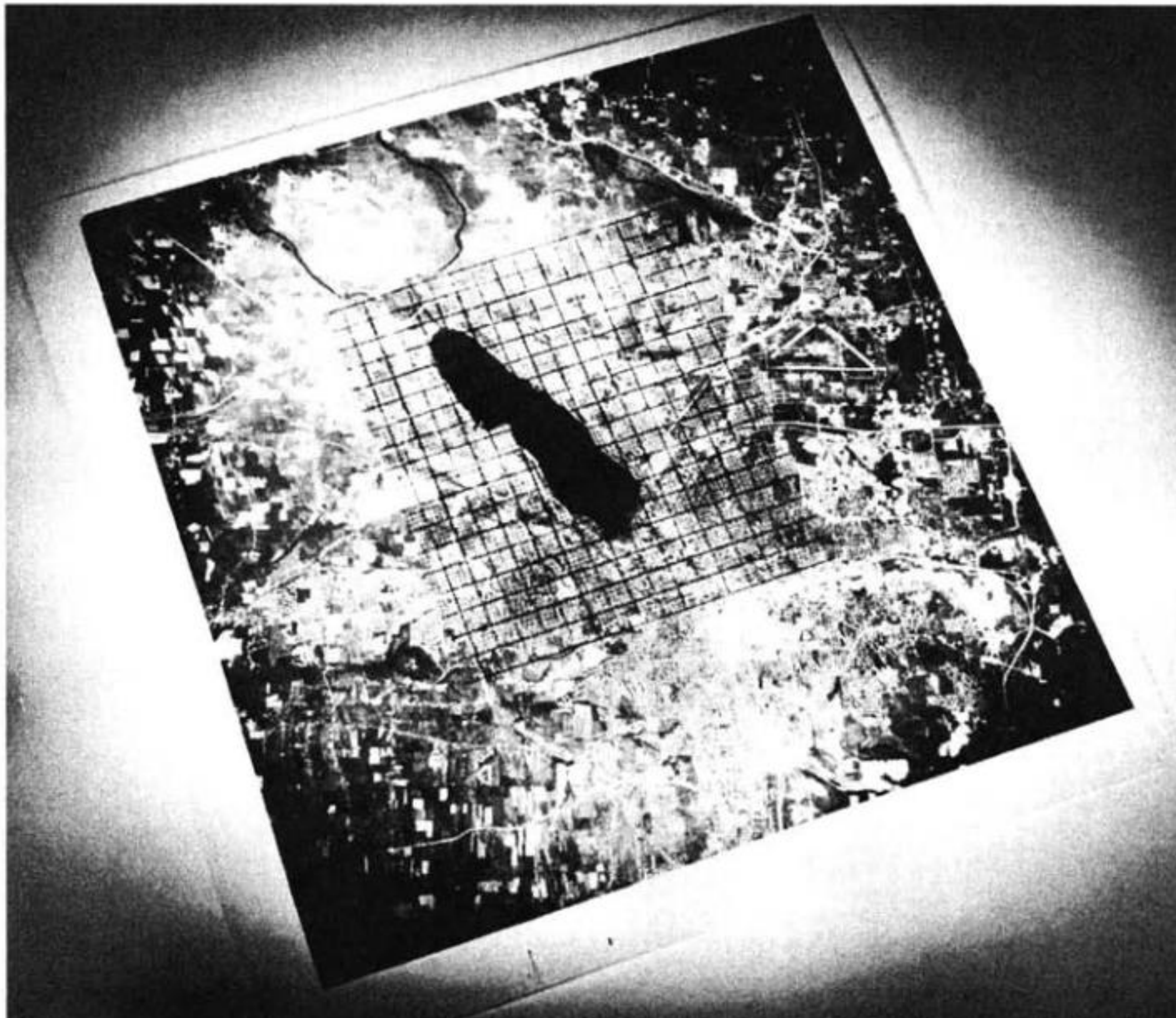
$$\text{Ground area} = 1730 \text{ m} \times 1026 \text{ m} = 1{,}774{,}980 \text{ m}^2 = 177 \text{ ha}$$

Manual Area Measurement

- For irregularly shaped objects:
  – Use of transparent grid overlay (“dot grid”)

A “dot grid”

- Composed of uniformly spaced dots
- Dot density (dots/cm^2) is known
- Super-imposed into the photo
- The dots falling within the region to be measured are counted and the area is computed using the number of dots and the dot density



Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley

Figure 3.10 Transparent dot grid overlay.

Example

- A flooded area is covered by 129 dots on a 25-dot/cm^2 grid on a 1:20,000 vertical aerial photograph. Find the ground area flooded.

Solution

$$\text{Dot density} = \frac{1\ \text{cm}^2}{25\ \text{dots}} \times 20{,}000^2 = 16{,}000{,}000\ \text{cm}^2/\text{dot} = 0.16\ \text{ha/dot}$$

$$\text{Ground area} = 129\ \text{dots} \times 0.16\ \text{ha/dot} = 20.6\ \text{ha}$$

Manual Area Measurement

- For irregularly shaped objects:
  - The ground area is usually determined by measuring the area of the feature on the photograph
  - The photo area is then converted to a ground area from the following relationship:

$$\text{Ground area} = \text{photo area} \times \frac{1}{S^2}$$

Example

- The area of a lake is 52.2 cm^2 on a 1:7,500 vertical photograph. Find the ground area of the lake

Solution

$$\text{Ground area} = \text{photo area} \times \frac{1}{S^2} = 0.00522\ \text{m}^2 \times 7500^2 = 293{,}625\ \text{m}^2 = 29.4\ \text{ha}$$

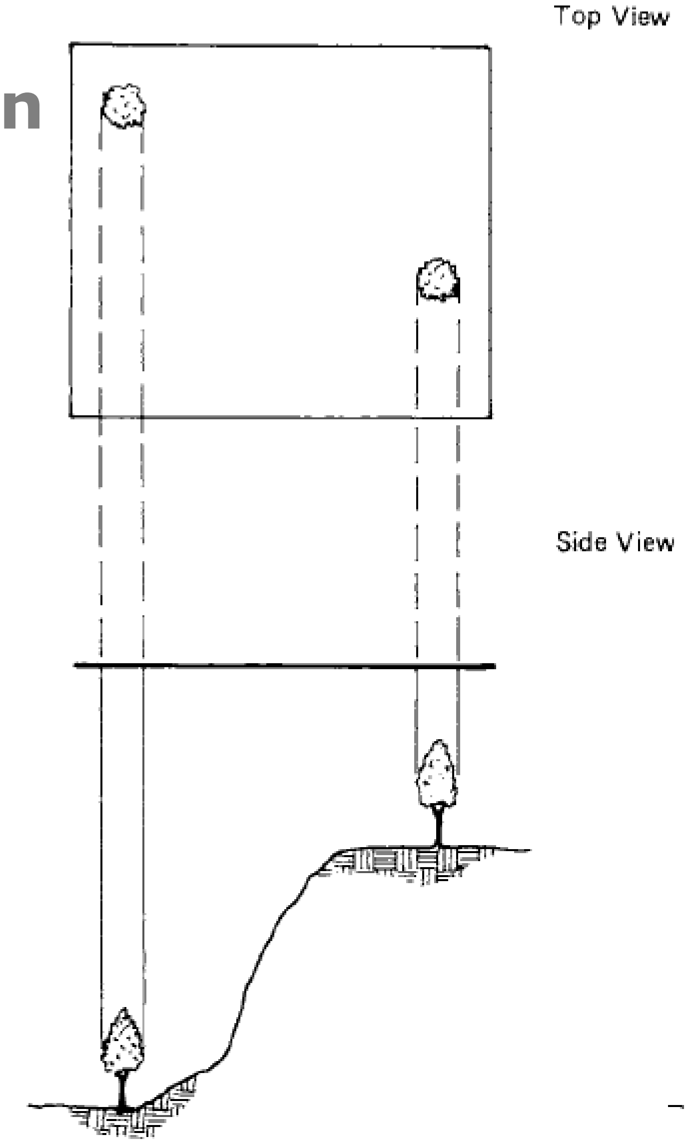
Remarks

- The use of dot grids in measuring area becomes tedious when there are numerous regions to be measured.
- The use of computer software, particularly, GIS, is an alternative and widely used nowadays.
  - The process is called "heads-up digitizing" or "on-screen digitizing"
  - The aerial photograph needs to be converted into digital format and inputted into a GIS software

RELIEF DISPLACEMENT IN AERIAL PHOTOGRAPHS

Relief Displacement Illustration

- On a **map**, we see a top view of objects in their true elative horizontal positions

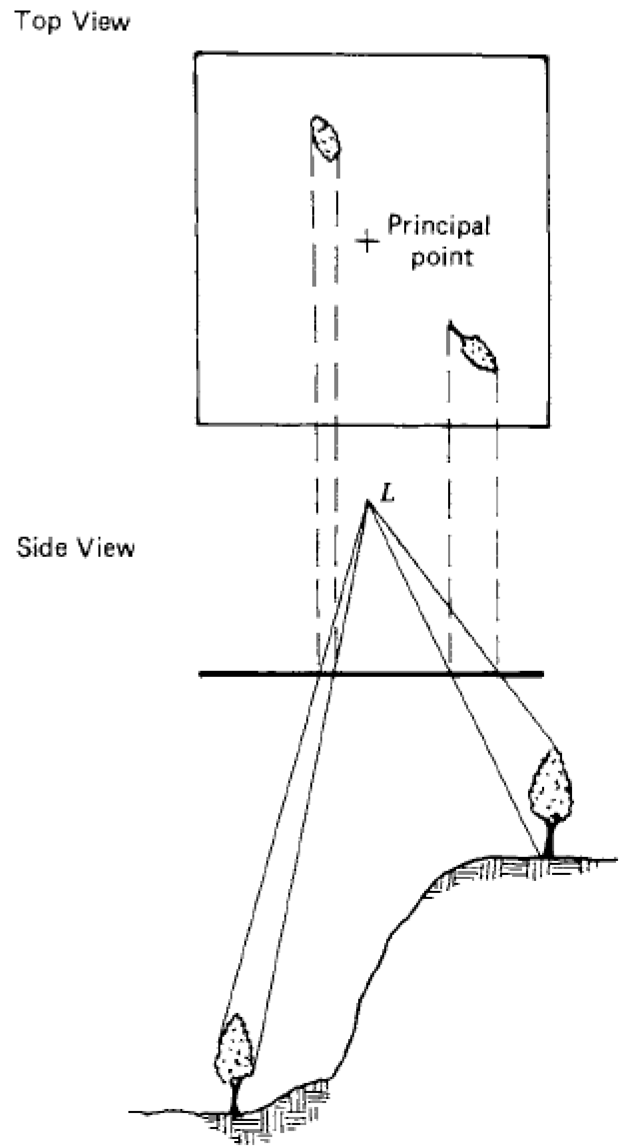


(a) Map (orthographic projection)
Constant scale
No relief displacement

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

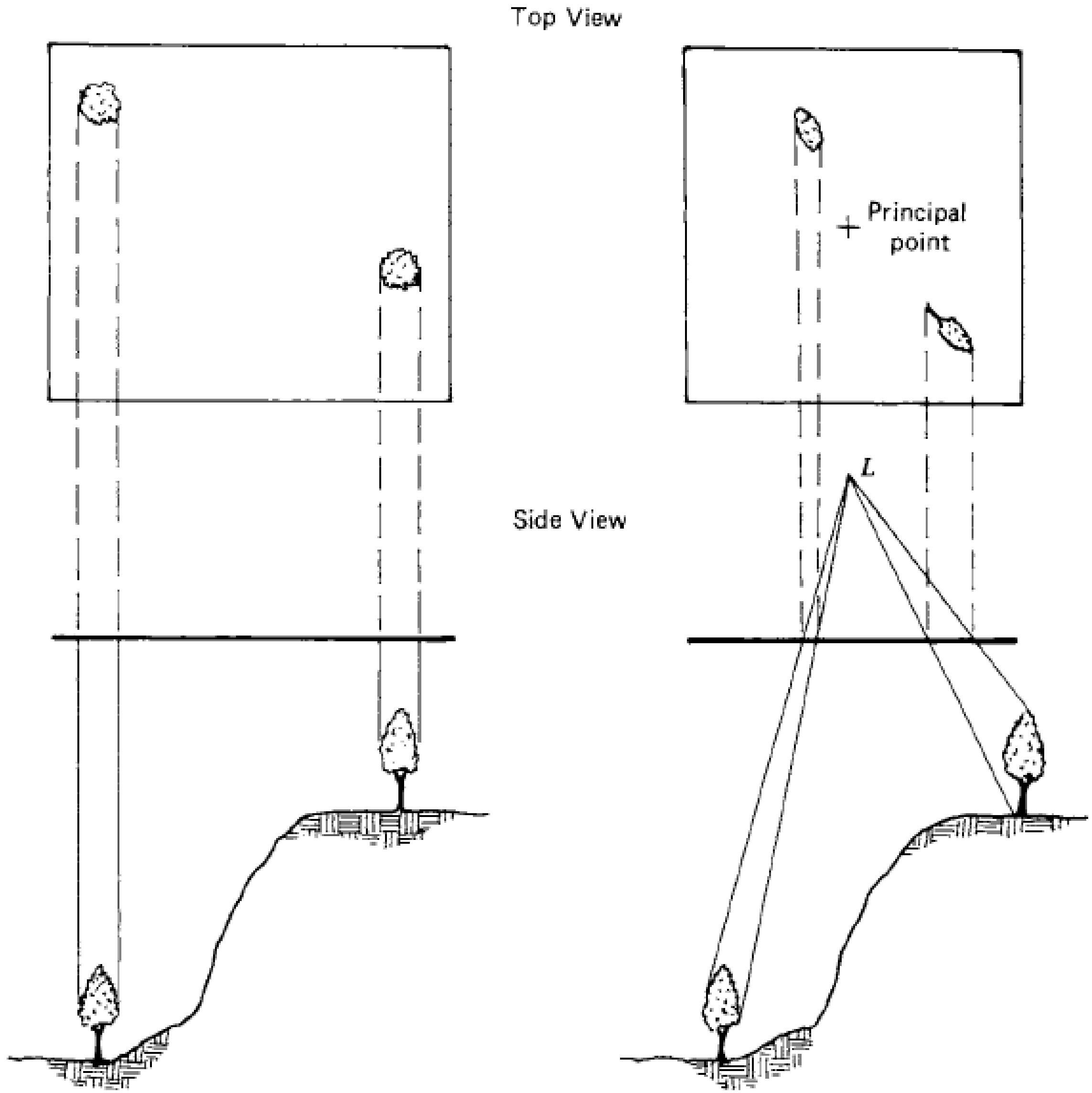
Relief Displacement Illustration

- On an aerial photograph, areas of terrain at the higher elevations lie closer to the camera at the time of exposure
  - Appear larger than corresponding areas lying at lower elevations
- The tops of objects are always displaced from their bases
  - This distortion is called ***relief displacement***



(b) Photo (perspective projection)
Varied scale
Relief displacement

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.



(a) Map (orthographic projection)
Constant scale
No relief displacement

(b) Photo (perspective projection)
Varied scale
Relief displacement

Figure 3.8 Comparative geometry of (a) a map and (b) a vertical aerial photograph. Note differences in size, shape, and location of the two trees.

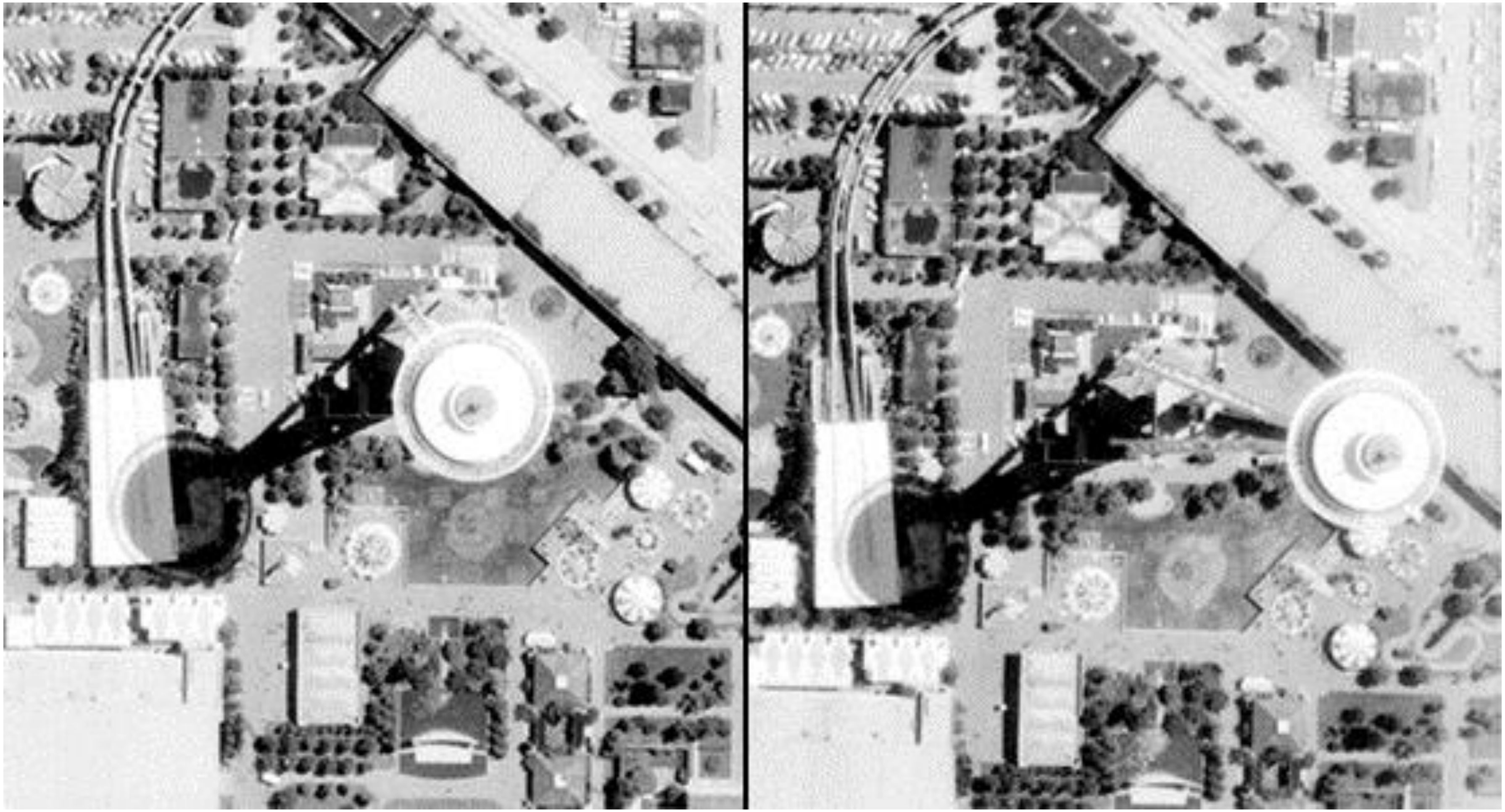
Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Relief Displacement in an Aerial Photograph

Source: http://www.efoto.eng.uerj.br/

- Relief Displacement causes any object standing above the terrain to “lean” away form the principal point of an aerial photograph ***radially***.

- Relief displacement is minimal in vertical aerial photographs of flat terrain



In the left image the Space Needle in Seattle was located close to the principal point so there is minimal displacement. In the right image the Space Needle is located further away from the principal point causing it the "lean" away from the center.

Source: http://gsp.humboldt.edu/olm_2015/Courses/GSP_216_Online/lesson2-2/distortion.html

Impact of Relief Displacement

- Failure to deal with geometric distortions due to relief displacement will often lead to a lack of geometric “fit” among image-derived and on-image data sources in a GIS

Geometric Components of Relief Displacement

- H = flying height above datum
- **Important:** when considering relief displacement of a vertical feature, it is convenient to arbitrarily assume a datum place placed at the base of the feature

→ **H must be correctly referenced to the same datum (not at MSL)**

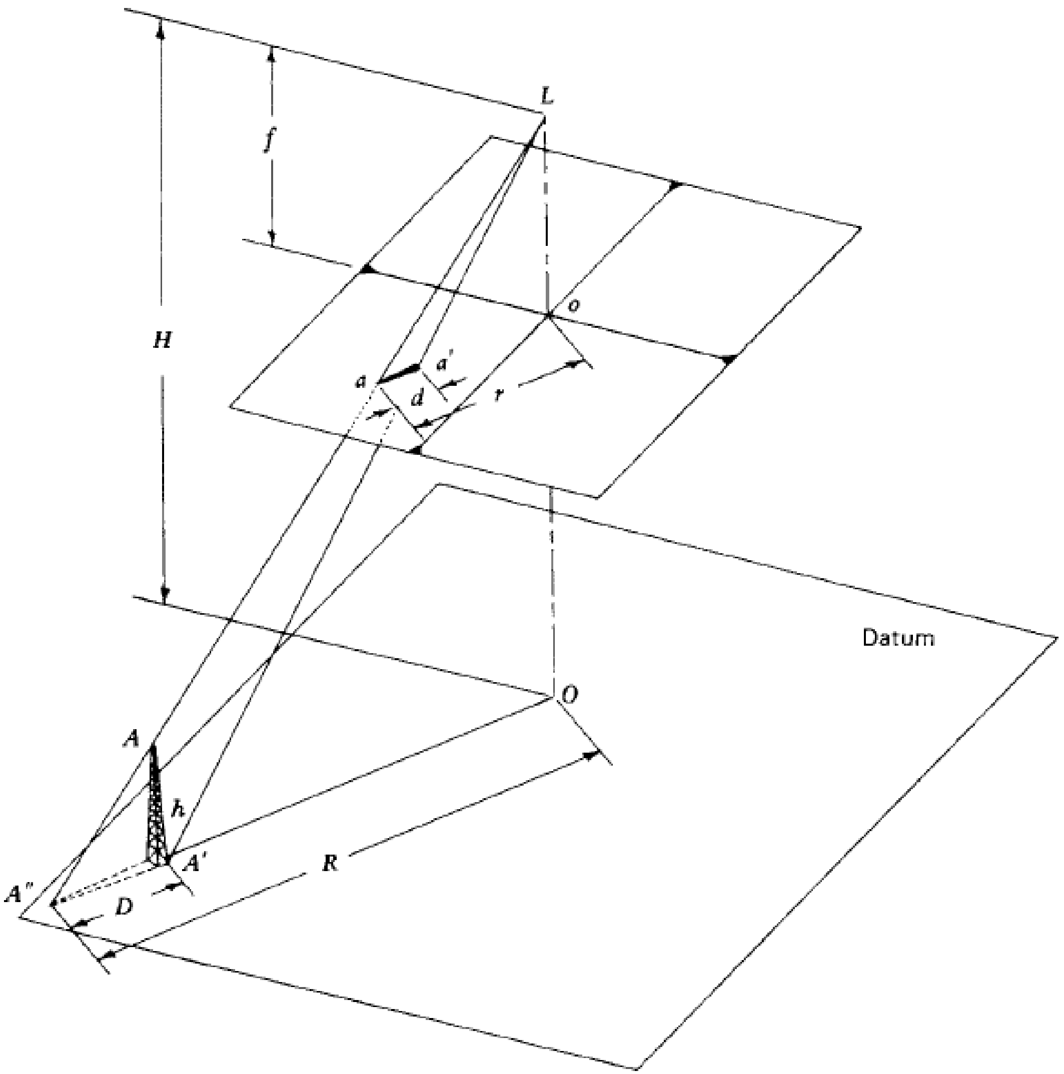


Figure 3.13 Geometric components of relief displacement.

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Geometric Components of Relief Displacement

- h = height of the **tower A** (the object where relief displacement is considered)
- Observations:
  - Top of tower A is imaged at ***a*** in the photograph whereas the base of tower, A', is imaged at a'
  - **The image of the top of the tower is radially displaced by distance *d* from that of the bottom**

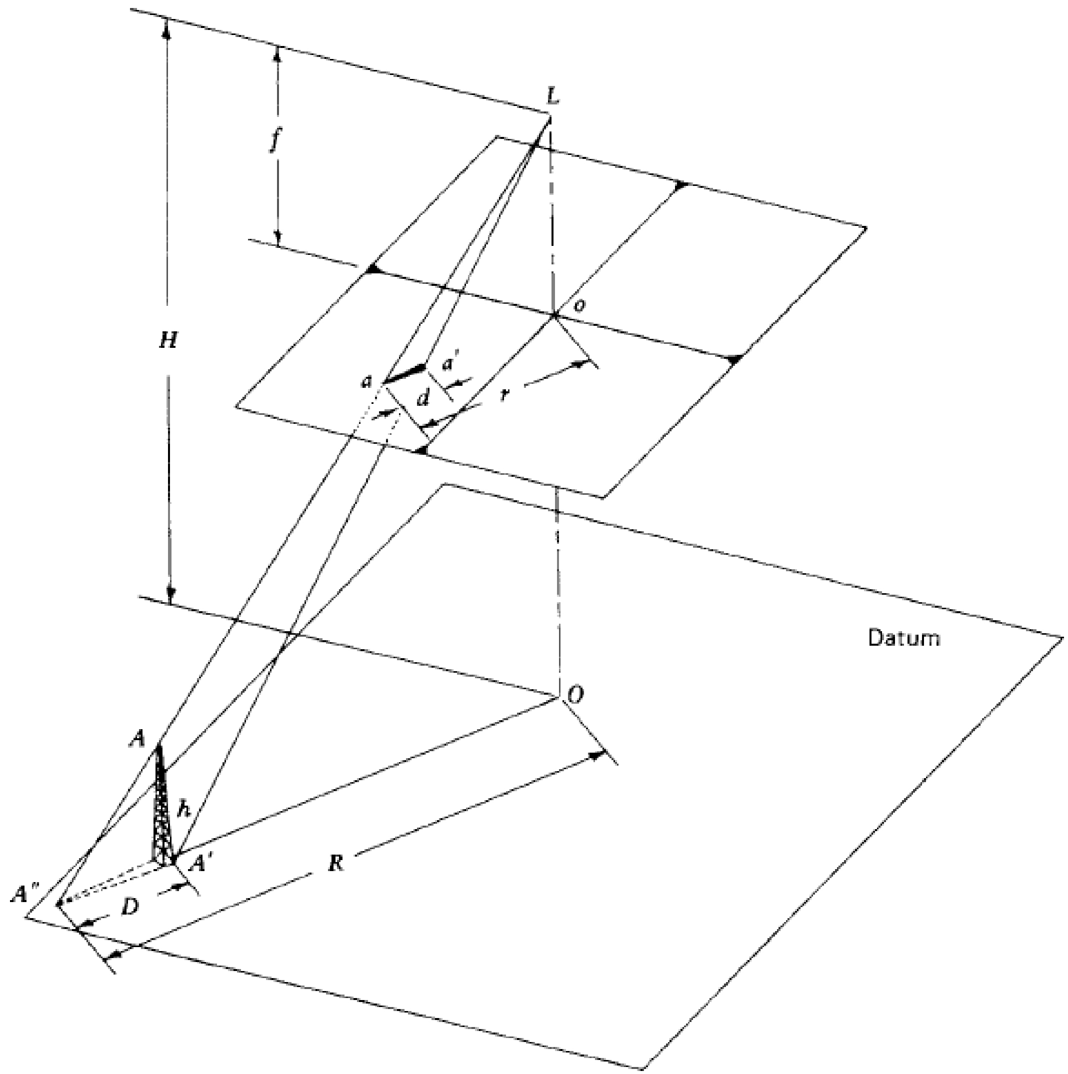


Figure 3.13 Geometric components of relief displacement.

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Geometric Components of Relief Displacement

- From similar triangles AA'A" and LOA":

$$D/h = R/H$$

- This can be expressed at the scale of the photograph:

$$d/h = r/H$$

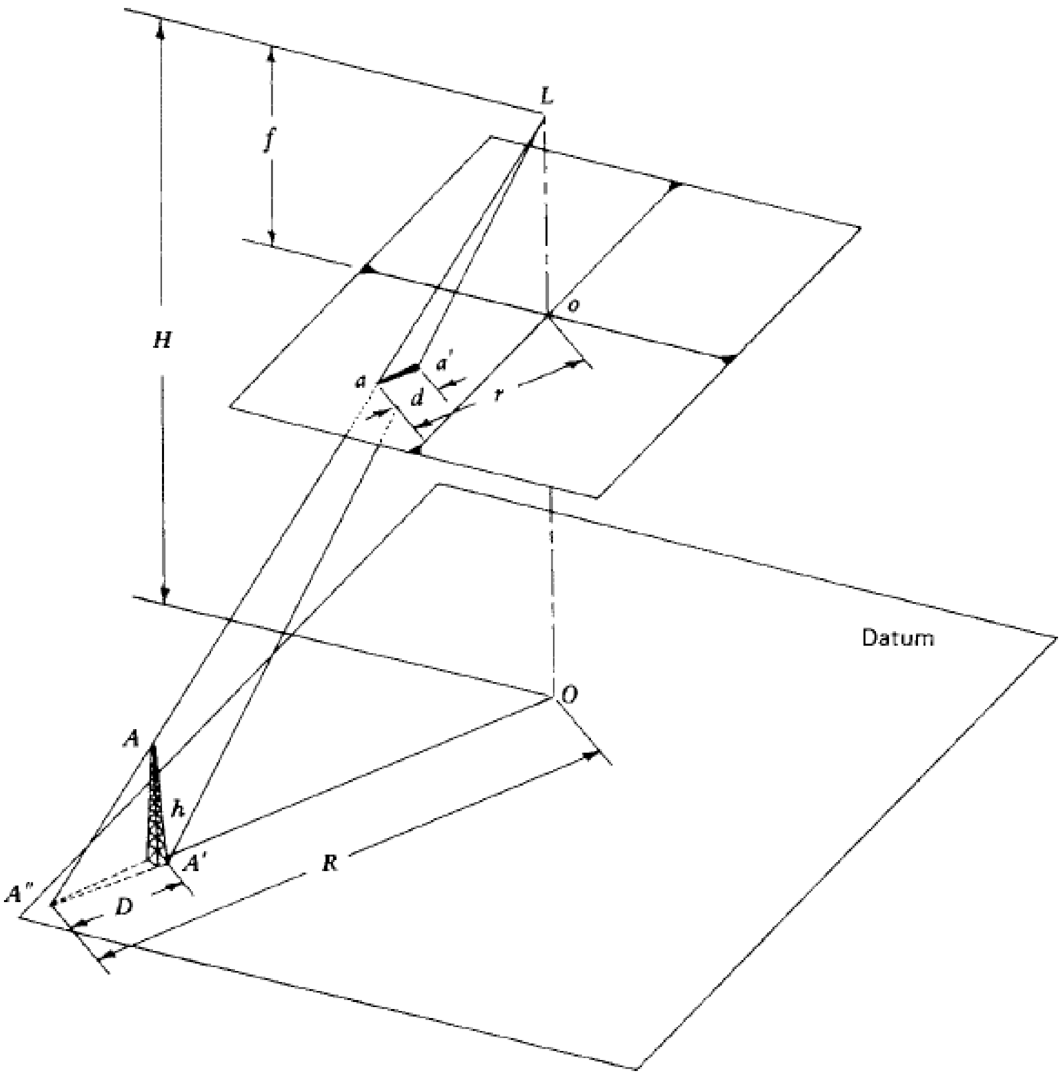


Figure 3.13 Geometric components of relief displacement.

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Geometric Components of Relief Displacement

- Re-arranging **d/h = r/H**
- **d = rh/H**
- Where:
  - d = relief displacment
  - R = radial distance on the photograph from the principal point to the displaced image point
  - h = height above datum of the object point
  - H = flying height above the same datum chosen to reference *h*

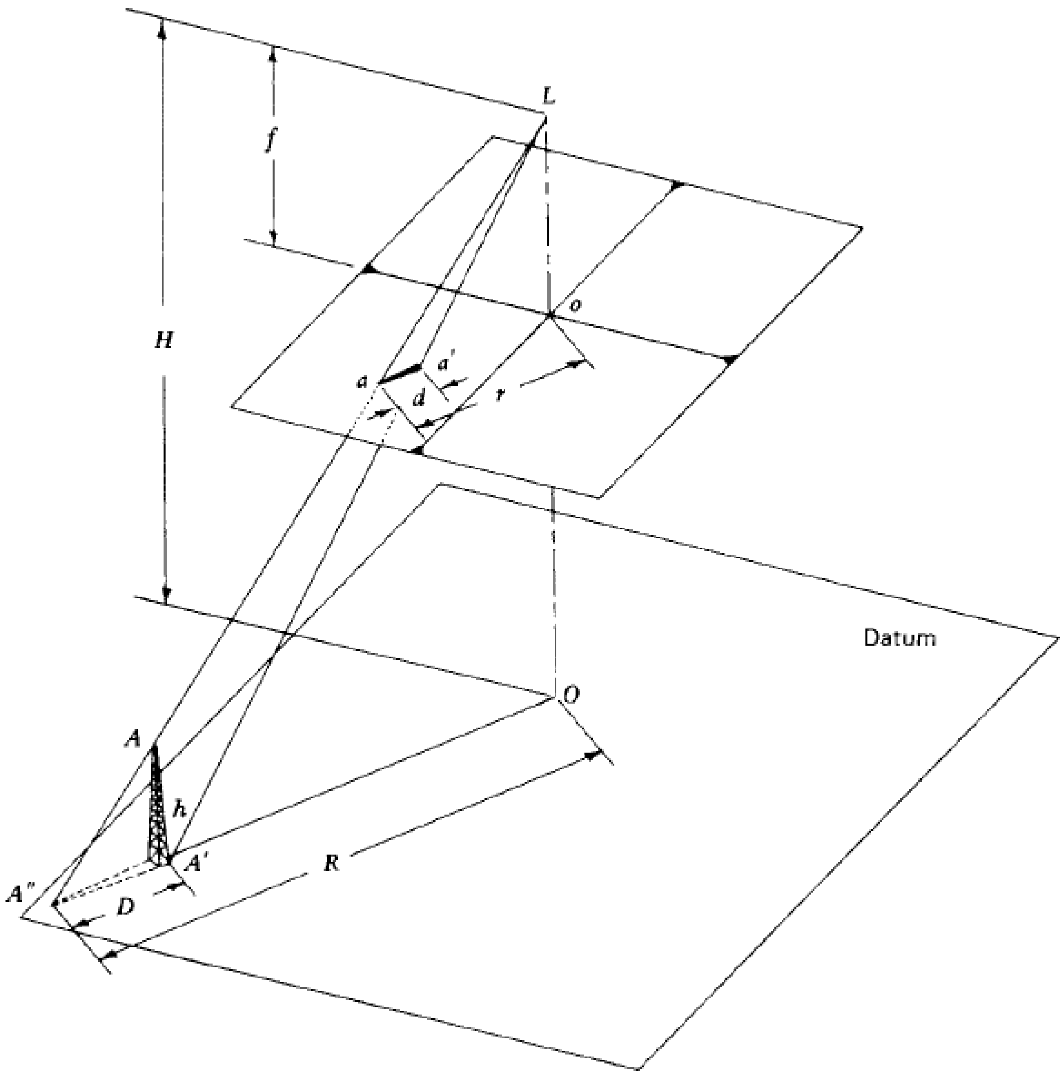


Figure 3.13 Geometric components of relief displacement.

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Geometric Components of Relief Displacement

- **$d = rh/H$**
- **Relief displacement of any given point increases as the distance from the principal point increases.**

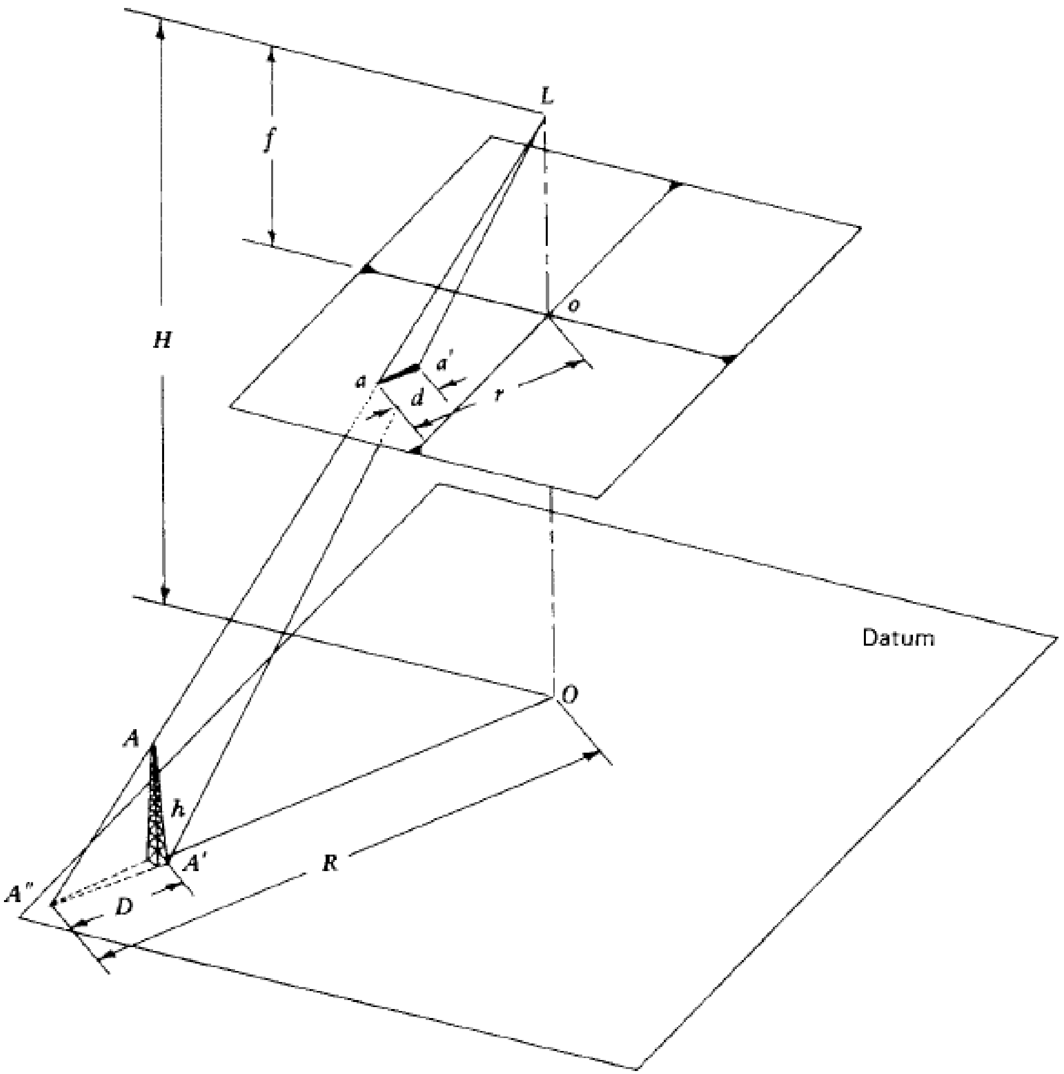


Figure 3.13 Geometric components of relief displacement.

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Source: http://geoinfo.amu.edu.pl/wpk/rst/rst/Sect11/Sect11_4.html

Object Height Determination from Relief Displacement Measurement

- It is possible to indirectly measure heights of objects appearing on aerial photographs:
- From the equation **d = rh/H**, we can get:

$$\mathbf{h = dH/r}$$

- To use the above equation, both the top and base of the object to be measured must be clearly identifiable on the photograph and the flying height *H* must be known
- **d** and **r** can be measured on the photograph (e.g., using a ruler)

Example

- For the photo whose geometry is shown on the right, assume that the relief displacement for the tower at A is 2.01 mm, and the radial distance from the center of the photo to the top of the tower is 56.43 mm. If the flying height is 1220 m above the base of the tower, find the height of the tower.

- Solution:

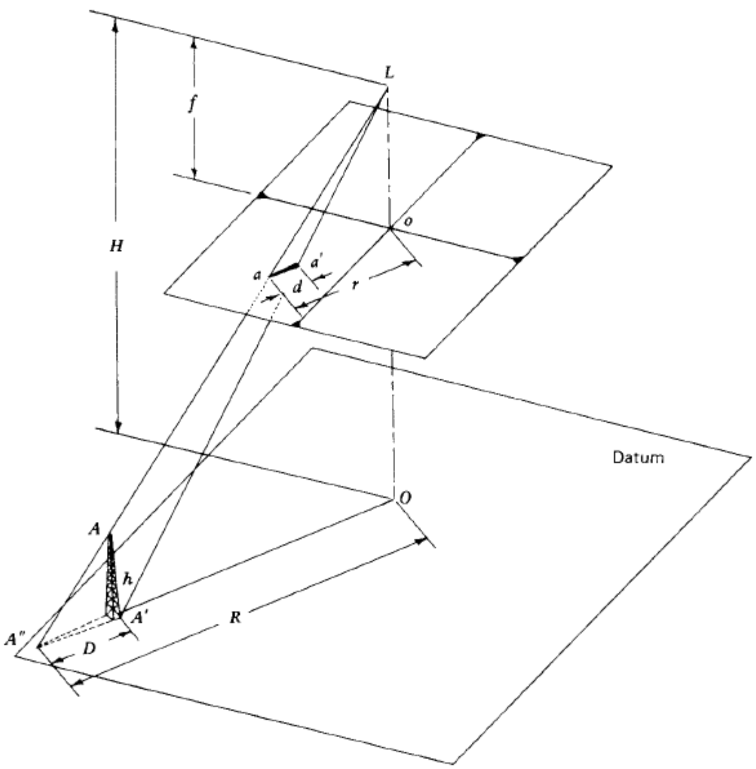
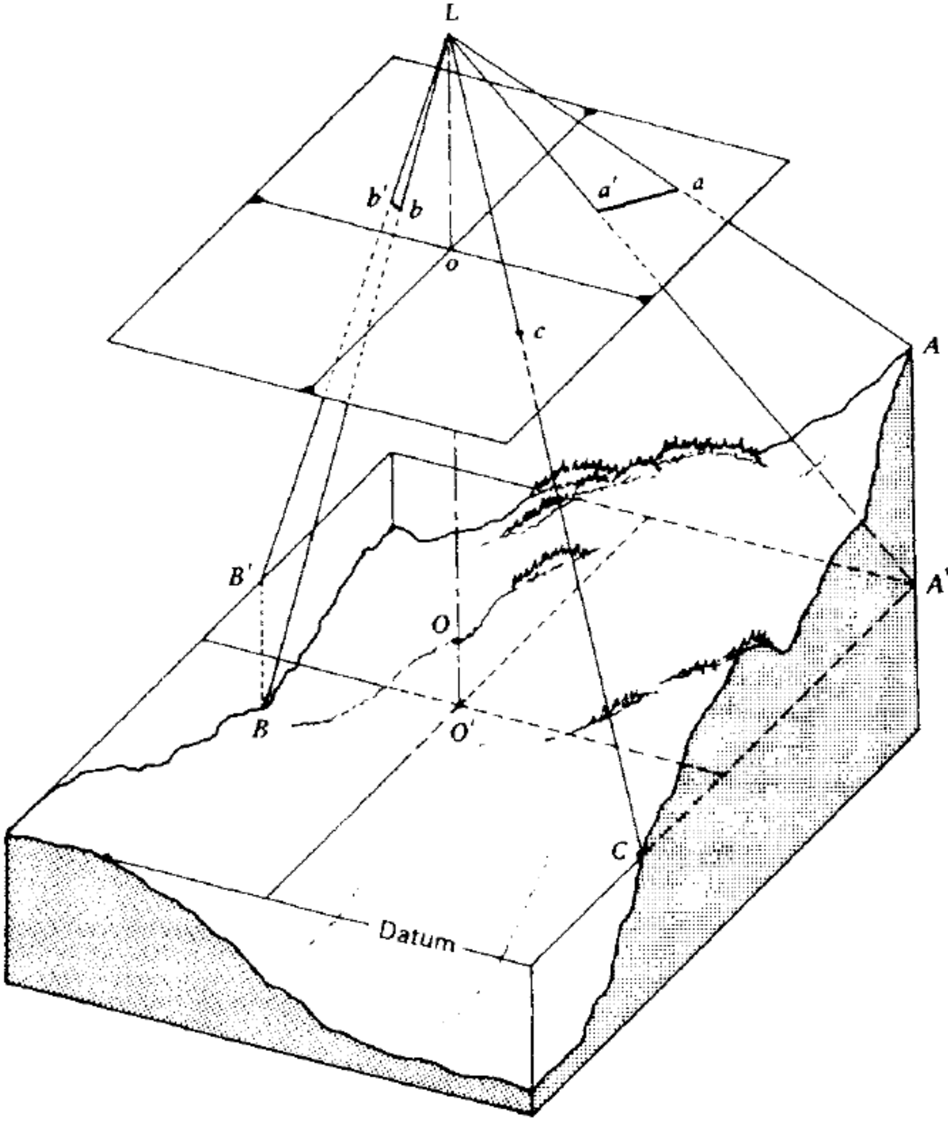


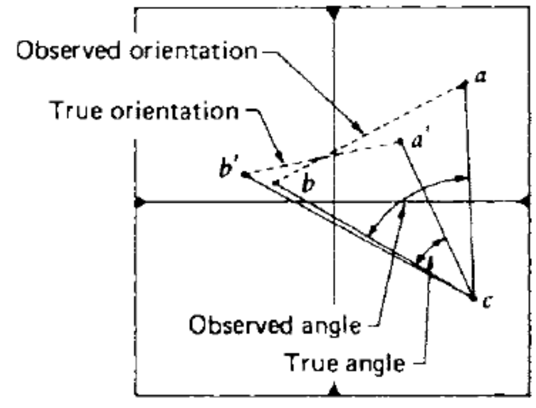
Figure 3.13 Geometric components of relief displacement.

$$h = \frac{dH}{r} = \frac{2.01 \text{ mm } (1220 \text{ m})}{56.43 \text{ mm}} = 43.4 \text{ m}$$

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.



(a)



(b)

- Terrain points in areas of varied relief or elevation exhibit relief displacement as do vertical objects.

Figure 3.14 Relief displacement on a photograph taken over varied terrain: (*a*) displacement of terrain points; (*b*) distortion of horizontal angles measured on photograph.

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Correcting for Relief Displacement

- Quantification of relief displacement can be used to correct the image positions of terrain points appearing in a photograph.

- Relief displacement can be corrected by using the equation **d = rh/H** on a point-by-point basis and then laying off the computed displacement distances radially (in reverse) on the photograph

Correcting for Relief Displacement

- The correction procedure establishes the datum-level image positions of the points and removes the relief distortions, resulting in planimetrically correct image positions at datum scale.

Source: http://geoinfo.amu.edu.pl/wpk/rst/rst/Sect11/Sect11_4.html

Example

- Assume that the radial distance $\boldsymbol{r_a}$ to point ***A*** is **63.84 mm** and the radial distance $\boldsymbol{r_b}$ to point ***B*** is **62.5 mm**. Flying height ***H*** is **1220 m** above datum, point ***A*** is **152 m** above datum, and point ***B*** is **168 m** below datum.

- Find the radial distance and direction one must lay off from points ***a*** and ***b*** to plot ***a′*** and *b′*.

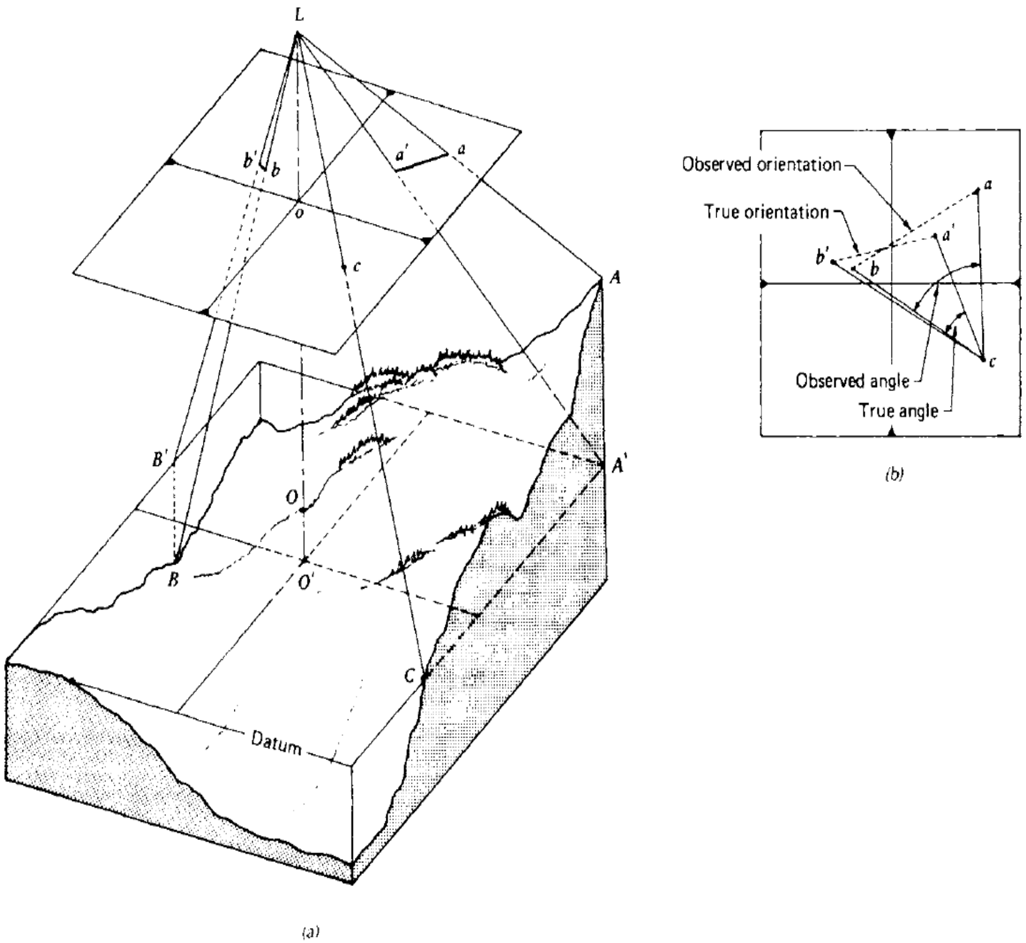


Figure 3.14 Relief displacement on a photograph taken over varied terrain: (*a*) displacement of terrain points; (*b*) distortion of horizontal angles measured on photograph.

Source: Lillesand et al 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiiley.

Solution

$$d_a = \frac{r_a h_a}{H} = \frac{63.84 \text{ mm} \times 152 \text{ m}}{1220 \text{ m}} = 7.95 \text{ mm} \qquad \text{(plot inward)}$$

$$d_b = \frac{r_b h_b}{H} = \frac{62.65 \text{ mm} \times (-168 \text{ m})}{1220 \text{ m}} = -8.63 \text{ mm} \qquad \text{(plot outward)}$$

FLIGHT PLANNING

Flight Planning Geometric Design Considerations/Parameters

- focal length of the camera to be used (f)
- film format size
- photo scale desired
- size of the area to be photographed
- average elevation of the area to be photographed
- overlap desired
- sidelap desired
- speed of the aircraft to be used

Flight Plan Preparation and Computations

- From those parameters, the mission planner prepares computations and a flight map that indicate to the flight crew the following:
  - Flying height above datum
  - Location, direction, and number of flight lines to be made over the area to be photographed
  - The time interval between photos
  - The number of photos on each flight line
  - The total number of photos necessary for the mission

Steps in Flight Plan Computation

1. Decide on the flying direction
   – Choose a direction that will minimize the number of flight lines
2. Find the flying height above terrain:

$$H' = f/S$$

3. Add the mean site elevation to find flying height above the required datum:

$$H = f/S + h_{avg}$$

4. Determine the ground coverage per photo on a side from film format size and photo scale

Ground Coverage (GC) on a side

= length of one side of photo/ photo scale in ratio form

Steps in Flight Plan Computation

5. Determine the ground separation distance (**GSD**) between the photos on a line based on the required endlap percentage

GSD = (100% - end lap %) * length of ground coverage on one side of the photo

6. Determine the time (**t**) between exposure:

t= GSD/ aircraft speed

7. If **t** is a whole number, proceed to #9. Else, **round down** the time between exposure to nearest second. By rounding down, required endlap coverage is ensured.

8. Recalculate the GSD between photo centers based on the rounded-down value of the time between exposure

(reverse the computation in #6 to get the new ground separation distance)

New GSD = t * aircraft speed

Steps in Flight Plan Computation

9. Compute the number of photos per flight line (**NPL**):

NPL = (length of one side of the project area parallel to the flight line / new GSD) + 1 +1

(**Round-up** to get a whole number to ensure coverage)

Note: the "+ 1 + 1" means that one photo is added to each end of the flight line

10. Calculate the distance between flight lines (**DFL**) based on the required side lap:

DFL = (100% - side lap %) * GC

Steps in Flight Plan Computation

11. Compute for the number of flight lines (**NFL**) to cover the width of the area:

NFL = number of spaces between flight line + 1

where: number of spaces = (Project Area Width / DFL)

Note: The division "Project Area Width / DFL" gives the number of spaces between flight lines; 1 is added to arrive at the final number of flight lines. **Round-up** to whole number to ensure coverage

12. Recalculate/adjust the spacing or distance between flight lines (DFL) based on the computed value of NFL:

New DFL = Project Area Width / (NFL - 1)

Steps in Flight Plan Computation

13. Find the total number of photos needed

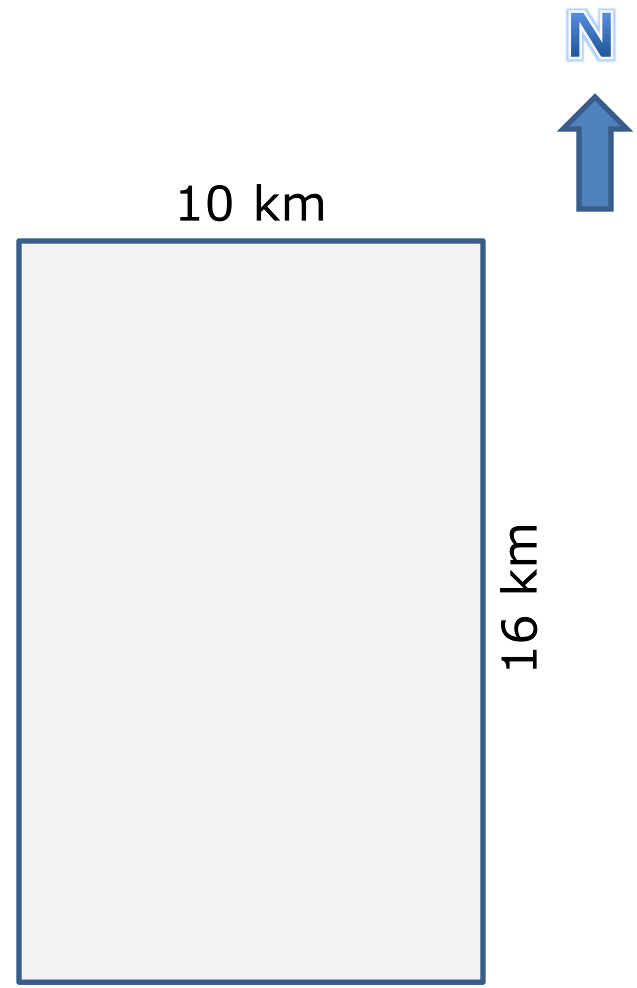
$$\textbf{No. of Photos} = \textbf{NPL} * \textbf{NFL}$$

14. Find the spacing of flight lines on the flight plan map, in mm (**DFL_{map}**):

$$\textbf{DFL}_{\textbf{map}} = \textbf{New DFL} * \textbf{Map Scale}$$

Example

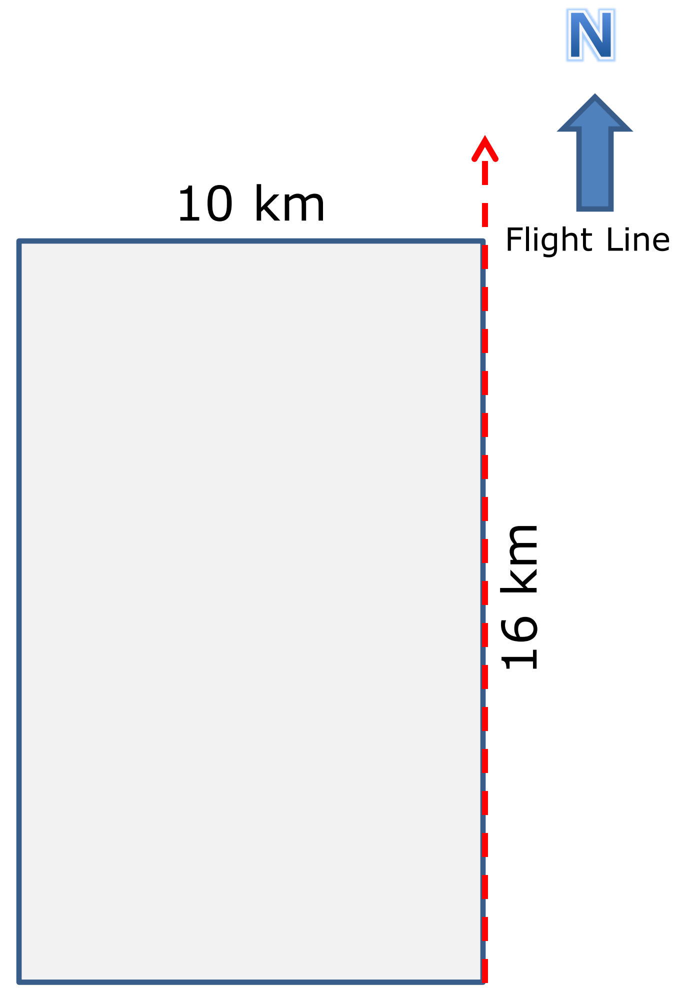
- A study area is 10 km wide in the east-west direction and 16 km long in the north-south direction.
- A camera having a 152.4 mm focal length lens and a 230 x 230 mm format is to be used
- The desired photo scale is 1:25,000
- The nominal endlap = 60%
- The nominal sidelap = 30%
- Beginning and ending of the flight lines are to be positioned along the boundaries of the study area
- The only topographic map available for the area is at a scale of 1:62,500
- Based on the map, the average terrain elevation is 300 m above datum.
- **Perform the computations necessary to develop a flight plan.**



Solution

1. Flight Direction:

North-South flight lines will be used. Using this direction minimizes the number of lines required and consequently the number of aircraft turns and realignments necessary.



Solution

2. Flying height above terrain:

$$H' = f/S$$

$$H' = 152.4 \text{ mm} * (1 \text{ m}/1000 \text{ mm}) / (1/25{,}000)$$

$$\mathbf{H' = 3{,}810\ m}$$

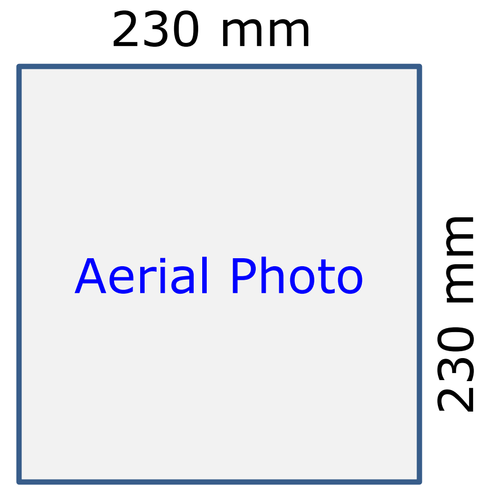
3. Flying height above datum (MSL):

$$H = H' + h_{avg}$$

$$\mathbf{H} = 3{,}810 \text{ m} + 300 \text{ m} = \mathbf{4{,}110\ m}$$

Solution

4. Determine the ground coverage per photo on a side from film format size and photo scale



Ground Coverage (GC) on a side

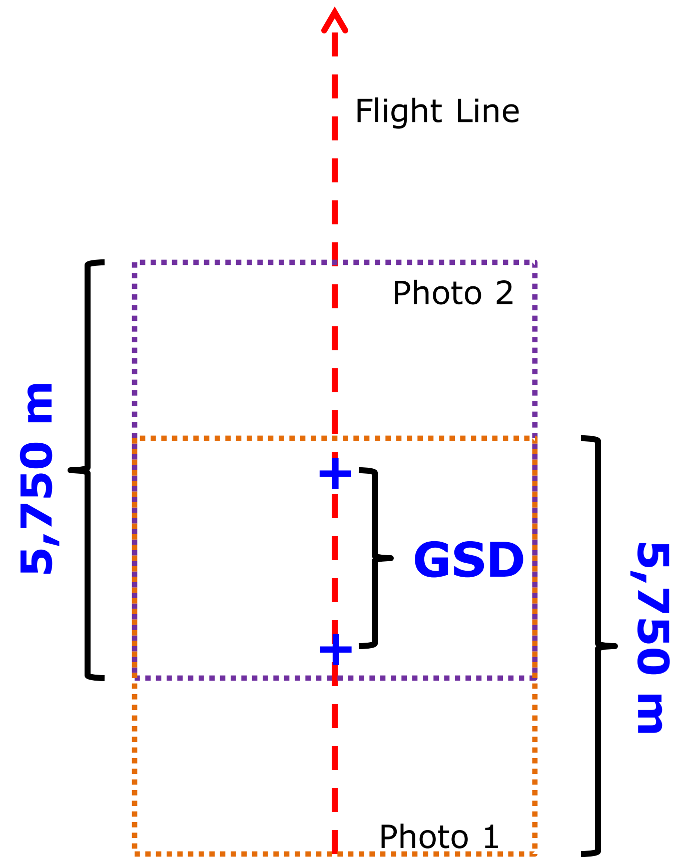
= length of one side of photo/ photo scale in ratio form

GC = 230 mm * (1 m / 1000 mm) / (1/25,000)

GC = 5,750 m on a side

Solution

5. Ground separation distance (**GSD**) between the photos on a line based on the required endlap percentage



GSD = (100% - end lap %) * length of ground coverage on one side of the photo

GSD = (100%-60%) * 5750 m

GSD = 40% * 5750 m

GSD = 2,300 m between photo centers

Solution

6. Time (**t**) between exposure:

t= GSD/ aircraft speed

t = (2,300 m / 160 km/hr)

t = (2,300 m / 160 km/hr)*(3600 sec/hr / 1000 m/km)

t = 51.75 sec

7. If **t** is a whole number, proceed to #9. Else, **round down** the time between exposure to nearest second. By rounding down, required endlap coverage is ensured.

→ t = 51 sec (rounded down)

Solution

8. New GSD between photo centers based on the rounded-down value of the time between exposure

New GSD = t * aircraft speed

= 51 sec * 160 km/hr / 3600 sec/hr * 1000 m/km

New GSD = 2,266 m

(rounded-down to ensure coverage)

Solution

9. Number of photos per flight line (**NPL**):

NPL = (length of one side of the project area parallel to the flight line / new GSD) + 1 +1

= [(16 km * 1000 m/km) / 2266 m] + 1 +1

NPL = 9.1

→ Use NPL = 10 (rounded up)

Solution

10. Distance between flight lines (**DFL**) based on the required side lap:

DFL = (100% - side lap %) * GC

DFL = (100% - 30%) * 5,750 m

DFL = 70% * 5,750 m

DFL = 4,025 m.

Solution

11. Number of flight lines (**NFL**) to cover the width of the area:

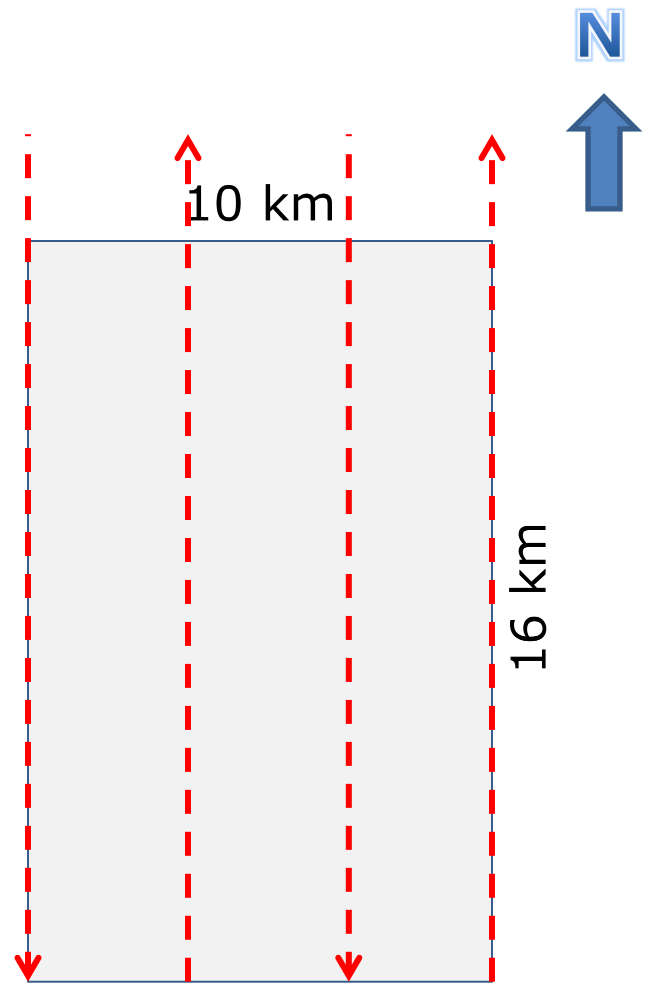
NFL = number of spaces between flight line + 1

where: number of spaces = (Project Area Width / DFL)

NFL = (10 km * 1000 m/km / 4,025) + 1

NFL = 3.48

→ **Use NFL = 4**



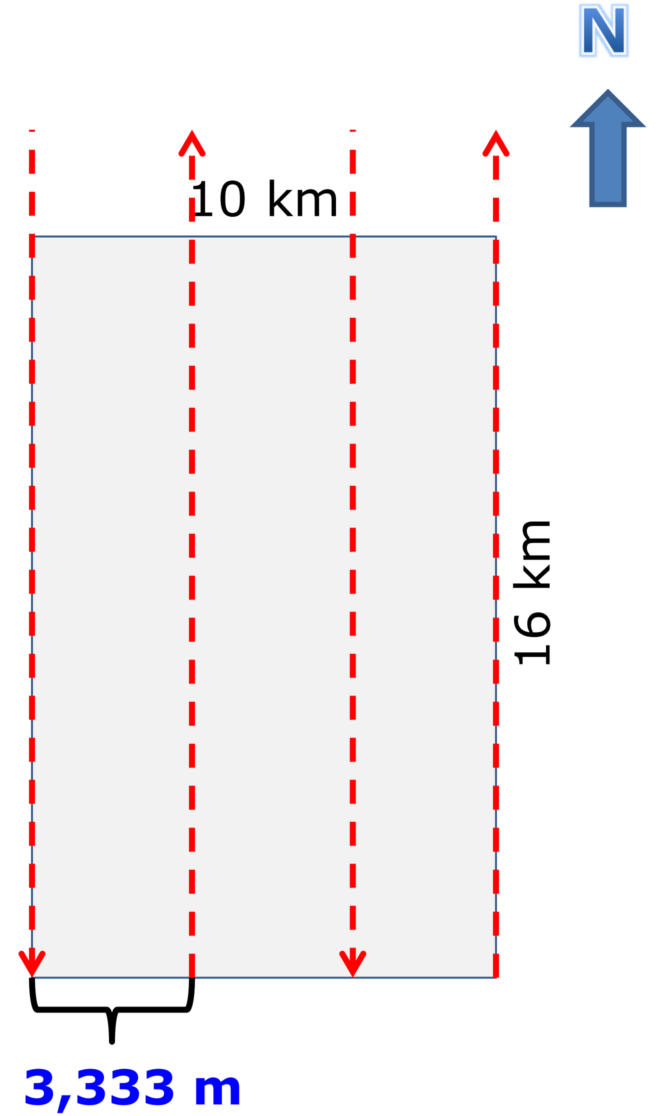
Solution

12. Adjusted spacing or distance between flight lines (DFL) based on the computed value of NFL:

New DFL = Project Area Width / (NFL - 1)

New DFL = 10 km * 1000 m/km / (4-1)

New DFL = 3,333 m



Solution

13. Total number of photos needed

$$\text{No. of Photos} = NPL * NFL$$

$$\text{No. of Photos} = 10 * 4$$

40 photos

14. Spacing of flight lines on the flight plan map, in mm (**DFL_{map}**):

$$DFL_{map} = \text{New DFL} * \text{Map Scale}$$

$$= 3{,}333 \text{ m} * (1/62{,}500)$$

$$= 3{,}333 \text{ m} * (1000 \text{ mm}/1 \text{ m}) * (1/62{,}500)$$

$$\mathbf{DFL_{map} = 53.3 \text{ mm}}$$

Further Reading

- Lillesand et al, 2004, Remote Sensing and Image Interpretation Fifth Edition, Wiley. (pp. 149-156)

or

- Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. , 2008. Remote Sensing and Image Interpretation 6th Edition. John Wiley & Sons, Inc., USA. (pp. 123-188)