Remote Sensing and GIS

- **Course no: CSC-624**
- **Full Marks: 45+30 (Theory + Laboratory)**
- **Pass Marks: 22.5+15**
- **Credit hours: 3**

Course Description:

This course covers the concepts and principles of remote sensing, global navigation satellite System (GNSS) and GIS

Internal Exam - Evaluation Criteria

Total Marks for Theory = 30

- Attendance = 3.75 (~3)
- Presentations-2 = 3.75 (~5)
- Assignments/project works = 3.75 (~4)
- Internal Exam (I) = 7.5 (~7)
- Internal Exam (II) = 11.25 (~11)

GIS (Geo-informatics Science)

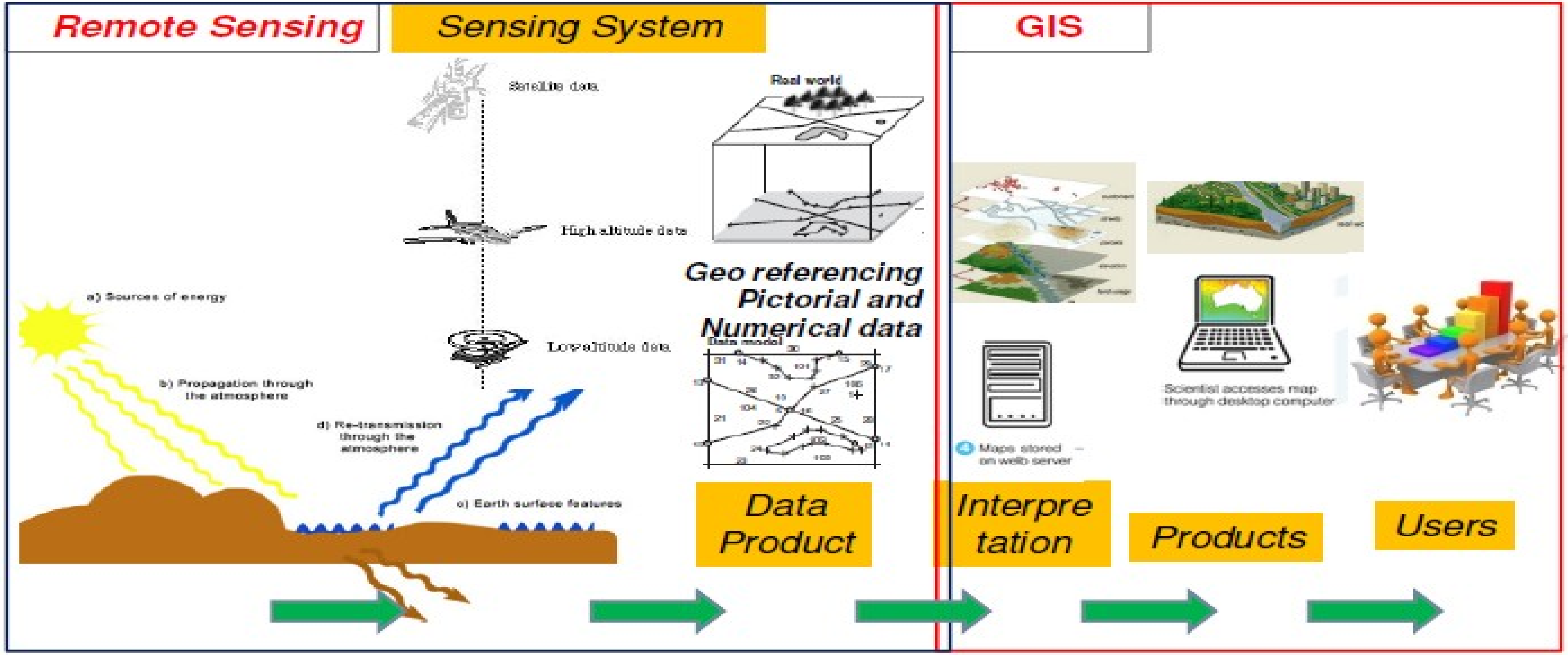
1. Geographic Information system(GI**S**)

2. Remote Sensing (R**S**)

3. Global Navigation Satellite System (GNS**S**)

3S

RS and GIS of Earth Resources



Electromagetic remote sensing of earth and its processing

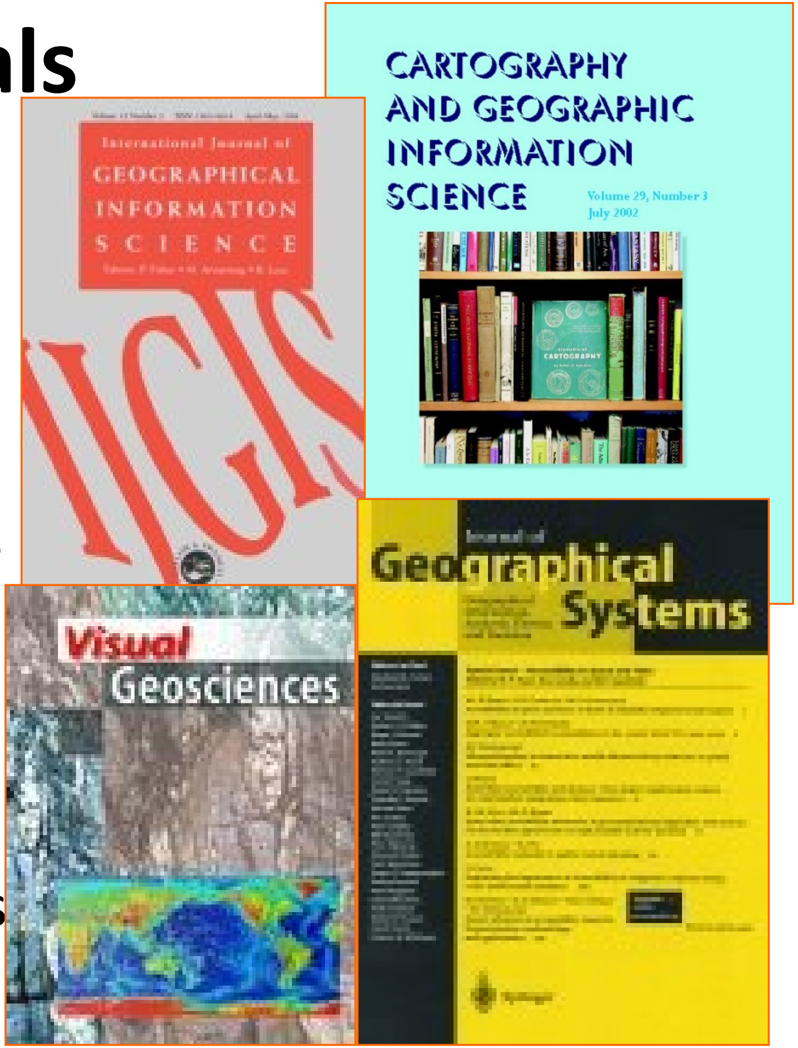
Reading Resources- Text Books

- Remote Sensing and GIS, Basudeb Bhatta, Second Edition, Oxford University Press
- Remote Sensing and GIS Integration, Theories, Methods, and Application, Qihao Weng, McGrawHill

- Principle of Remote Sensing; https://webapps.itc.utwente.nl/librarywww/papers_2009/general/principlesremotesensing.pdf
- Principle of GIS; https://webapps.itc.utwente.nl/librarywww/papers_2009/general/principlesgis.pdf
- Introduction to Photogrammetry, T. Schenk, 2005, The Ohio State University

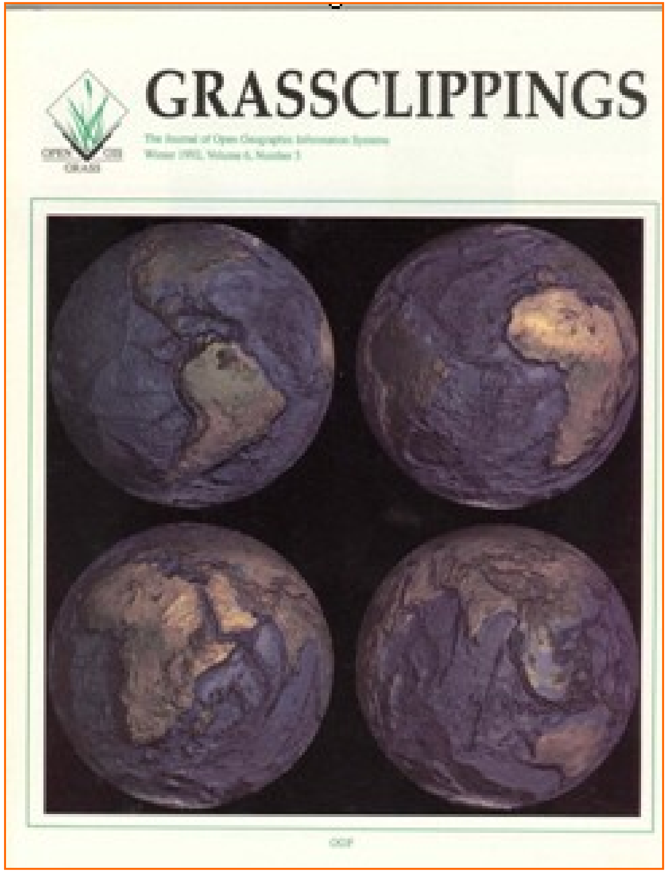
Major GIS-Only Journals

- Cartography and Geographic Information Science
- Geographic Information Systems
- GeoInformatica
- International Journal of Geographical Information Science
- Journal of Geographical Systems
- Visual Geosciences
- Transactions in GIS
- Journal of Geographic Information and Decision Analysis



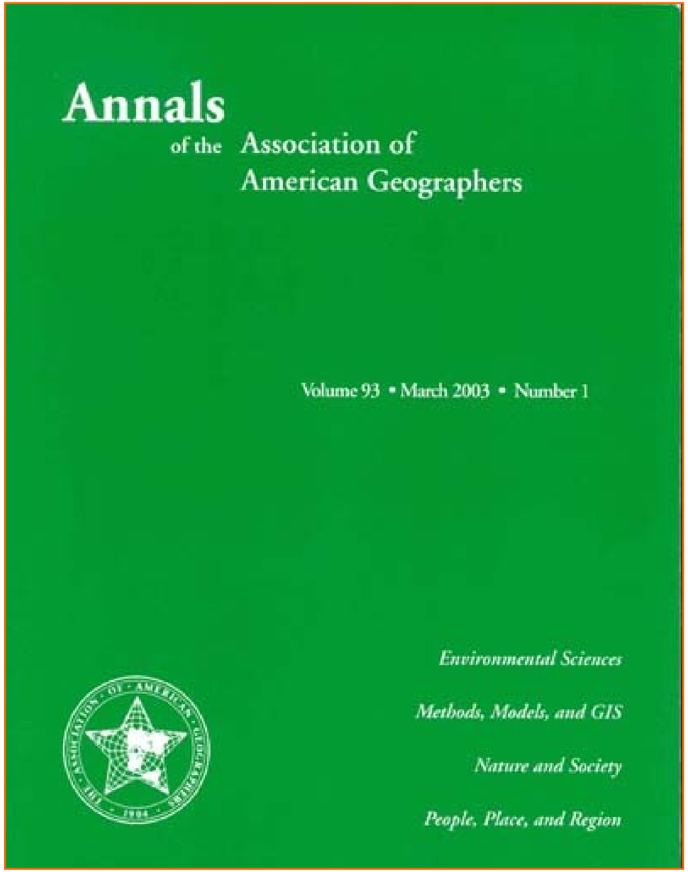
Specialty Journals

- GIS Law
- GrassClippings
- GIS Asia/Pacific
- GIS World Report/CANADA
- GIS Europe
- Mapping Awareness



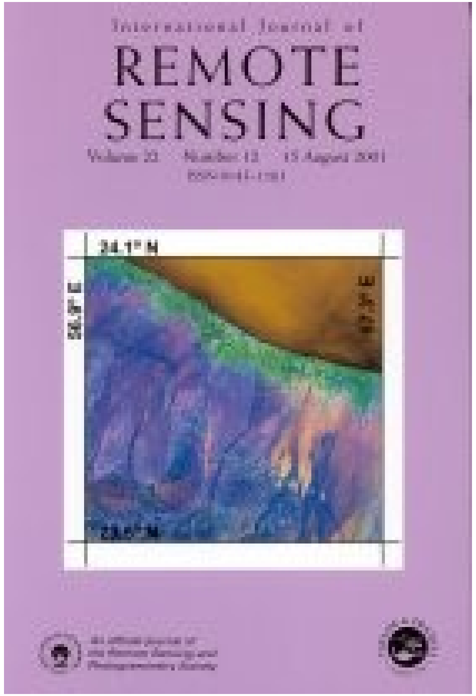
Regular GIS Papers

- Annals of the Association of American Geographers
- Cartographica
- Cartography and GIS
- Computers, Environment, and Urban Systems
- Computers and Geosciences
- IEEE Transactions on Computer Graphics and Applications
- Photogrammetric Engineering and Remote Sensing



Occasional GIS papers

- Cartographic Perspectives
- Journal of Cartography
- Geocarto International
- IEEE Geosciences
- International Journal of Remote Sensing
- Landscape Ecology
- Remote Sensing Review
- Mapping Science and Remote Sensing
- Infoworld



Popular Distribution Magazines some with free subscriptions

- Geospatial Solutions
- ArcNews
- ArcUser
- Geoplace (online)
- GPS World

Unit 1: Concept of Remote Sensing-4 hrs

- Introduction;
- Distance and Definition of Remote Sensing;
- Remote Sensing: Art and/or Science;
- Data;
- Remote Sensing Process;
- Source of Energy;
- Interaction with Atmosphere;
- Interaction with Target;
- Recording of Energy by Sensor;
- Transmission, Reception, and Processing;
- Interpretation and Analysis;
- Applications, Advantages, and Limitations of Remote Sensing;
- Ideal Remote Sensing System

Remote Sensing

- Remote sensing has been variously defined but basically it is the art or science of **telling something** about an object **without touching** it. (Fischer et al., 1976, p. 34)
- Remote sensing is the **acquisition of physical data** of an **object** without **touch or contact.** (Lintz and Simonett, 1976, p. 1)
- Remote sensing is the **observation** of a **target** by a device separated from it by **some distance.** (Barrett and Curtis, 1976, p. 3)
- The term "remote sensing" in its broadest sense merely means "**reconnaissance** at a **distance.**" (Colwell, 1966, p. 71)
- Remote sensing is the art, science and technology of **obtaining reliable information** about physical **objects and the environment**, through the process of recording, measuring and interpreting imagery and digital representations of **energy patterns** derived from **noncontact sensor systems** (Lecture Note by Wataru, 2009)

Remote Sensing

- Remote sensing is the **science of deriving information** about an **object** from **measurements** made at a **distance** from the object, i.e., **without actually coming in contact with it**. The quantity most frequently measured in present-day remote sensing systems is the **electromagnetic energy** emanating from objects of interest, and although there are other possibilities (e.g., seismic waves, sonic waves, and gravitational force), our attention . . . is focused upon systems which measure electromagnetic energy. (D. A. Landgrebe, quoted in Swain and Davis, 1978, p. 1)

- *Remote sensing is the practice of **deriving information** about the **Earth's land** and water surfaces using images acquired from an **overhead perspective**, using **electromagnetic radiation** in one or more regions of the electromagnetic spectrum, **reflected or emitted** from the Earth's surface.* (James B. Campbell, Randolph H. Wynne (2011): Introduction to Remote Sensing)

Is remote sensing limited to use of electromagnetic radiation !!!?

Remote Sensing

Depending on the scope, remote sensing may be broken down into

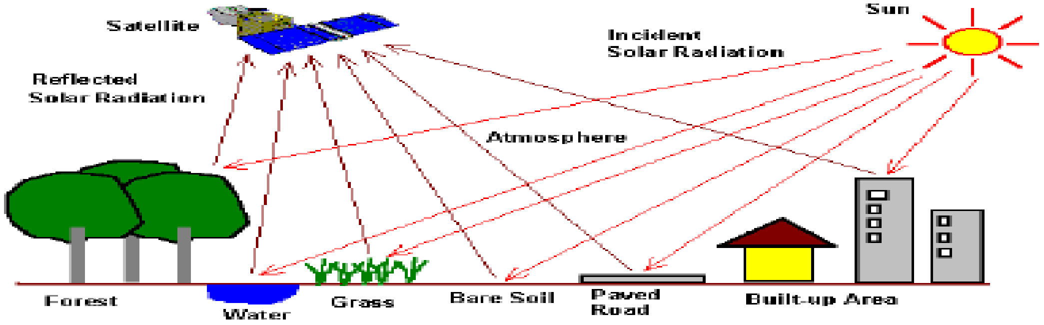
- **Satellite remote sensing** (when satellite platforms are used),
- **Photography and photogrammetry** (when photographs are used to capture visible light),
- **Thermal remote sensing** (when the thermal infrared portion of the spectrum is used),
- **Radar remote sensing** (when microwave wavelengths are used), and
- **LiDAR remote sensing** (when laser pulses are transmitted toward the ground and the distance between the sensor and the ground is measured based on the return time of each pulse).

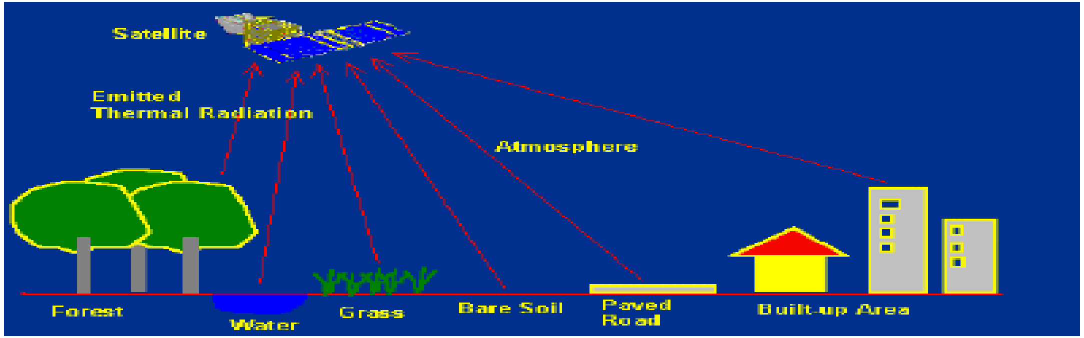
What is being detected?

- Electromagnetic (EM) radiation

- Day – reflected and emitted
- Night – emitted

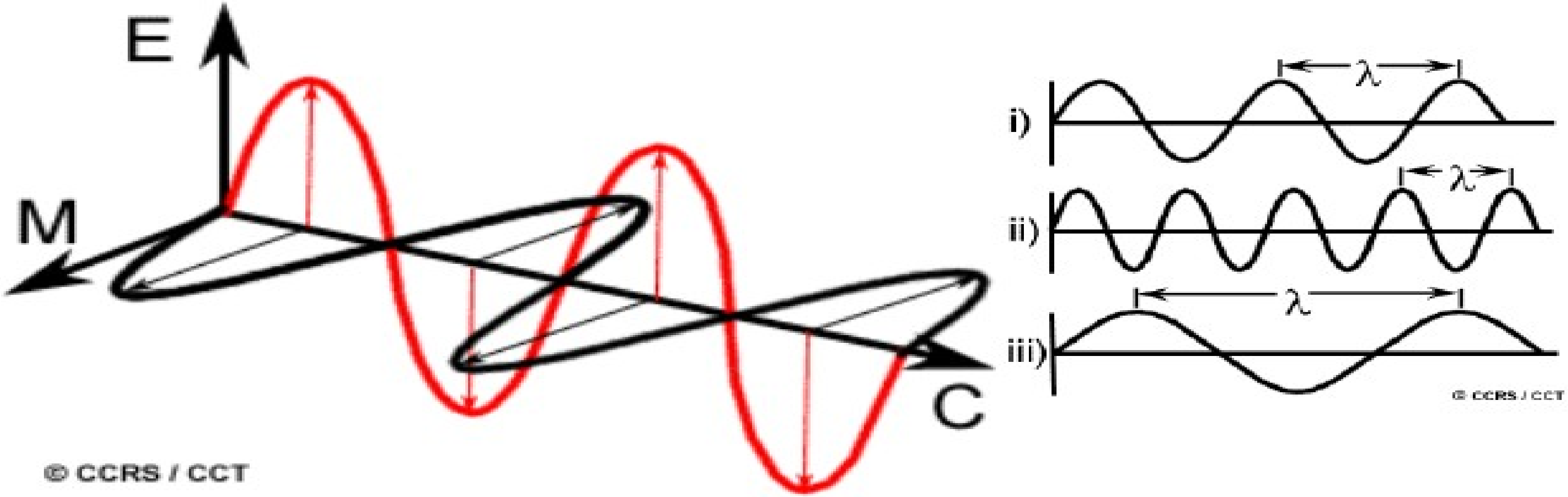
- Contrast with other geophysical techniques (e.g., acoustic, seismic)





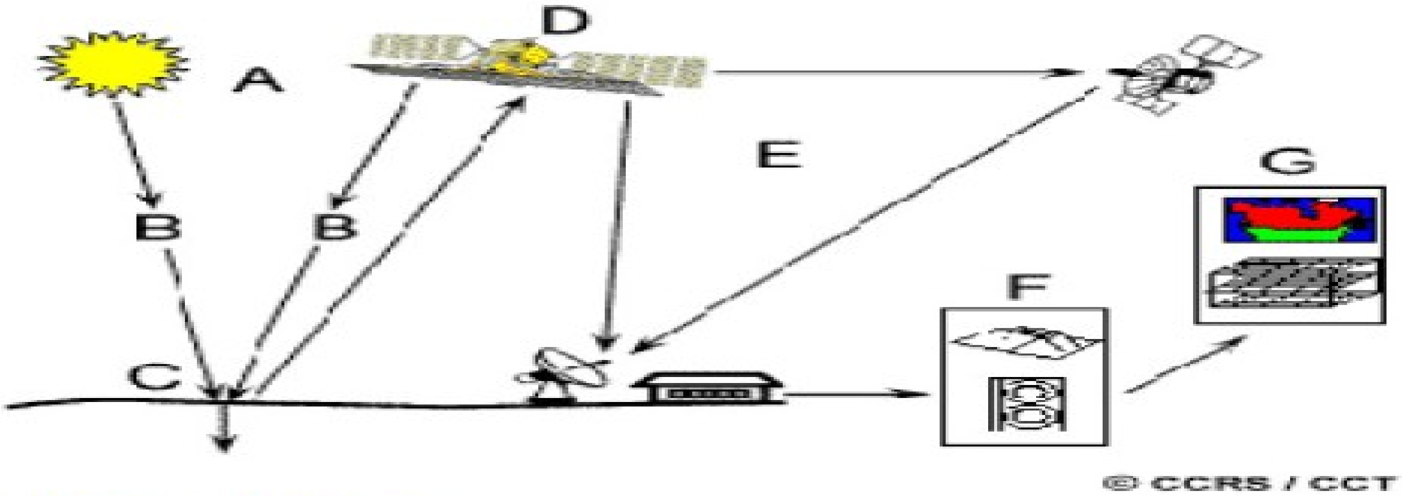
By recording emitted or reflected radiation and applying knowledge of its behaviour as it passes through the Earth's atmosphere and interacts with objects, remote sensing analysts develop knowledge of the character of features such as vegetation, structures, soils, rock, or water bodies on the Earth's surface.

Electromagnetic waves



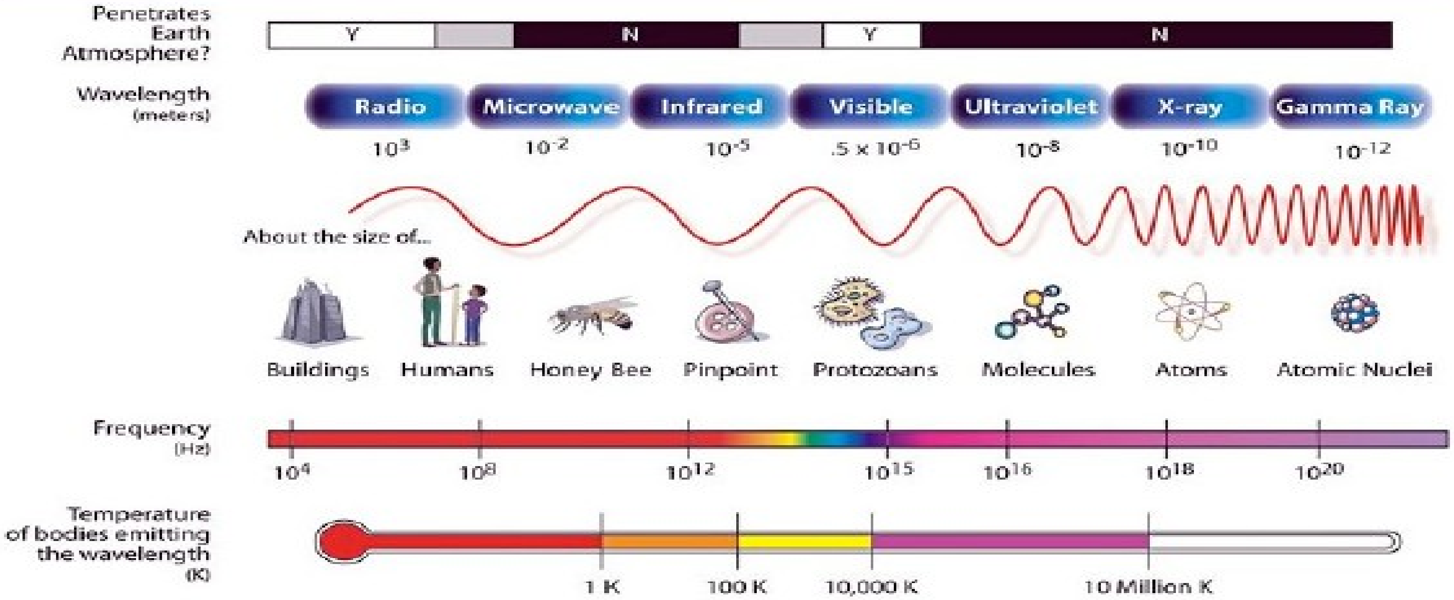
- Electric field (E)
- Magnetic field (M)
- Perpendicular and travel at velocity, c (3×10^8 ms^{-1})
- Characterized by wavelength (λ), frequency and energy

Various Steps in RS



(A) Energy Source
(B) Radiation and the Atmosphere
(C) Interaction with the Target
(D) Recording of Energy by the Sensor
(E) Transmission, Reception, and Processing
(F) Interpretation and Analysis
(G) Application

Electromagnetic (EM) Spectrum



The most familiar form of EMR is visible light, which forms only a small (but very important) portion of the full EM spectrum.

The large segments of this spectrum that lie outside the visible range require our special attention because they may behave in ways that are quite foreign to our everyday experience with visible radiation.

Electromagnetic (EM) Spectrum

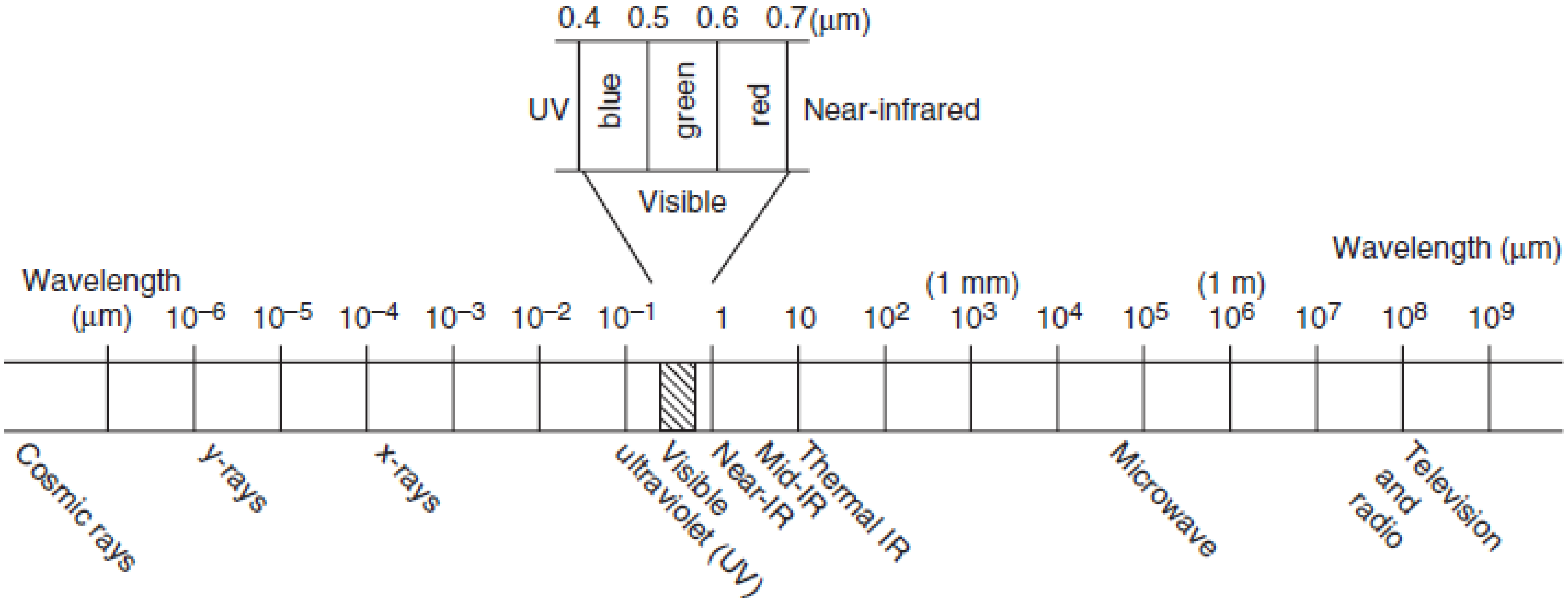


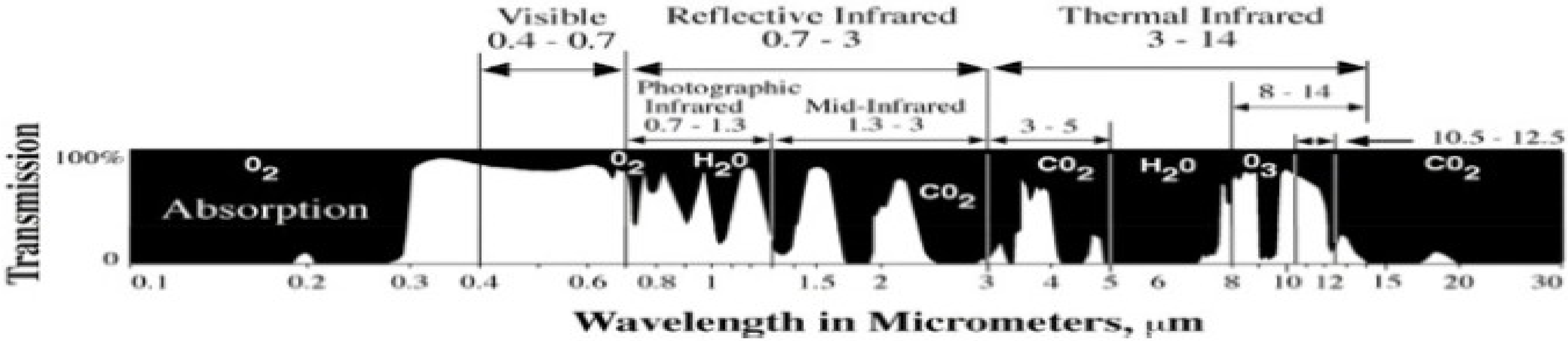
Table 1. Electromagnetic spectral regions

Wave length region name	Wavelength	Comments
Gamma Ray	<0.03 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
X-ray	0.03 to 30 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
Ultraviolet	0.03 to 0.4 micrometers	Wavelengths from 0.03 to 0.3 micrometers absorbed by ozone in the Earth's atmosphere.
Photographic Ultraviolet	0.3 to 0.4 micrometers	Available for remote sensing the Earth. Can be imaged with cameras and sensors.
Visible	0.4 to 0.7 micrometers	Available for remote sensing the Earth. Can be imaged with cameras and sensors.
Near and Mid Infrared	0.7 to 3.0 micrometers	Available for remote sensing the Earth. Can be imaged with cameras and sensors.
Thermal Infrared	3.0 to 14 micrometers	Available for remote sensing the Earth. This wavelength cannot be captured by film cameras. Sensors are used to image this wavelength band.
Micowave or Radar	0.1 to 100 centimeters	Longer wavelengths of this band can pass through clouds, fog, and rain. Images using this band can be made with sensors that actively emit microwaves.
Radio	>100 centimeters	Not normally used for remote sensing the Earth.

Source: Boumann (2010)

Atmospheric Windows

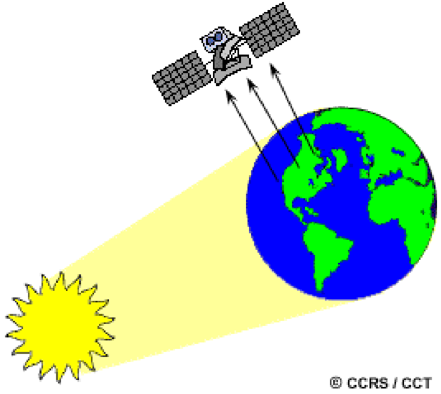
- Earth's atmosphere is by no means completely transparent to electromagnetic radiation because the gases (O3, O2, CO2 & H2O) together form important barriers to transmission of electromagnetic radiation through the atmosphere
- Atmosphere selectively transmits energy of certain wavelengths; those wavelengths that are relatively easily transmitted through the atmosphere are referred to as *atmospheric windows*

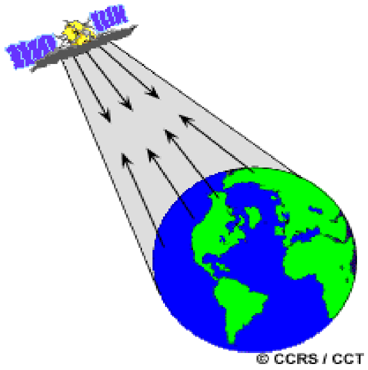


Atmospheric windows are vitally important to the development of sensors for remote sensing

Types of Remote Sensing

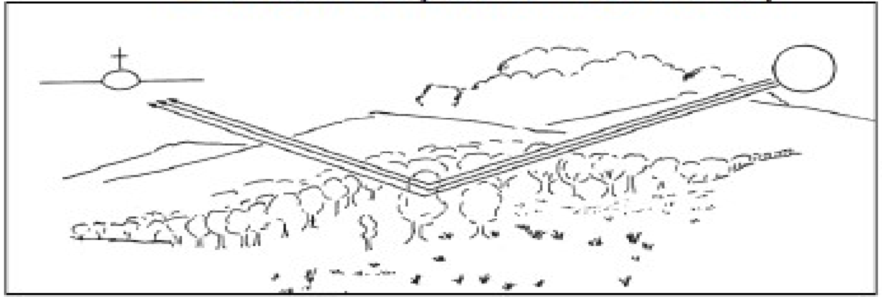
- Passive remote sensing:
  - can only be used to detect energy when the naturally occurring energy is available.
- Active remote sensing :
  - provide their own energy source for illumination.
  - radar used by police to measure the speed of traveling vehicles is a use of active remote sensing,
- A camera provides an example of both passive and active sensors



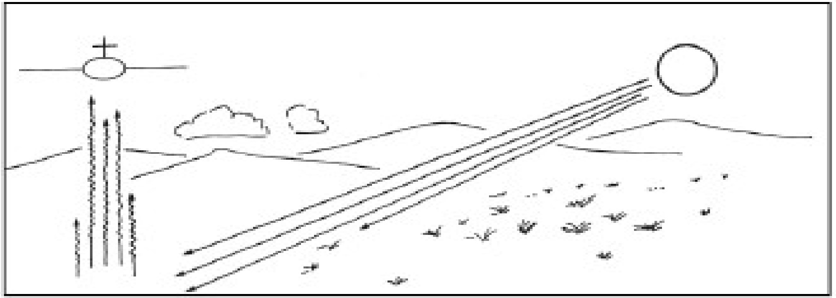


Type of Remote Sensing (RS)

- **Passive RS**
  - Natural (EMR from Sun)

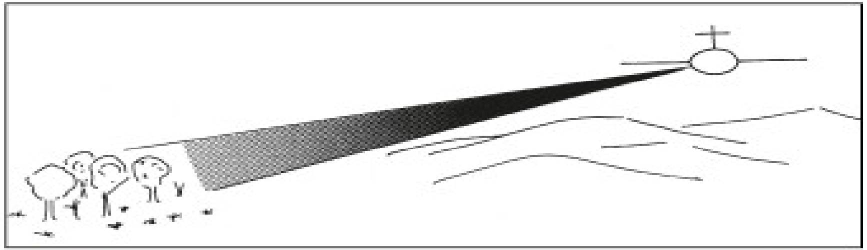


RS using reflected solar radiation



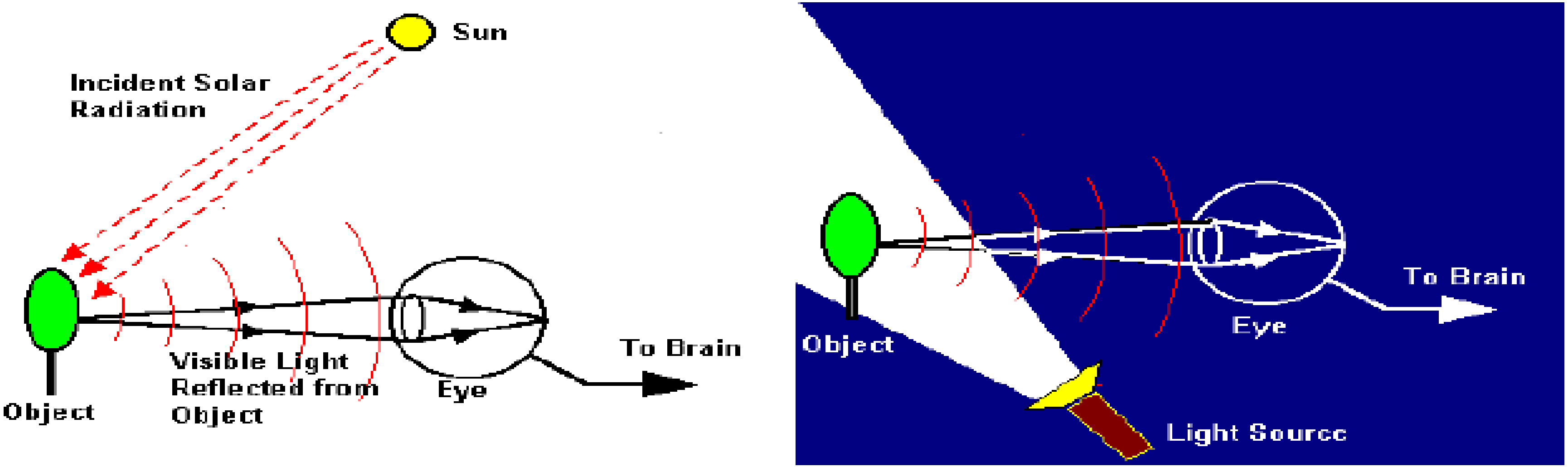
RS using emitted terrestrial radiation

- **Active RS**
  - Technological Assisted Radiation



RS using senor's transmitted radiation

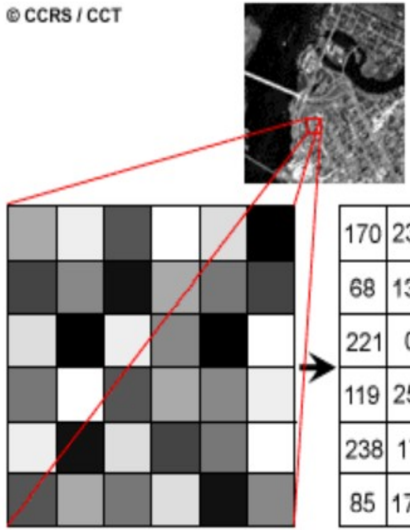
Passive vs. active systems



- Passive: measures naturally occurring radiation
- Active: Radar (radio), Lidar (visible light)

Characteristics of Image

- Electromagnetic energy may be detected either photographically or electronically,
- The photographic process uses chemical reactions on the surface of light-sensitive film to detect and record energy variations,
- An image refers to any pictorial representation, regardless of what wavelengths or remote sensing device has been used to detect and record the electromagnetic energy,
- A photograph refers specifically to images that have been detected as well as recorded on photographic film,
- Photos are normally recorded over the wavelength range from 0.3 µm to 0.9 µm - visible and reflected infrared,
- A photograph could also be represented and displayed in a digital format by subdividing the image into small equal-sized and shaped areas, called picture elements or pixels, and representing the brightness of each area with a numerical value,
- Remote sensing data are displayed either pictorially or digitally, and interchangeable as they convey the same information,



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

All photographs are images, but not all images are photographs

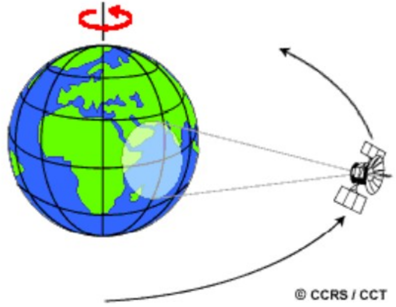
Platforms in RS

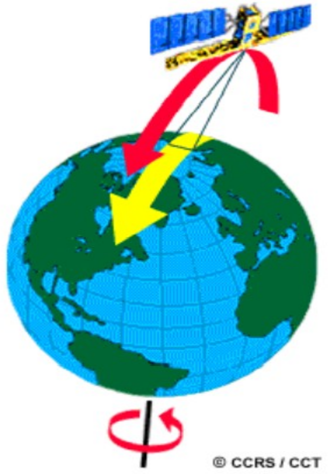
- Ground-borne platforms- Ground vehicles, handheld camera, Towers/Cranes
- Air-borne platforms– Drone, Balloon, Aircraft, Helicopter
- Space-borne platforms– Space Shuttles (Satellites)

Satellite Characteristics

Orbits and Swaths

- Orbit selection can vary in terms of altitude, their orientation and rotation relative to the Earth.
  - geostationary orbits:
    - 36,000 km, revolve at speeds which match the rotation of the Earth,
    - collect information continuously over specific areas. Weather and communications satellites commonly have these types of orbits
    - typically low spatial resolution due to high altitude
    - Cannot see poles very well (orbit over equator)
  - near-polar orbits-
    - Orbit follows north-south direction
    - orbits are also sun-synchronous such that they cover each area of the world at a constant local time of day
    - the satellite travels northwards on one side of the Earth and then toward the southern pole on the second half of its orbit.

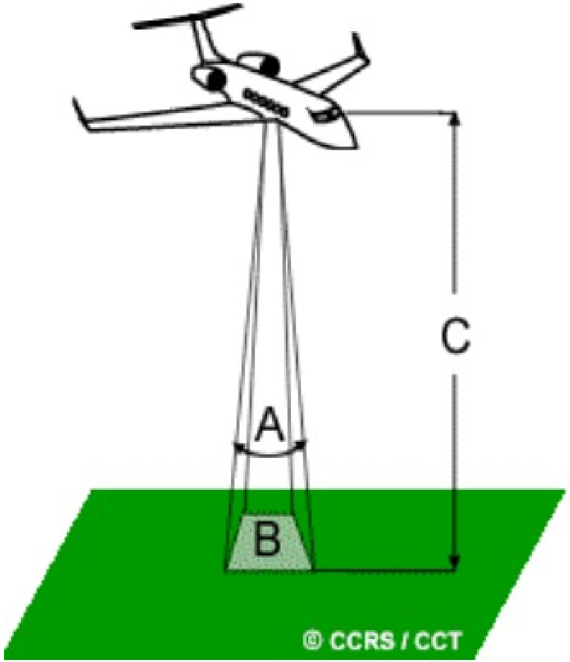


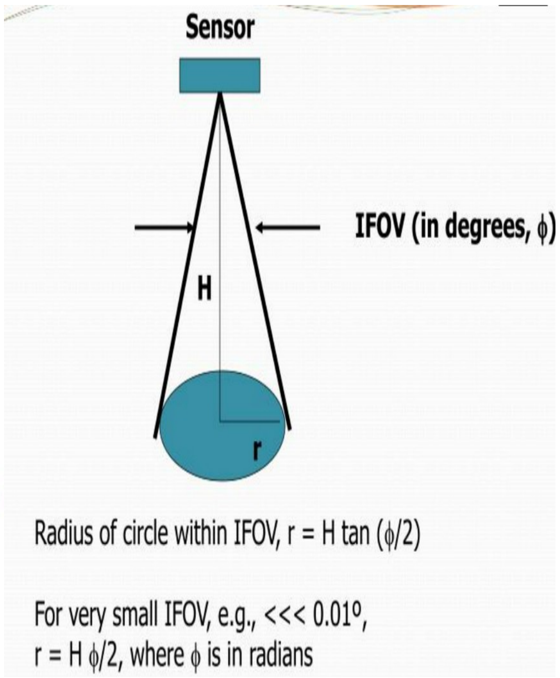


Satellite Characteristics

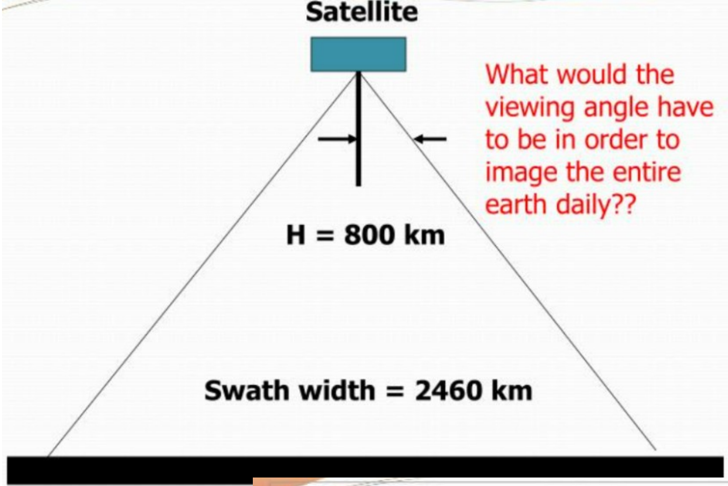
Instantaneous Field of View (IFOV), Swaths, Nadir

- The area covered by sensor to image on the surface, is referred to as the swath.
- Imaging swaths for space borne sensors vary between tens and hundreds of km wide.





Narrow and Wide Swath



$\text{Tan}(\phi) = \frac{0.5*\text{width}}{\text{height}}$

$\text{Tan}(\phi) = (0.5*2460)/800$

$\text{Tan}(\phi) = 1.65$

$\phi = \arctan(1.65) =$ 57 degrees

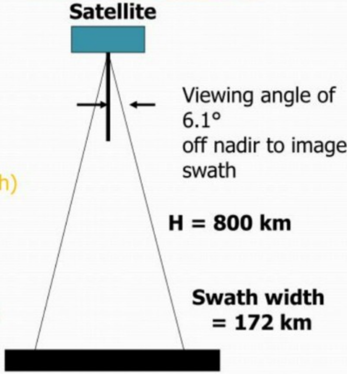
H = 800 km
Swath width = 2460 km

How long to cover the Earth with this system?

16 orbits/day * 172 km =
2752 km/day imaged (width)

Earth's circumference =
39,350 km

39, 350/2752 = 14.3 days



	Wide Swath / Low Resolution	Narrow Swath/ High Resolution
Image Size	2460 by 2460 km	172 by 172 km
Ground area size (resolution or pixel size)	1 by 1 km	0.05 by 0.05 km (50 by 50 m)
Number of radiometer channels	4	4
Images per orbit	16	228.8
Pixels per image per channel	6 million	11.8 million
Pixels per orbit per channel	96 million	2.7 billion
Pixels per orbit for all channels	384 million	10.8 billion

If a sensor were to be both high resolution AND wide swath:
Pixels per orbit for 4 channels: 155 billion
Daily Pixels for Earth: 2.5 trillion
Monthly Pixels for Earth: 743 trillion

Relation between Swath and Resolution of Image

	Narrow-Swath, Higher Resolution	Wide-Swath, Lower Resolution
Temporal resolution	-Coverage only every 15 to 20 days (less if cloud cover exists)	+Daily coverage of area
Spatial resolution	+High resolution imagery	-Low resolution imagery
Data volume	-Higher data volumes requires on-board recording or direct transmission	+Lower data volumes result in less stringent recording/direct transmission requirements
Atmospheric effects	+Narrow viewing angle results in lower atmospheric / bi-directional scattering effects, and consistent across-swath resolution	-Wider viewing angle results in greater atmospheric / bi-directional scattering effects, and variable across-swath resolution

Sensor Resolutions

- **Spectral resolution-** what reflectance characteristics to measure
- **Radiometric resolution** - how precisely to measure the characteristics
- **Spatial resolution** – how large are the features or what is the size of patch being detected by the sensors
- **Temporal resolution** – when and how frequently measure the features

Introduction of GIS and Spatial Data Analysis -Review

What is GIS?

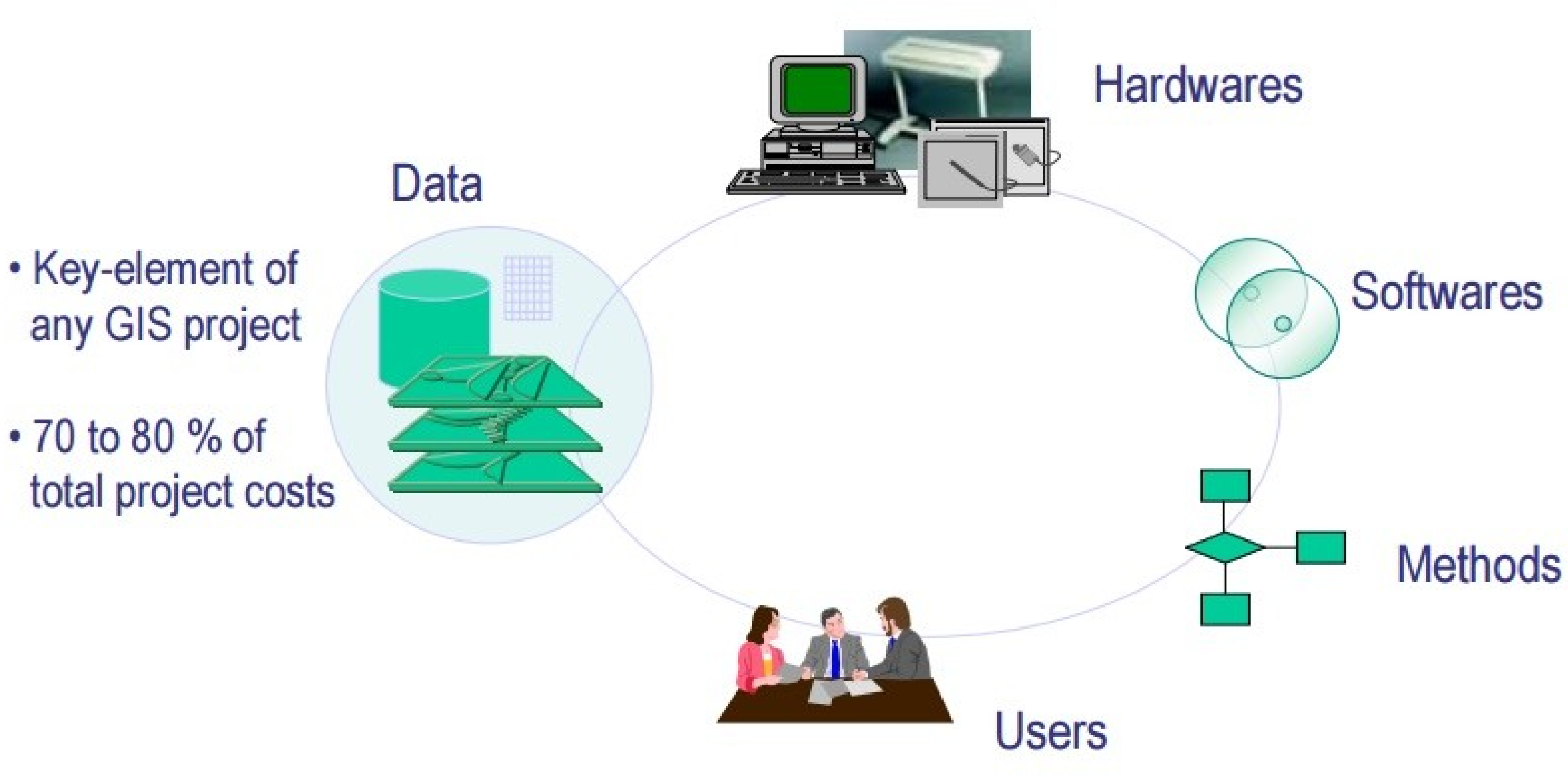
- A special kind of Data base Management Information System (DBMS).
- A simple **database** might be a single file with many records, each of which references the same set of fields. However, a **GIS database** includes **data** about the spatial locations and shapes of geographic features recorded as points, lines, areas, pixels, grid cells, or TINs, as well as their attributes.
- Special information about *what is where* on the Earth's surface
- (GIS) is a computer-based system including software, hardware, people, and geographic information, which can **capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data**.

Components of GIS

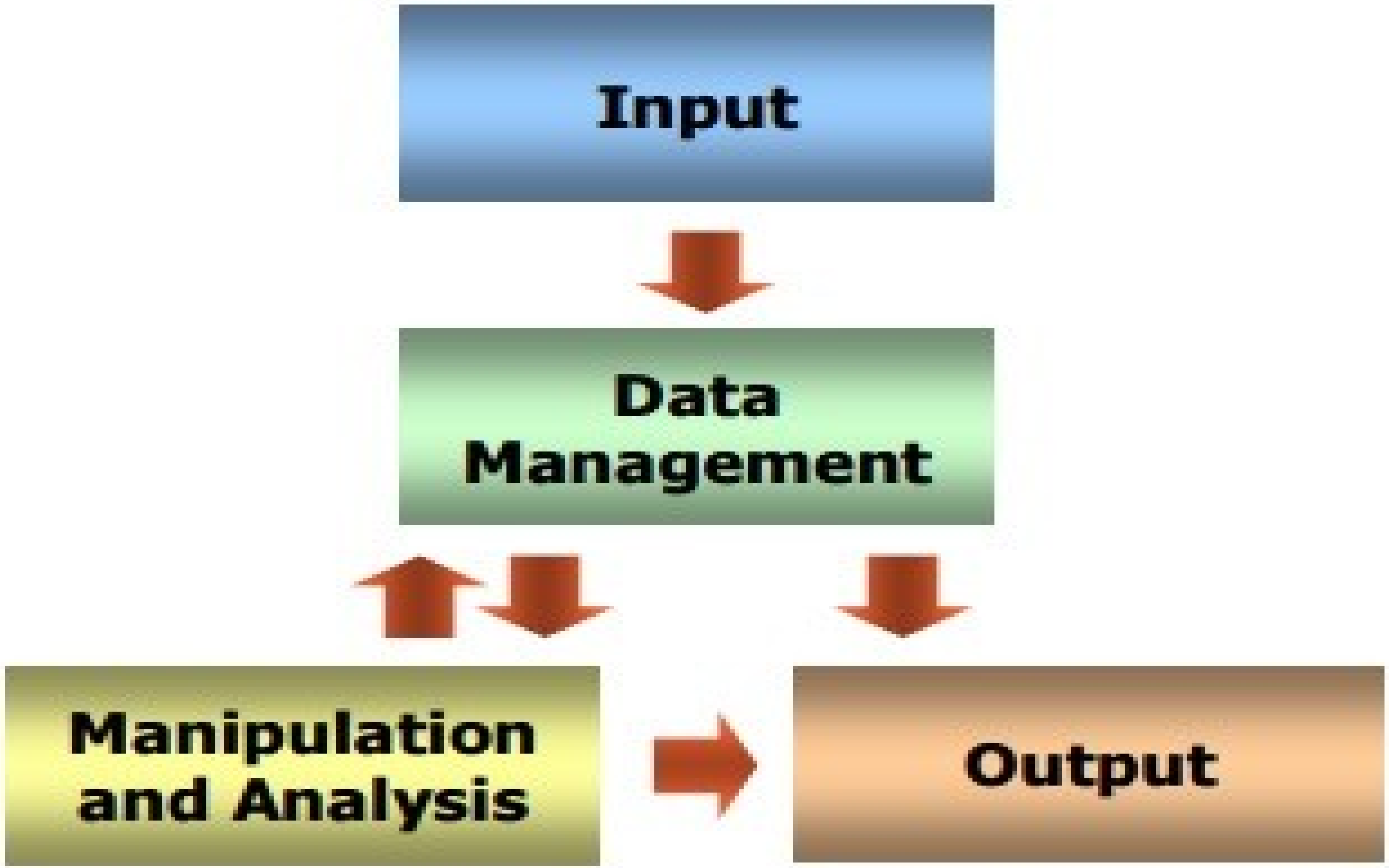
- Computer Hardware
- Computer Software
  - Tools for the input and manipulation of geographic information
  - A database management system (DBMS)
  - Tools that support geographic query, analysis, and visualization
  - A graphical user interface (GUI) for easy access to tools

Spatial Data from REAL WORLD
  - One of the most important but often expensive component
- Trained Personnel
- Methods

Components of GIS



Functional Components of GIS



Functions of GIS

GIS Functions:

To manage and analyze spatial data, a GIS has 6 majors functions.

GIS software must provide the user with the ability to:

- Capture,
- Store,
- Edit or Manipulate,
- Query,
- Analyze,
- and Display

... spatial data

Benefit of GIS

- Cost Savings from Greater Efficiency
- Improved Communication
- Better Decision Making
- Better Record Keeping
- Managing Geographically

http://www.esri.com/what-is-gis

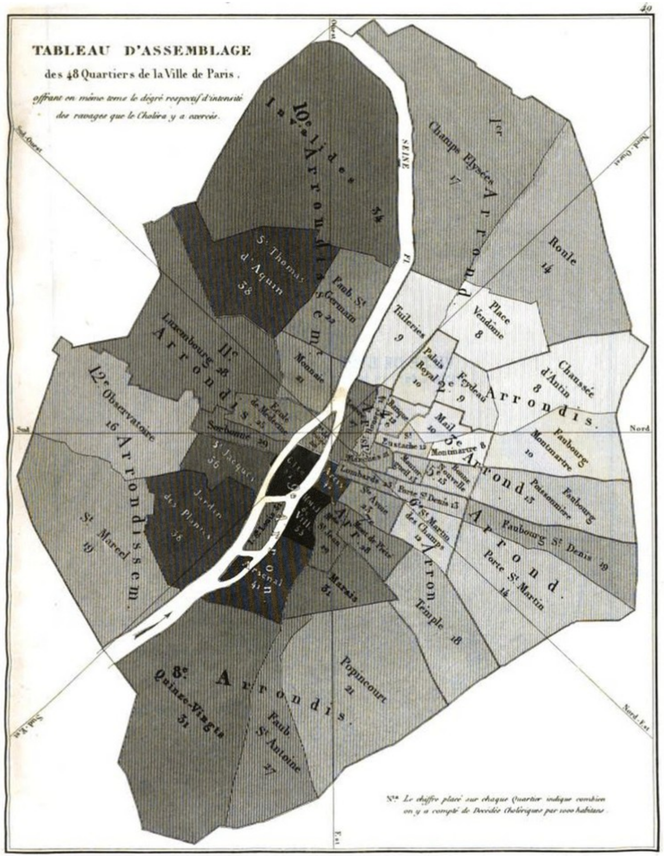
History of GIS

Four distinct phases in the development of GIS

I. early 1960s and the mid 1970s
II. mid 1970s to early 1980s
III. 1982 until the late 1980s
IV. since the late 1980s

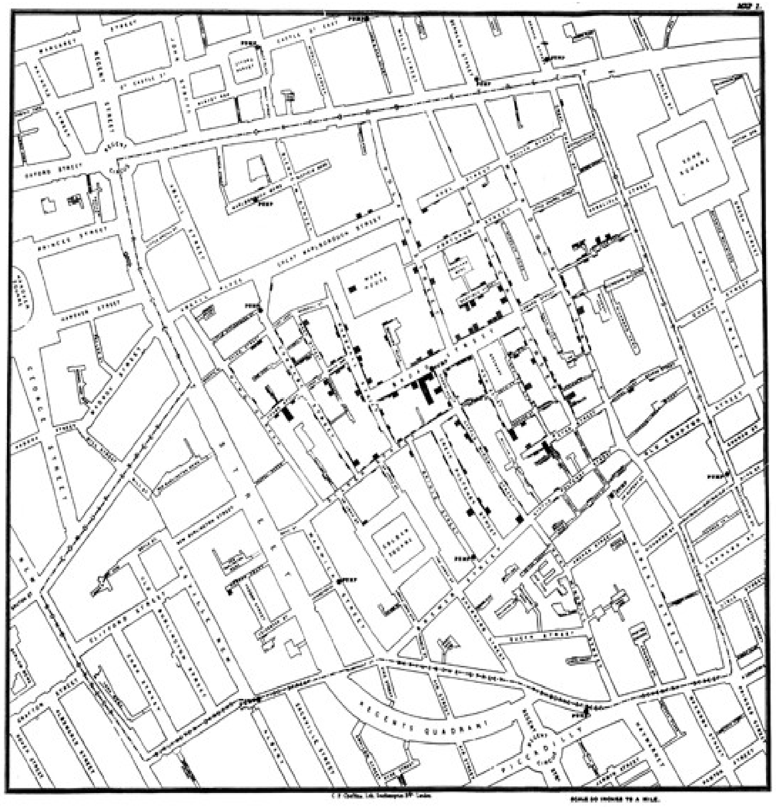
History of GIS- Beginnings of Spatial Analysis

- First documented application *France in 1832*
- French Geographer, Charles Picquet created a map based representation of cholera
- Representing the 48 districts of Paris with different halftone color gradients, an early version of a heat map



History of GIS- Beginnings of Spatial Analysis

- In 1854, John Snow depicting cholera deaths in London using points on a map



History of GIS: the 1960's

- First attempts at computer-based map overlay
- Leader: Canada GIS (CGIS)
  - Goal: to develop land management plans for large areas of rural Canada
  - Factors: forest & mineral resources, wildlife habitats, water resources
  - Hindered by limitations of computers similar to our modern hand calculator!

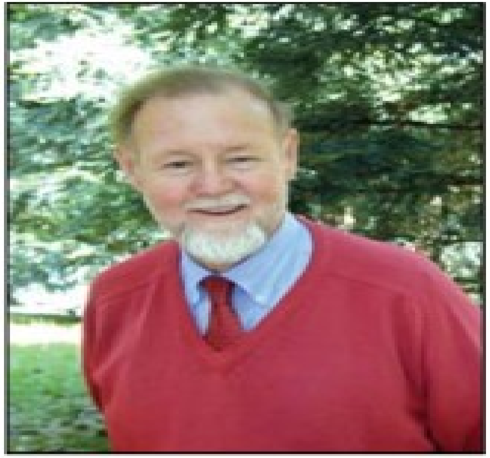
History of GIS: the 1960's

- the **Canadian Geographic Information System** (CGIS) was the first operational GIS

- developed in the early 1960's (era of large mainframe computer systems)

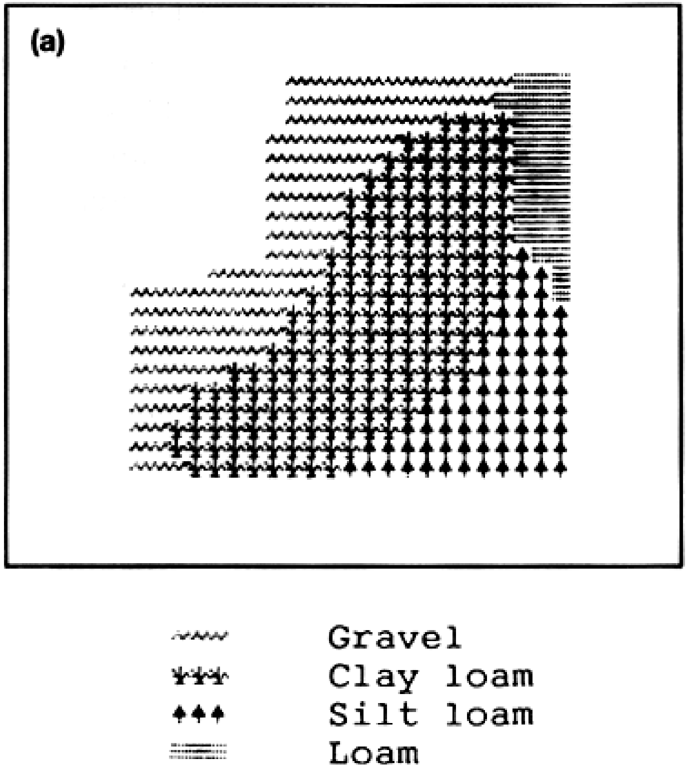
- the system was designed to inventory land use and assist in the management of natural resources in Canada

-Roger Tomlinson is considered the "Father of GIS" for his role in the development of the CGIS



1960's: Academia

- Harvard Laboratories – "SYMAP"
- First real demonstration of computer's ability to make maps
- Aim: produce thematic maps of statistical data depicted in census tracts quickly and cheaply



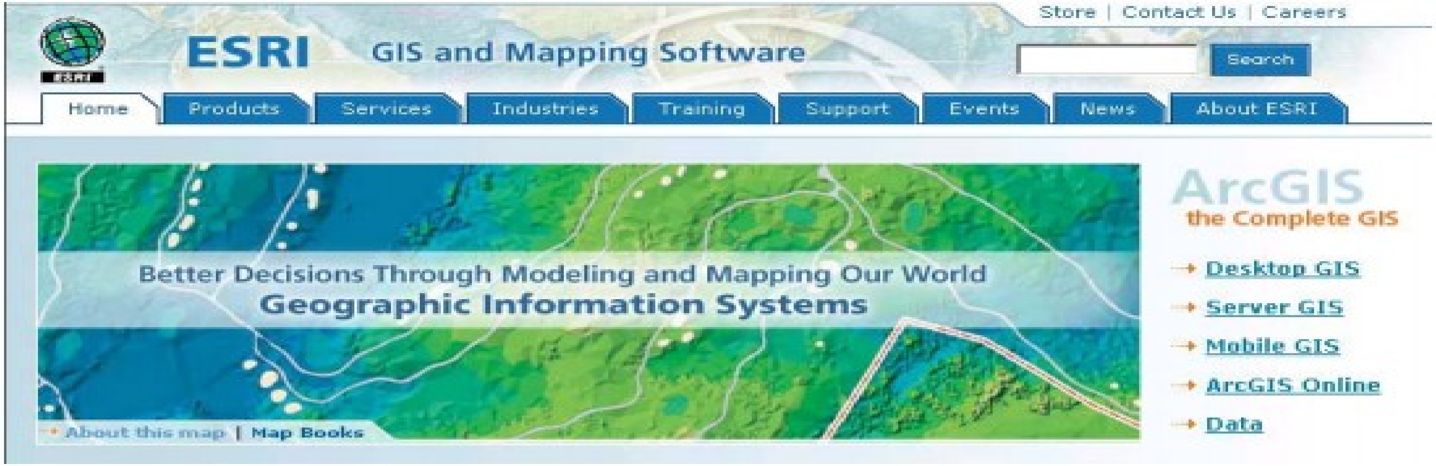
US Government: The Census Bureau

- Goal: Create a digital version of various types of maps
- Functions needed:
  - Comprehensive set of street maps for whole country
  - Analyze and report data at different levels: *Addresses > Blocks > Census tracts*
- 1970 census included a digital map

Industry

- Environmental Systems Research Institute (ESRI)
  - Environmental consulting firm founded in 1969
  - Digital mapping products needed were unavailable, so…
- Intergraph
  - Founded by former IBM Engineer in 1969 as M&S Computing
  - Later renamed to *Intergraph Corporation* in 1980
  - Initially: Computer-Assisted Drafting (CAD) and Computer-Assisted Manufacturing (CAM)

GIS Software



- we use GIS software products developed by Esri
  - original name: Environmental Systems Research Institute
  - then became known as ESRI – now Esri

- Esri is a privately held software company
  - owned by Jack and Laura Dangermond

- headquarters located in Redlands, California
  - regional offices throughout the U.S. and the world

Esri Software History

- prior to the summer of 2001 ESRI had two main software products

1) ARC/INFO

- a professional GIS originally developed in the 1970's

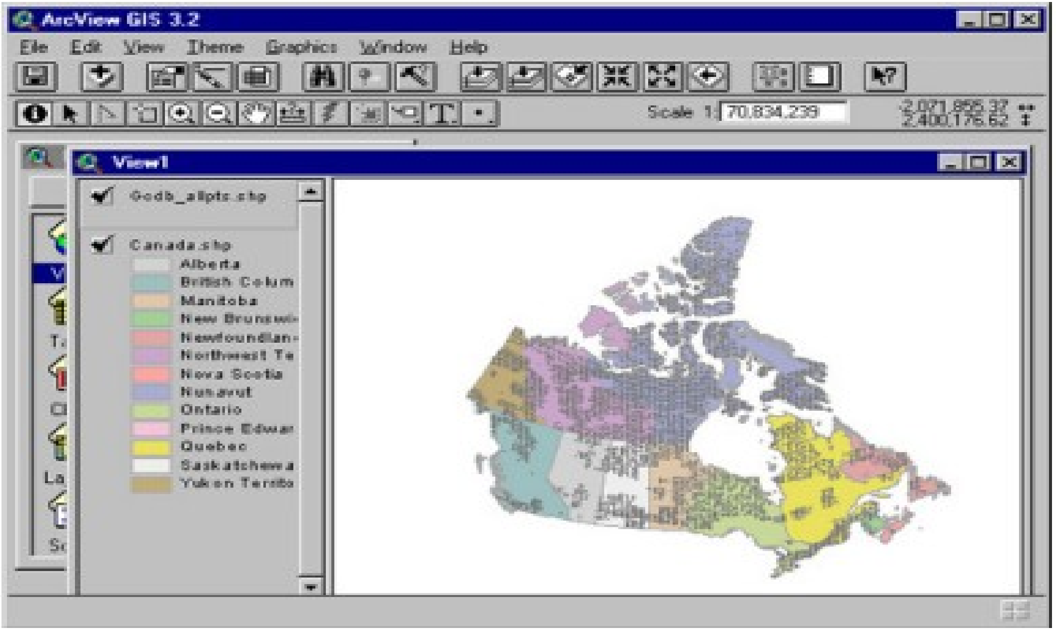
- command-line software package (used DOS) – difficult to use

2) ArcView

- a desktop GIS using Windows - developed in the 1990's

- original version was developed as a viewer for data analyzed in ARC/INFO

- throughout the 1990's ArcView evolved into a powerful desktop GIS



- easy to use
- graphic user interface

Esri Software History

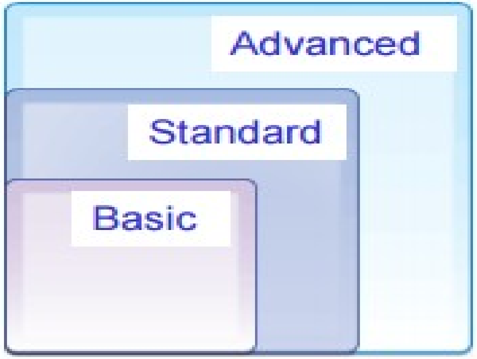
Summer 2001

- ESRI introduced **ArcGIS** (a suite of GIS software programs)

- main advantage is one user interface with all functionality

- ArcGIS 10 consists of two main application programs:
  - <u>ArcMap</u> and <u>ArcCatalog</u>

- can be licensed at three levels with increasing functionality:
  Basic, Standard, and Advanced



- there are also many extensions available to the core ArcGIS software including:
  - Spatial Analyst
  - 3D Analyst
  - Network Analyst
  - Business Analyst, etc

Esri Software History

Summary: **1970s to 2000 Two Separate Programs**

ARC/INFO
- professional GIS

ArcView
- desktop GIS

summer 2001

ArcGIS
- suite of software
- two main application programs inside ArcGIS

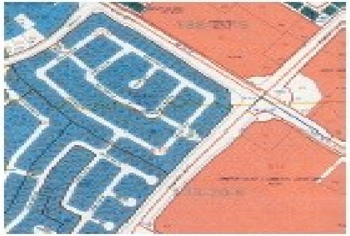
ArcMap
- mapping and analysis

ArcCatalog
- file management

versions of ArcGIS with increasing functionality

	ArcMap	ArcCatalog
Advanced	X	X
Standard	X	X
Basic	X	X

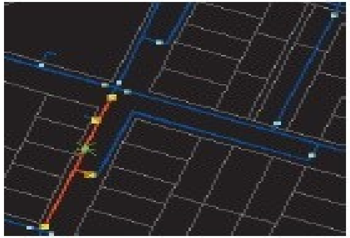
Application area of GIS



A tax assessor's office produces land use maps for appraisers and planners.

An engineering department monitors the condition of roads and bridges and produces planning maps for natural disasters.

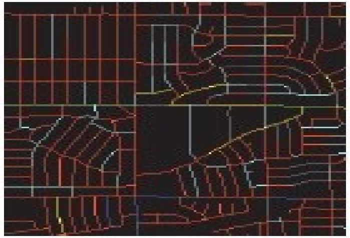
A water department finds the valves to isolate a ruptured water main.



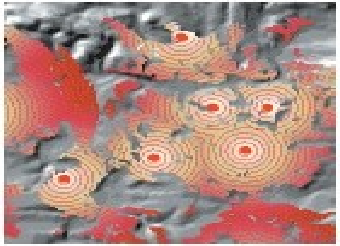
A transit department produces maps of bicycle paths for commuters.

A police department studies crime patterns to intelligently deploy its personnel and to monitor the effectiveness of neighborhood watch programs.

A wastewater department prioritizes areas for repairs after an earthquake.

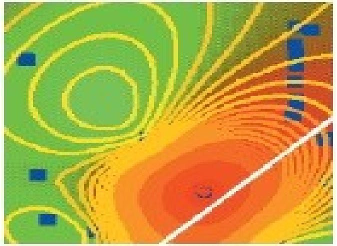


Application area of GIS

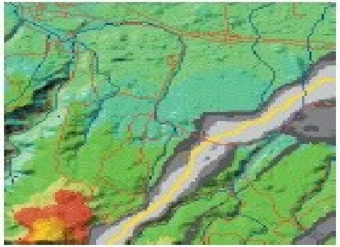


A telecommunication company studies the terrain to find locations for new cell phone antennae.

A hydrologist monitors water quality to protect public health.



A pipeline company finds the least-cost path for a new pipeline.

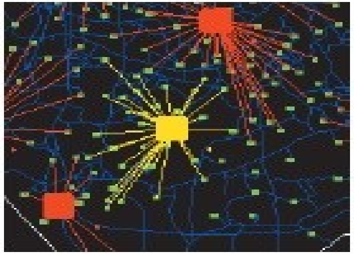


A biologist studies the impact of construction plans on a watershed.

An electric utility models its circuits to minimize power loss and to plan the placement of new devices.

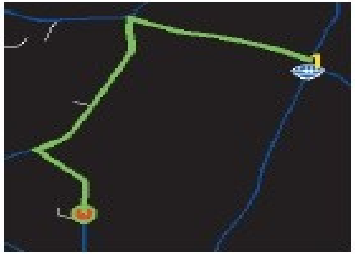
A meteorologist issues warnings for counties in the path of a severe storm.

Application area of GIS

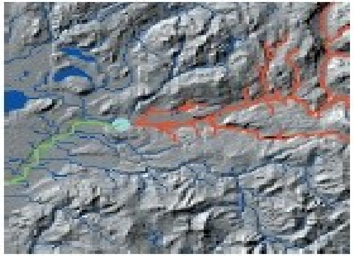


A business evaluates locations for new retail outlets by considering nearby concentrations of customers.

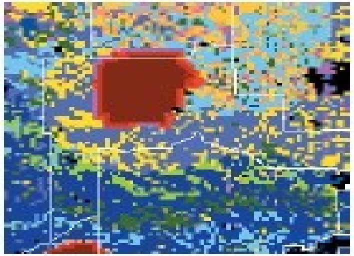
A police dispatcher finds the fastest route to an emergency.



An emergency management agency plans relief facilities by modeling demand and accessibility.



A water resource manager traces upstream to find the possible sources of a contaminant.



A fire fighting team predicts the spread of a forest fire using terrain and weather data.

Digital Mapping Concept

Digital Mapping Concept

Map is a representation usually on a flat surface, of the whole or a part of an area

Virtual Maps vs. Real Maps

- Real Maps - A hard copy or conventional map
- Virtual map - Information that can be converted into a real map, i.e. information on a computer screen, mental images, field information, notes, and remote sensing information.

Digital Mapping Concept

Advantages/Benefits of Maps

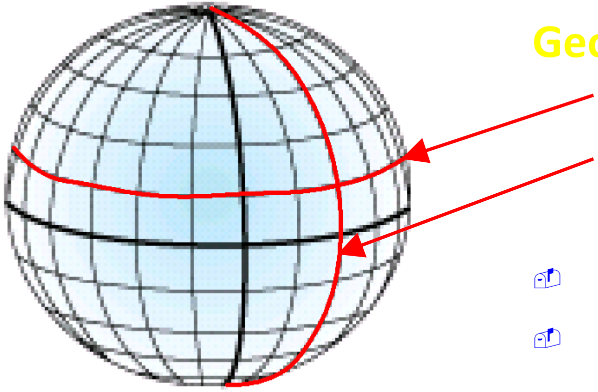
- Way of recording and storing information
- Mean of analyzing distributions and spatial patterns
- Method of presenting information and communication findings

Map Scale and Resolution

- Map scale is the extent of the reduction necessary to put a proportion of the earth's surface on a sheet of paper.
- Resolution refers to how accurately the location and shape of the map features can be depicted for a given map scale

Geographic features/attributes

Geography – The study of where features are located on the Earth's surface.



Geographic coordinate systems

latitude

longitude

- **Represent exact positions on the Earth**
- **27.7172° N, 85.3240° E (lat. long. for Kathmandu)**

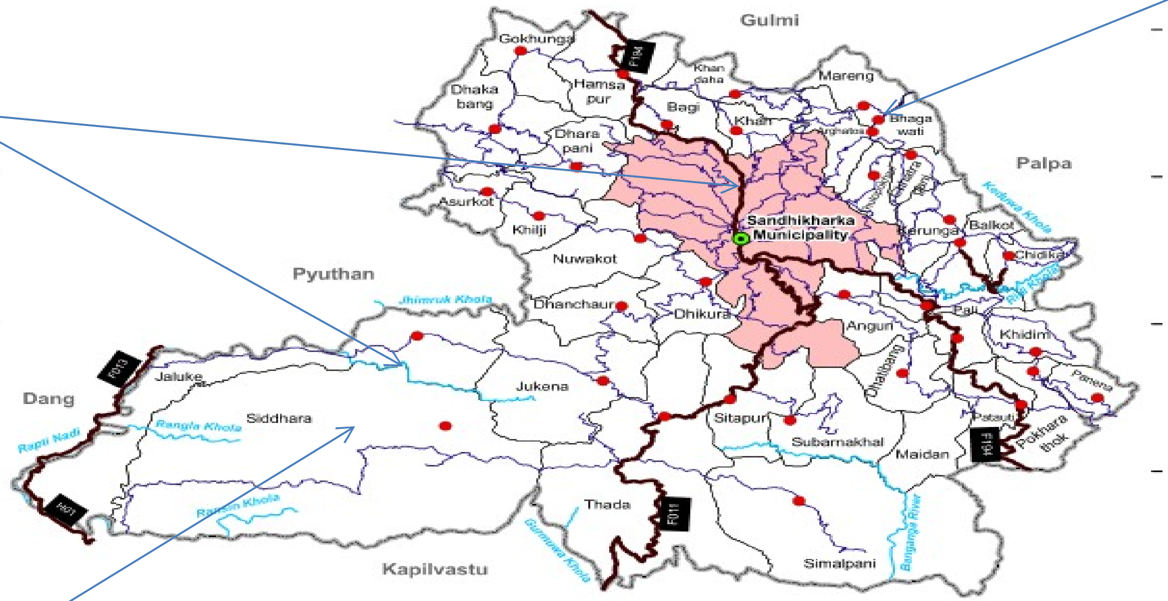
Georeferencing / Geocoding – The process of assigning geographic coordinates to features to represent their location.

Geographic features and attributes

Geographic feature representation: *points, lines, polygons, rasters.*

Points –

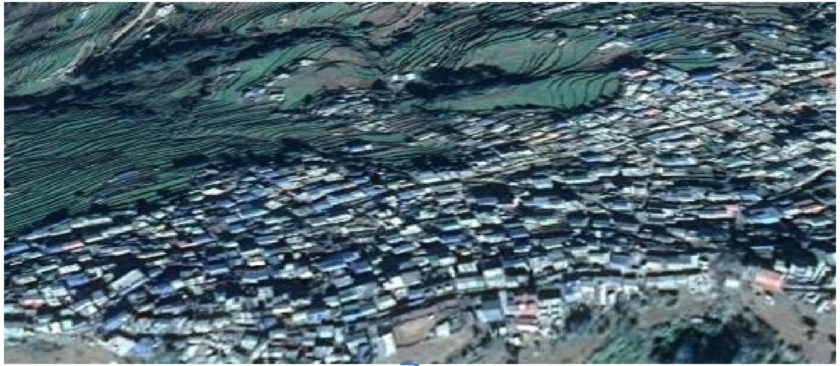
Lines –



Polygons –

Geographic features and attributes

Geographic feature representation: *points, lines, polygons, raster.*



Raster – Barpak, Gorkha Google Image (Pre-EQ, EQ and Post-EQ image)

Geographic features and attributes

Information about the geographic features and non-spatial data – stored in tabular form

Attributes of cities

NAME	ST	POP2000	MED_AGE	FEMALES	MALES
Honolulu	HI	371657	39.7	189029	182628
Juneau	AK	30711	35.3	15242	15469
Boise City	ID	185787	32.8	93773	92014
Olympia	WA	42514	36	22195	20319
Salem	OR	136924	33.6	68172	68752
Carson	NV	52457	38.7	25355	27102
Sacramento	CA	407018	32.8	209234	197784
Phoenix	AZ	1321045	30.7	649285	671760
Salt Lake City	UT	181743	30	89698	92045
Cheyenne	WY	53011	36.6	27141	25870
Denver	CO	554636	33.1	274429	280207
Santa Fe	NM	62203	39.8	32445	29758
Oklahoma City	OK	506132	34	258819	247313
Topeka	KS	122377	36.3	63618	58759
Lincoln	NE	225581	31.3	113220	112361
Des Moines	IA	198682	33.8	102525	96157
Jefferson City	MO	39636	36.5	19307	20329
Little Rock	AR	183133	34.5	96811	86322
Austin	TX	656562	29.6	318993	337569

Record: 0 Show: All Selected Records

Points – U.S. Cities

Attributes of Streets

HWY_TYPE	NAME	SPEED_MPH	ZIP_L	ZIP_R	STATE
I	90	65	02111	02111	Massachusetts
I	90	65	02111	02111	Massachusetts
I	90	65	02111	02111	Massachusetts
I	90	65	02111	02118	Massachusetts
I	90	65	02111	02118	Massachusetts
I	93	65	02111	02111	Massachusetts
I	93	65	02111	02111	Massachusetts
I	93	65	02111	02111	Massachusetts
I	93	65	02111	02111	Massachusetts
I	93	65	02111	02111	Massachusetts

Record: 0 Show: All Selected Records

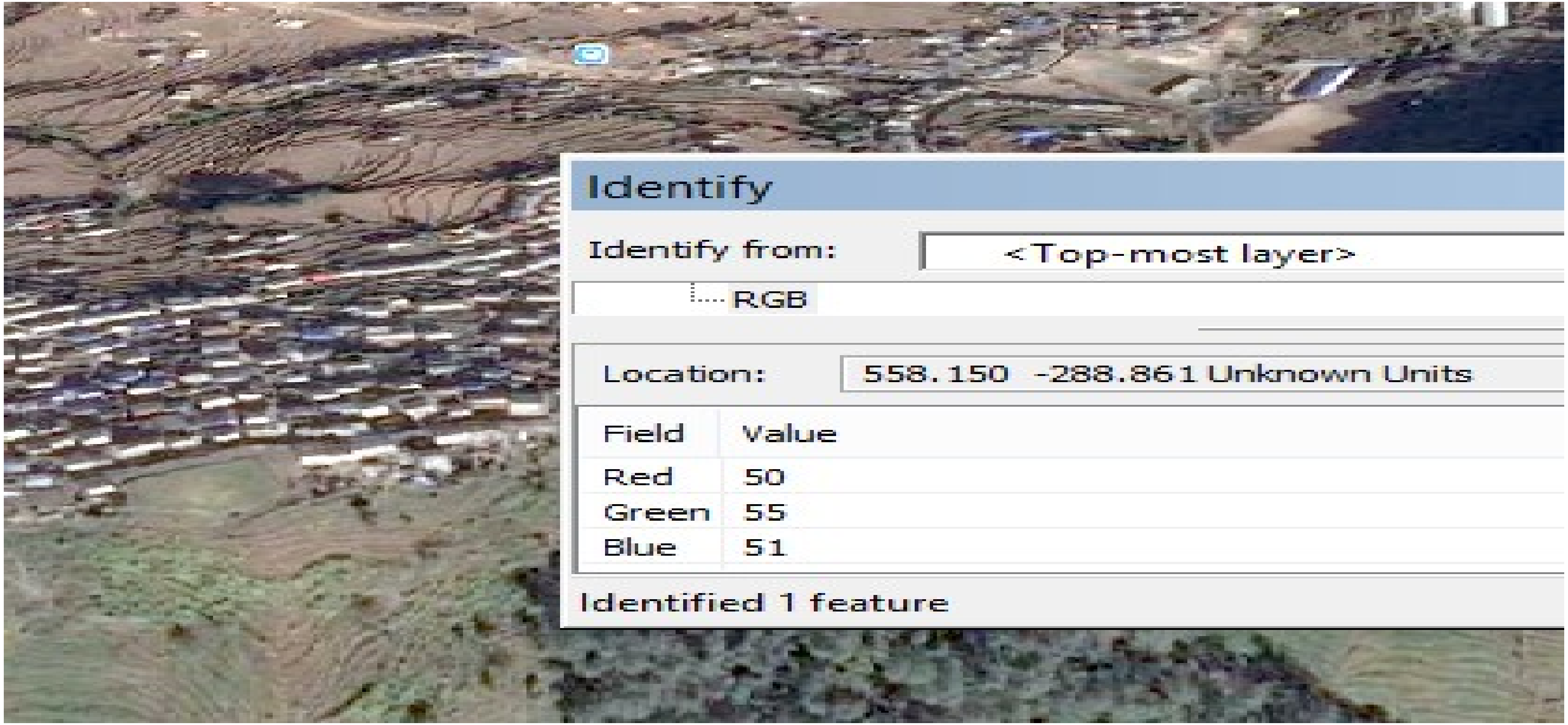
Attributes of states

STATE_NAME	SQMI	POP2000	POP00_SQMI
Hawaii	6381	1211537	190
Washington	67290	5894121	88
Montana	147245	902195	6
Maine	32162	1274923	40
North Dakota	70812	642200	9
South Dakota	77195	754844	10
Wyoming	97803	493782	5
Wisconsin	56088	5363675	96
Idaho	83344	1293953	16
Vermont	9603	608827	63
Minnesota	84520	4919479	58
Oregon	97074	3421399	35
New Hampshire	9260	1235786	133
Iowa	56258	2926324	52
Massachusetts	8173	6349097	777
Nebraska	77330	1711263	22

Record: 0 Show: All

Polygons – U.S. States

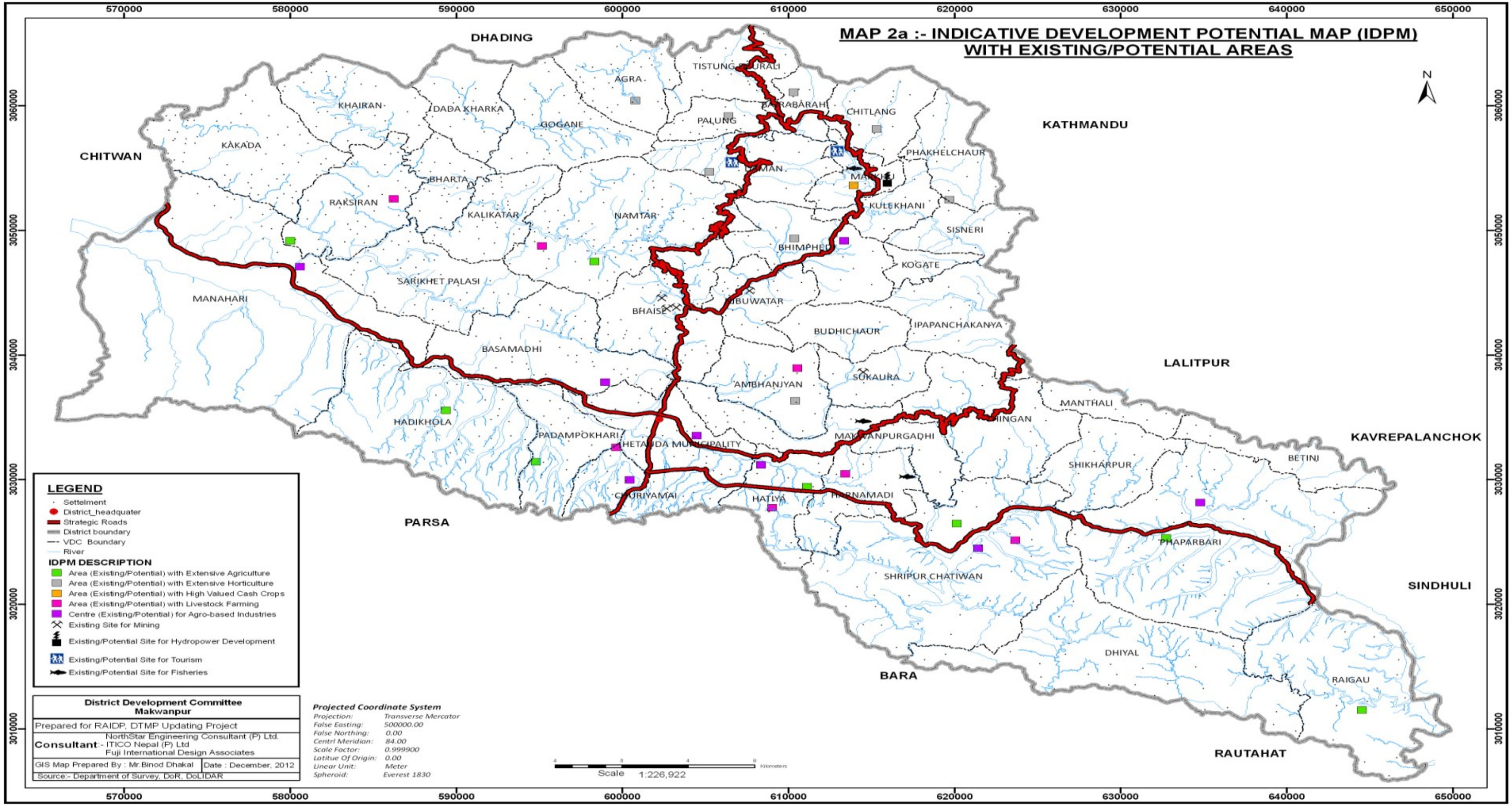
Geographic features and attributes



Raster – Barpak Google image

Map Elements

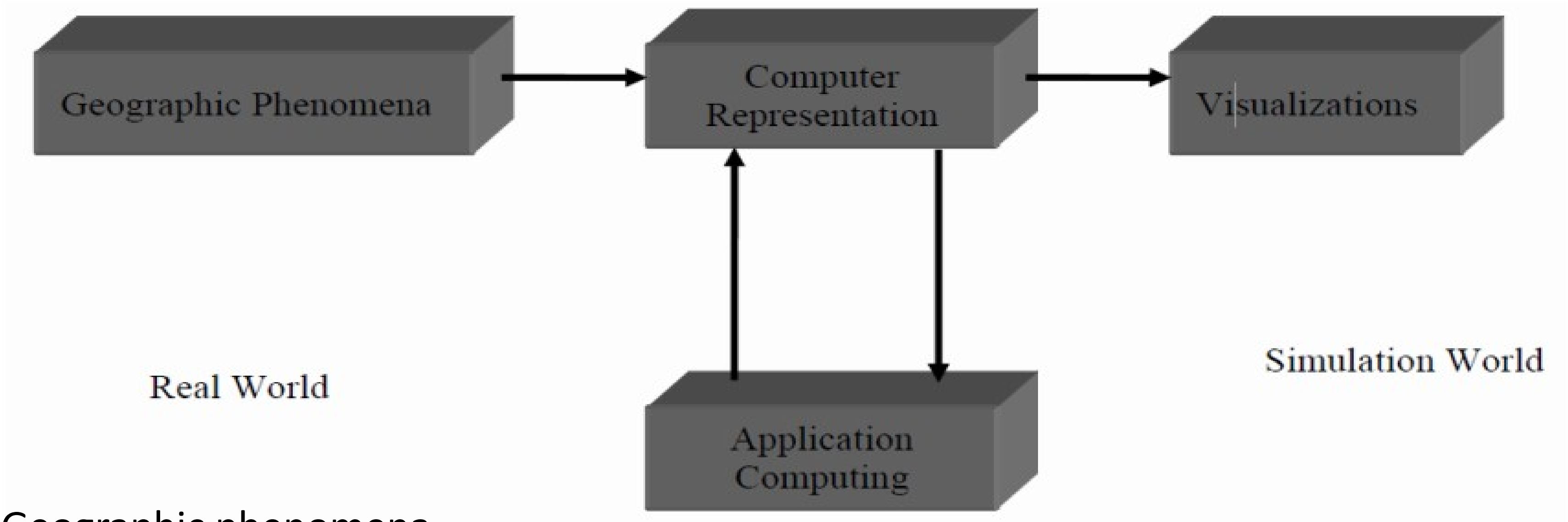
- Data Frame
- Title
- Legend
- Scale
- North Arrow
- Projection System
- Grid
- Source/Citation



MAP 2a :- INDICATIVE DEVELOPMENT POTENTIAL MAP (IDPM)
WITH EXISTING/POTENTIAL AREAS
N
570000
580000
590000
600000
610000
620000
630000
640000
650000
3060000
3050000
3040000
3030000
3020000
3010000
DHADING
CHITWAN
KATHMANDU
LALITPUR
KAVREPALANCHOK
SINDHULI
RAUTAHAT
BARA
PARSA
TISTUNG
AGRA
KHAIRAN
DADA KHARKA
GOGANE
KAKADA
BHARTA
RAKSIRAN
KALIKATAR
NAMTAR
PALUNG
CHITLANG
PHAKHELCHAUR
KULEKHANI
SISNERI
BHIMPHEDI
KOGATE
SARIKHET PALASI
MANAHARI
BHAISE
BUDHICHAUR
BASAMADHI
AMBHANJYAN
SUKAURA
MANTHALI
HADIKHOLA
PADAMPOKHARI
MAKWANPURGADHI
SHIKHARPUR
BETINI
CHURIYAMAI
HATIYA
PHAPARBARI
SHRIPUR CHATIWAN
DHIYAL
RAIGAU
LEGEND
Settlement
District_headquater
Strategic Roads
District boundary
VDC Boundary
River
IDPM DESCRIPTION
Area (Existing/Potential) with Extensive Agriculture
Area (Existing/Potential) with Extensive Horticulture
Area (Existing/Potential) with High Valued Cash Crops
Area (Existing/Potential) with Livestock Farming
Centre (Existing/Potential) for Agro-based Industries
Existing Site for Mining
Existing/Potential Site for Hydropower Development
Existing/Potential Site for Tourism
Existing/Potential Site for Fisheries
District Development Committee
Makwanpur
Prepared for RAIDP, DTMP Updating Project
Consultant :- NorthStar Engineering Consultant (P) Ltd.
ITICO Nepal (P) Ltd
Fuji International Design Associates
GIS Map Prepared By : Mr.Binod Dhakal
Date : December, 2012
Source:- Department of Survey, DoR, DoLIDAR
Projected Coordinate System
Projection: Transverse Mercator
False Easting: 500000.00
False Northing: 0.00
Centrl Meridian: 84.00
Scale Factor: 0.999900
Latitue Of Origin: 0.00
Linear Unit: Meter
Spheroid: Everest 1830
Scale 1:226,922
Kilometers

Geographic Phenomena and Spatial Modeling

Store spatial data in computer-virtual maps



Geographic phenomena exist in the real world

Geographic Phenomena and Spatial Modeling

- Geographic fields
  - a geographic phenomena for which for every point in the study area, a value can be measured
  - temperature, barometric pressure and elevation are **Continuous geographic field**
  - Administrative boundary, land use and soil classification are **discrete field**

Geographic Phenomena and Spatial Modeling

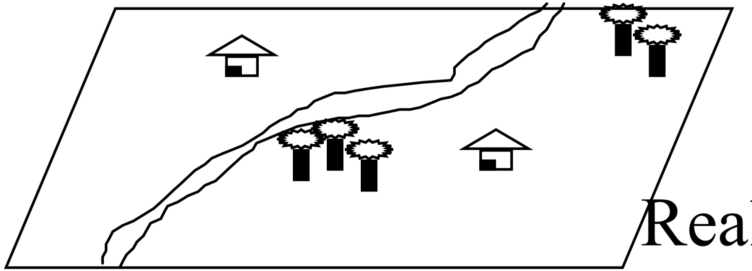
- **Geographic objects** - is a geographic phenomena do not spread themselves everywhere in the study area, but only in certain localities
- In general, **natural geographic phenomena are more often fields**, and **man-made phenomena are more often objects.**

Spatial Data Model

Concept of Vector and Raster data

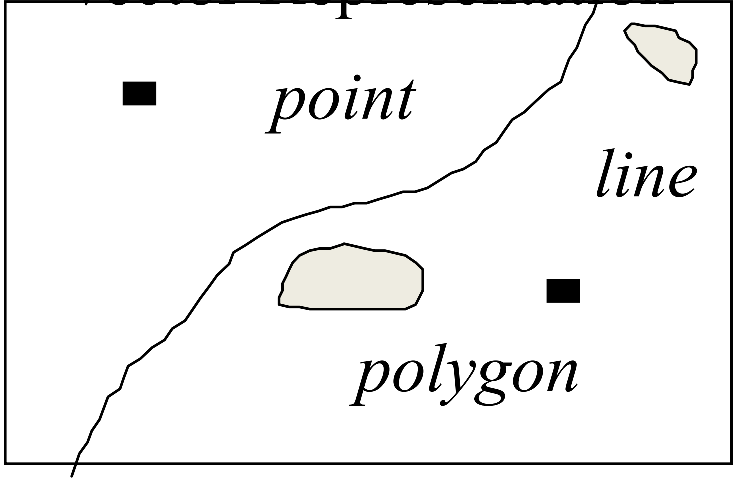
Raster Representation

	0	1	2	3	4	5	6	7	8	9
0								R	T	
1							R			T
2		H					R			
3							R			
4					R	R				
5				R						
6			R		T	T		H		
7			R		T	T				
8		R								
9		R								



Real World

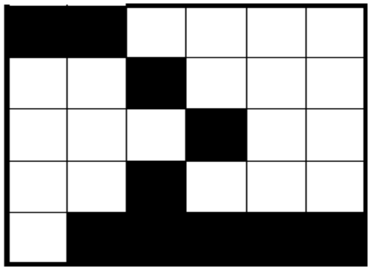
Vector Representation



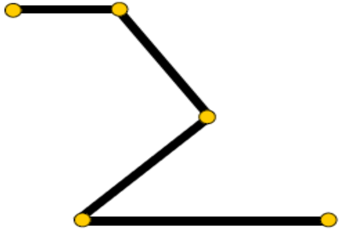
Spatial Data Model

⌘ How should discrete objects be coded?

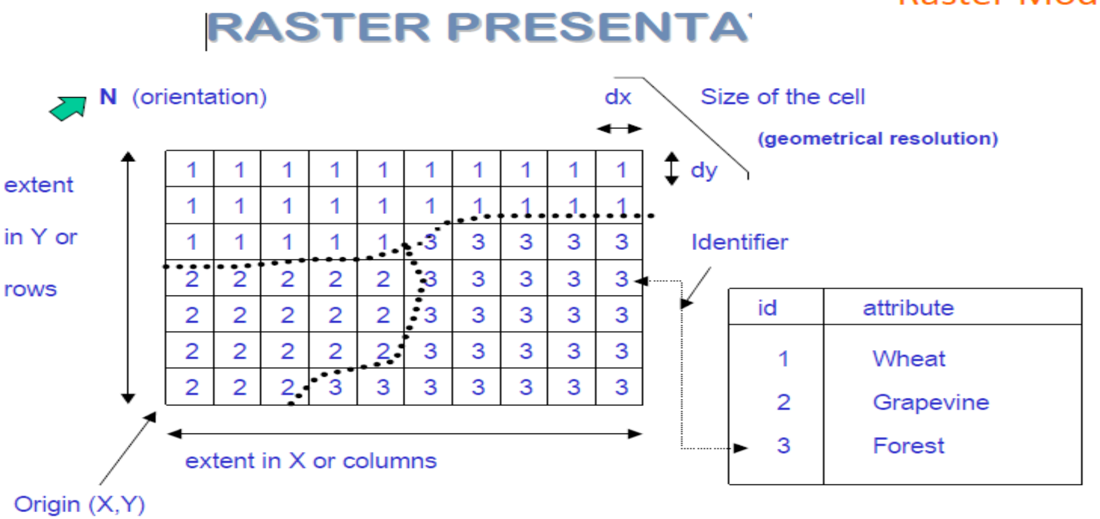
- Vector Data Model
- Raster Data Model



Raster Model



Vector Model



Spatial Data Model

Simple Vector Data Structure

Vector Line

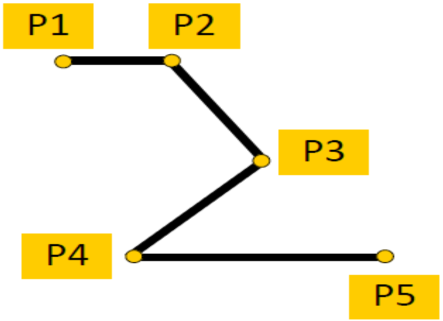


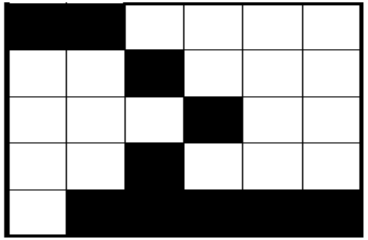
Table of Points

ID	X	Y
P1	503200	3200522
P2	503250	3200522
P3	503300	3200460
P4	503245	3200410
P5	503350	3200410

(in UTM coordinates)

Simple Raster Data Structure:

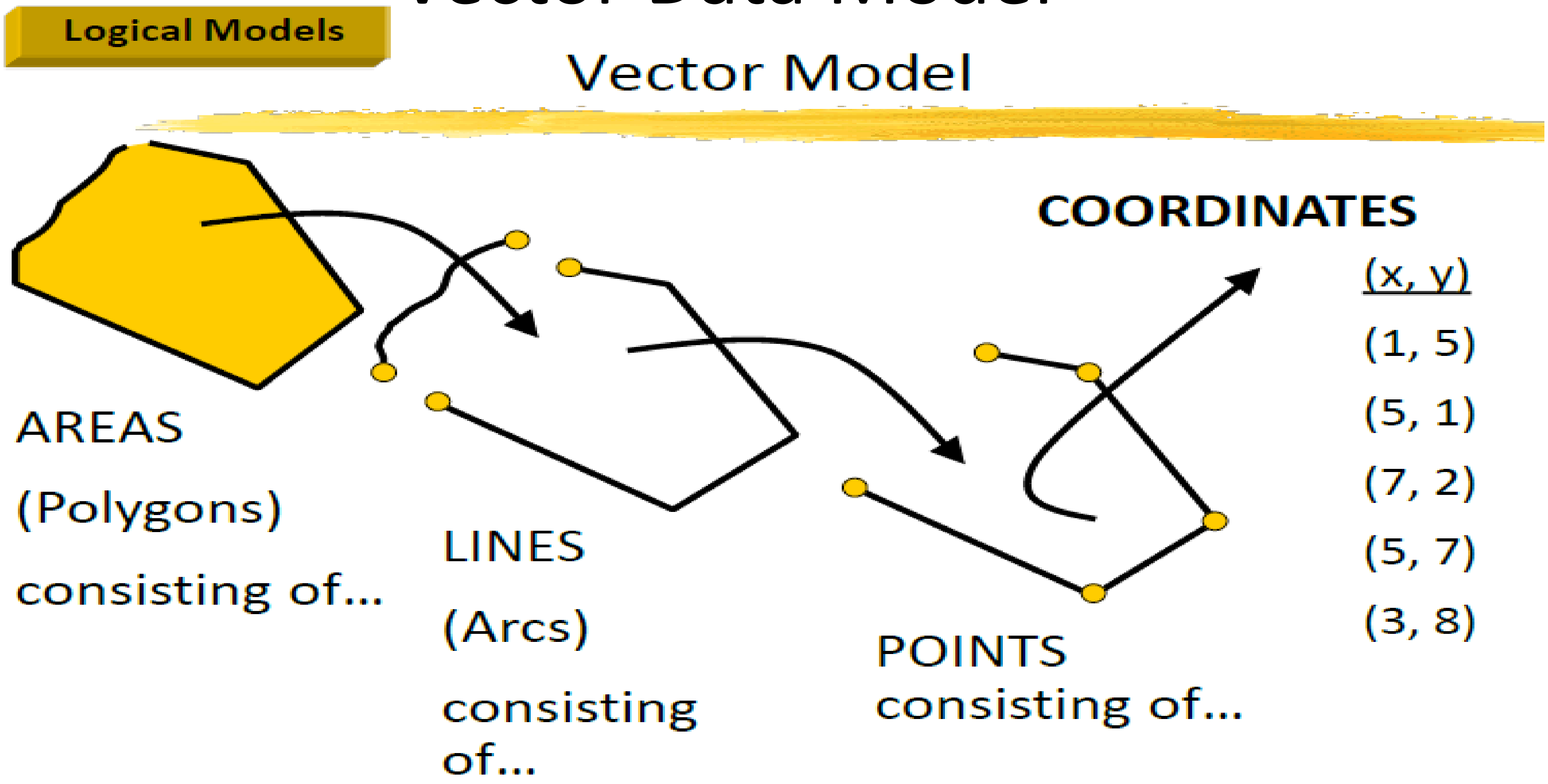
Raster Line



Equivalent Binary Flat File

```
1 1 0 0 0 0
0 0 1 0 0 0
0 0 0 1 0 0
0 0 1 0 0 0
0 1 1 1 1 1
```

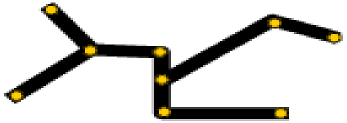
Vector Data Model



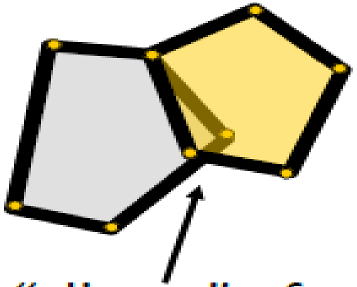
Vector Data Model

“Graphical” Vector Model

- Lines have arbitrary beginning and end, like spaghetti on a plate



- Common lines between adjacent polygons duplicated



  - Can leads to “slivers” of unassigned area = “sliver polygons”

Vector Data Model

Topological Vector Model

- Store pts. as x,y geographic coordinates
- Store lines as paths of connected pts.
- Store polygons as closed paths

Also explicitly store ....

- Where lines start and end (connectivity)
- Which polygons are to the right and left side of a common line (adjacency)

Components of Topology

Three basic components

- Connectivity (Arc – Node Topology):
  - Points along an arc that define its shape are called Vertices.
  - Endpoints of the arc are called Nodes.
  - Arcs join only at the Nodes.
- Area Definition / Containment (Polygon – Arc Topology):
  - An enclosed polygon has a measurable area.
  - Lists of arcs define boundaries and closed areas are maintained.
  - Polygons are represented as a series of (x, y) coordinates that connect to define an area.

Components of Topology

- Contiguity:
  - Every arc has a direction
  - A GIS maintains a list of Polygons on the left and right side of each arc.
  - The computer then uses this information to determine which features are next to one another.

Vector Data Model

Lines: Arc-Node Topology

Vertex Table

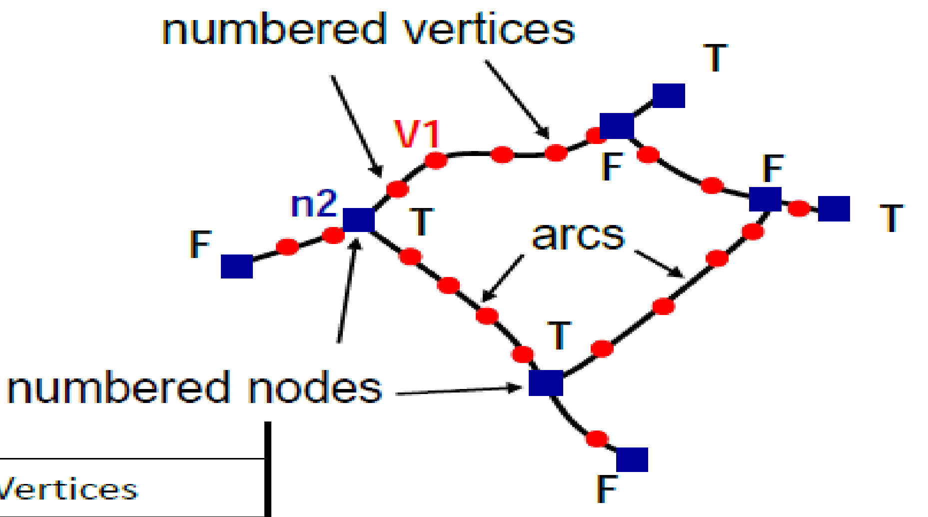
ID	x	y
1	0	0
.	.	.
.	.	.
19	3	5

Node Table

ID	x	y
1	0	0
.	.	.
.	.	.
8	3	5

Arc Table

ID	FID	F Node	T Node	Vertices
1	100	1	2	1, 2
2	102	3	2	3, 4, 5, 6, 7
3	103	3	4	null



F ="Start" node (F: "From" node)

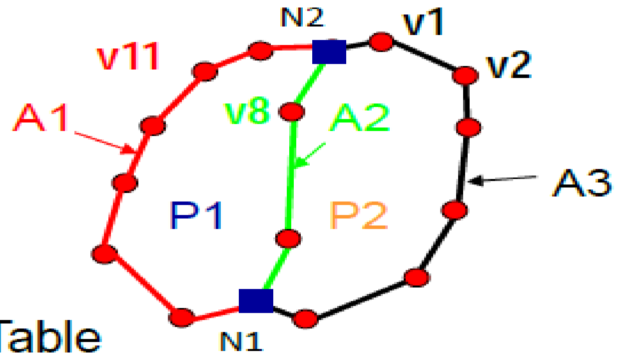
T = "End" node or (T: "To" node)

Vector Data Model

Polygons: Polygon-Arc Topology

Arc Table

Arc ID	L. Poly	R. Poly	F Node	T Node
A1	World	P1	N1	N2
A2	P1	P2	N2	N1
A3	P2	World	N2	N1



Polygon Table

Poly ID	FID	Arcs.
P1	100	A1, A2
P2	102	A2, A3

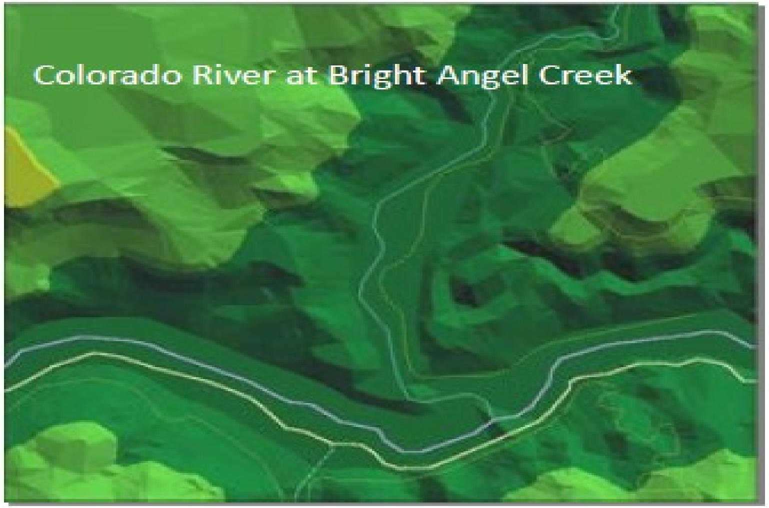
Arc Coordinates Table

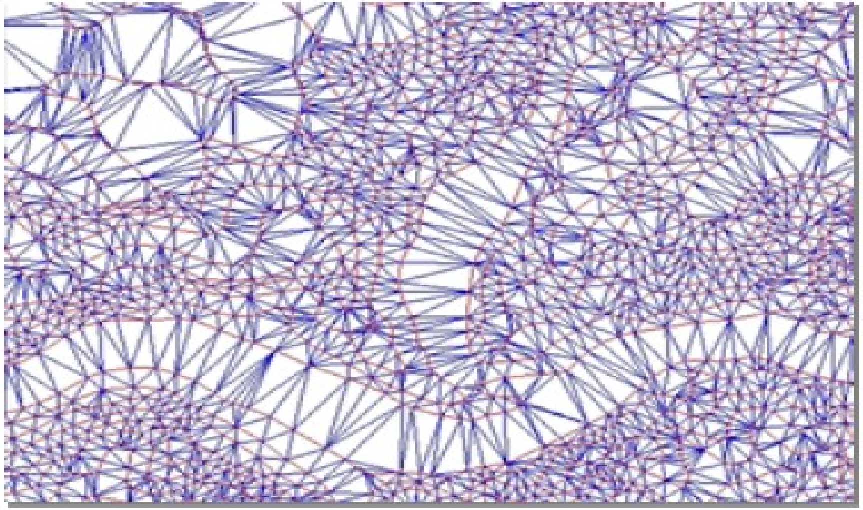
Arc	Start	Vertices	End
A1	N1	v7, …,v11, …	N2
A2	N2	…, v8	N1
A3	N2	v1, v2, …,v6	N1

Vector Data Model

Triangulated Irregular Network -TIN

- Topological 3-D model for representing continuous surfaces using a tessellation of triangles

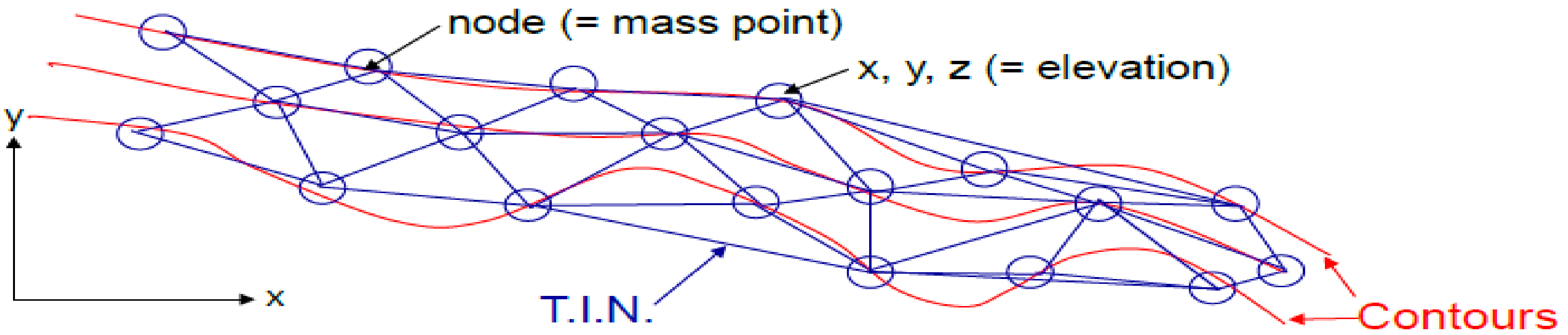




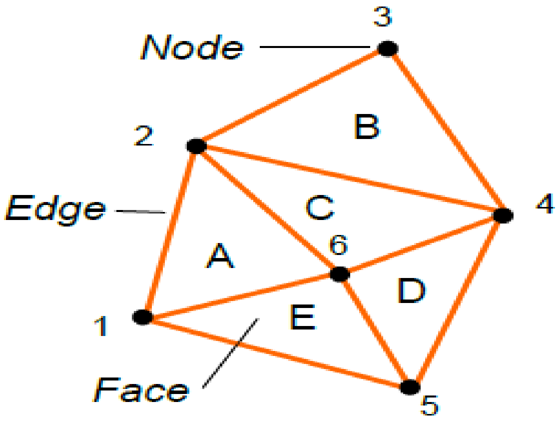
Vector Data Model

Triangular Irregular Network

- Network of interlocking triangles from irregularly spaced points with x, y and z values
- Density of triangles varies with density of data points (e.g. spacing of contours) - c.f. raster with uniform data density
- Triangle sides are constructed by connecting adjacent points so that the minimum angle of each triangle is maximized
- Can render faces, calculate slope, aspect, surface shade, hidden-line removal, etc.



Vector Data Model
TIN Topology



Node Table

Node	x	y	z
1	3	5	5
2	5	9	12
3	11	12	16
4	15	5	3
5	13	3	44
6	10	7	50

Node Elevations

Tin Topology Table

Triangle	Node list	Neighbors
A	1, 2, 6	-, C, E
B	2, 3, 4	-, -, C
C	2, 4, 6	B, D, A
D	4, 5, 6	E, C, -
E	5, 1, 6	A, C, D

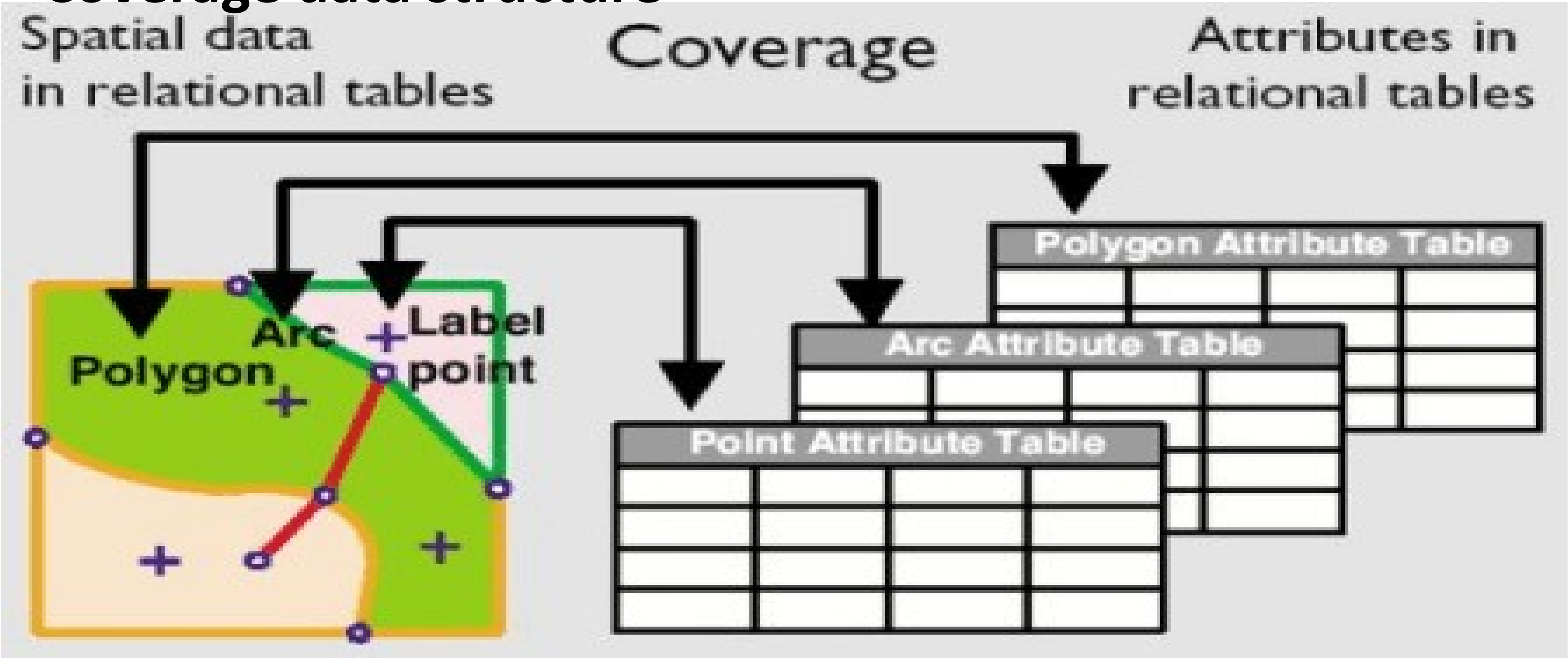
After Zeiler, Modeling our World, p. 165

Topology in different GIS Format

- **Coverage**
  - is a topology based vector data format and can be a point coverage, line coverage, or polygon coverage
- The coverage model supports three basic topological relationships.
  - Connectivity: Arc connects to each other at nodes
  - Area definition: An Area is defined by a series of connected arcs
  - Contiguity: Arcs have directions and left and right polygon.

Topology in different GIS Format

Coverage data structure



Topology in different GIS Format

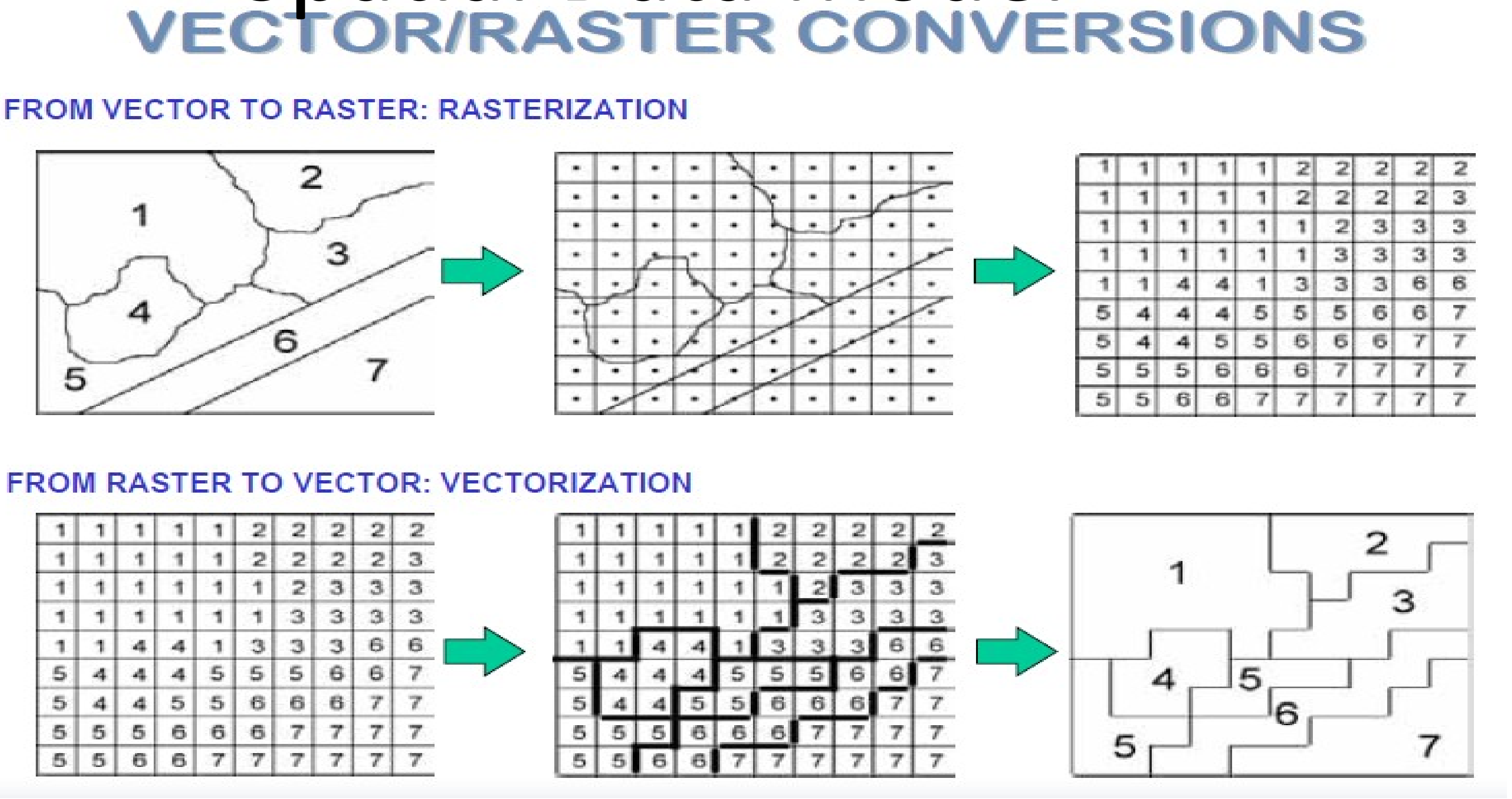
Shapefile

- is a standard non topological data format and is a digital vector storage format for storing geometric location and associated attribute information
- A Shapefile is actually a set of several files
  - .shp — shape format; the feature geometry itself
  - .shx — shape index format; a positional index of the feature geometry to allow seeking forwards and backwards quickly
  - .dbf — attribute format; columnar attributes for each shape, in dBase III format
  - .prj — projection format; the coordinate system and projection information, a plain text file describing the projection using well-known text format
  - .sbn- This is a binary spatial index file, which is used only by ESRI software
  - .sbx — a spatial index of the features
  - .shp.xml — metadata in XML format

Topology in different GIS Format

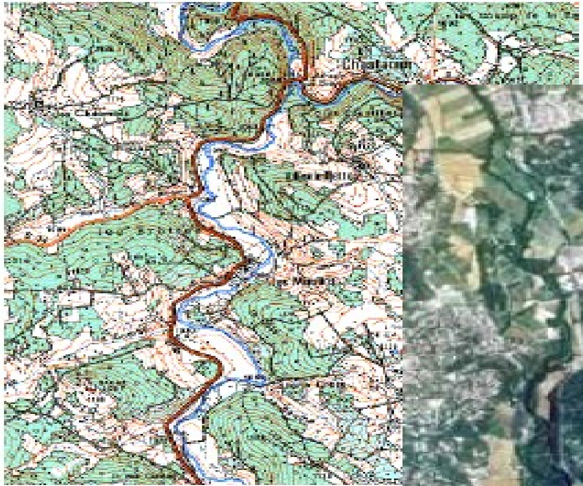
- **DXF (Drawing exchange format)**
  - It maintains data in separate layers. But it does not support topology. It is AutoCAD format
- **Geodatabase**
  - A geodatabase is a relational database that store geographic information
  - It is Object-oriented model

Spatial Data Model



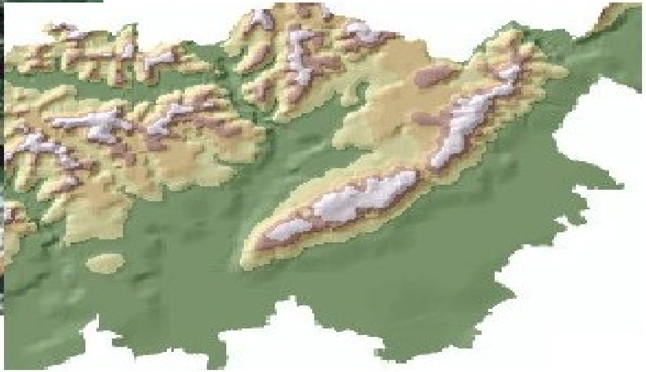
Spatial Data Model

RASTER REPRESENTATION: IMAGE DATA



Map (scanned)

Orthophotography



Digital Elevation Model

Geospatial data analysis- Vector Data analysis

Usually involves manipulations or calculation of coordinates or attribute variables with a various operators (tools), such as:

Overlay
Measurement
Queries & Selection
Reclassification
Buffering
Network Analysis

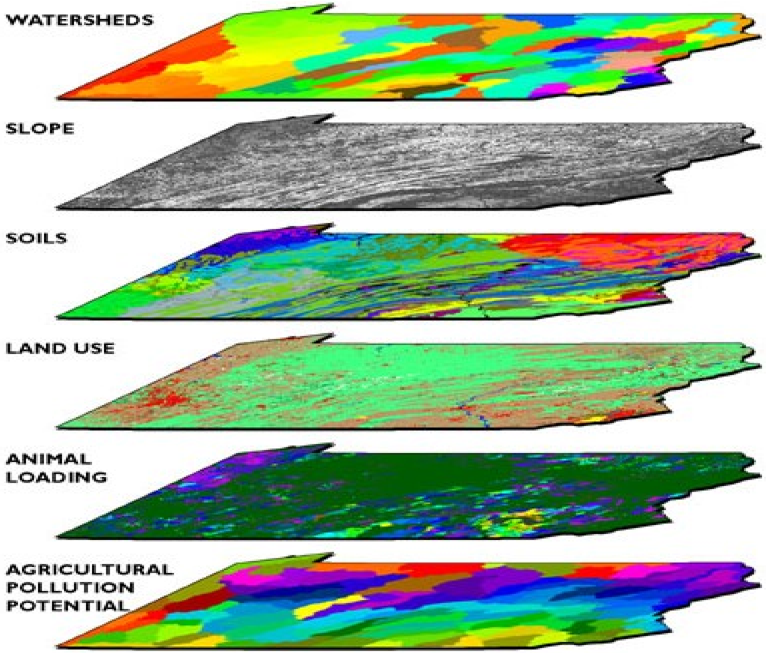
Overlay Operations

Overlay

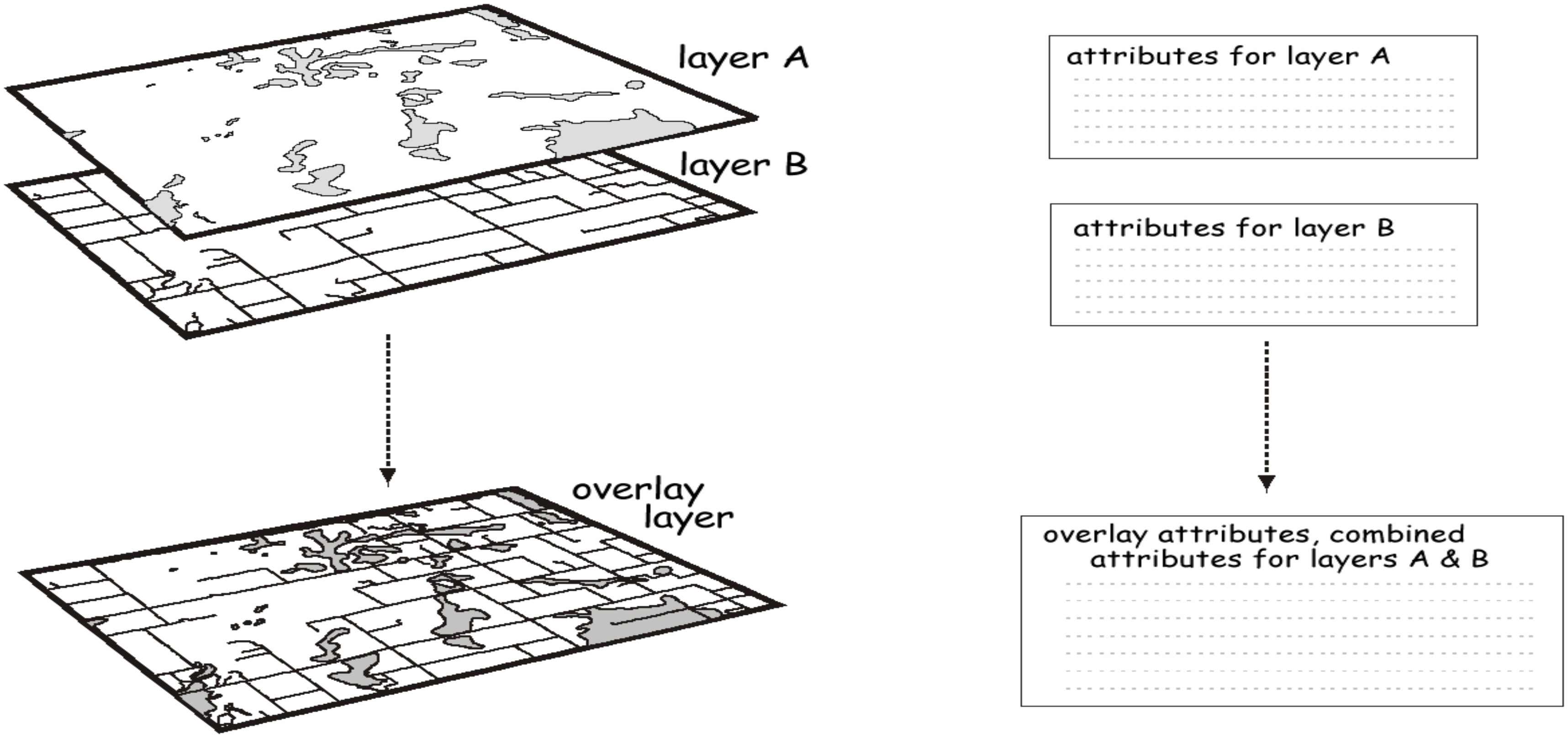
Combination of different data layers
Both spatial and attribute data is combined

Requires that data layers use a commo coordinate system

A new data layer is created



Overlay Operations



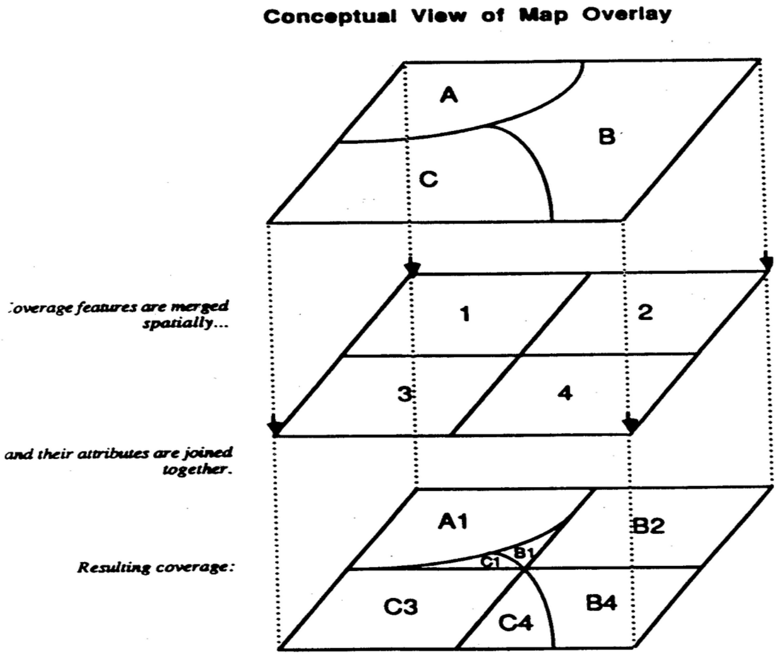
Vector Overlay

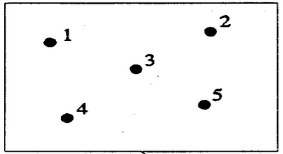
- Topology is likely to be different
- Vector overlays often identify line intersection points automatically.
- Intersecting lines are split and a node placed at the intersection point
- Topology must be recreated for later processing

Any type of vector may be overlain with any other type
Output typically takes the <u>lowest</u> dimension of the inputs

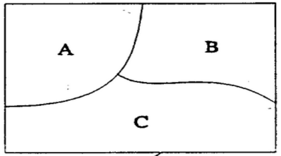
For example: Point on Polygon results in a point

Overlay Operations

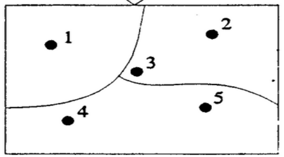




ID	Owner
1	Dickinson
2	Murray
3	Smith
4	McBran
5	Harris



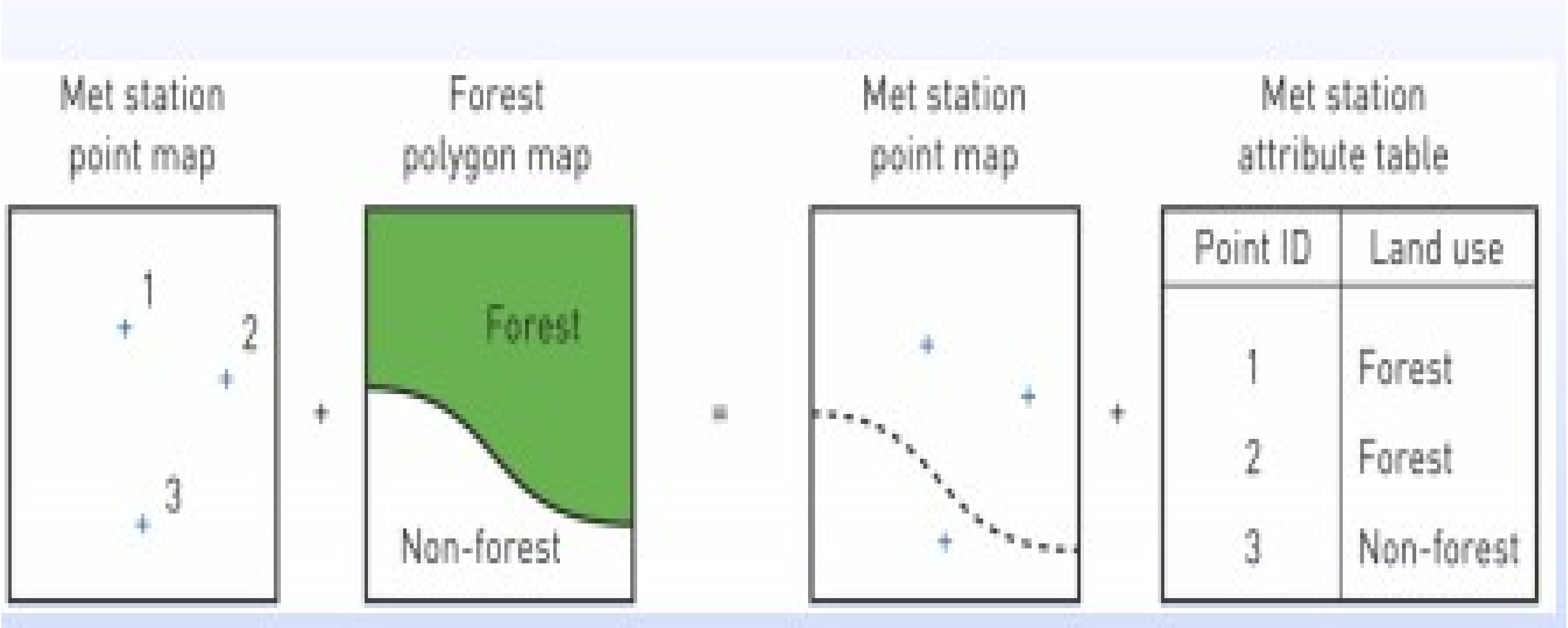
ID	County
A	Black
B	Cole
C	Fall



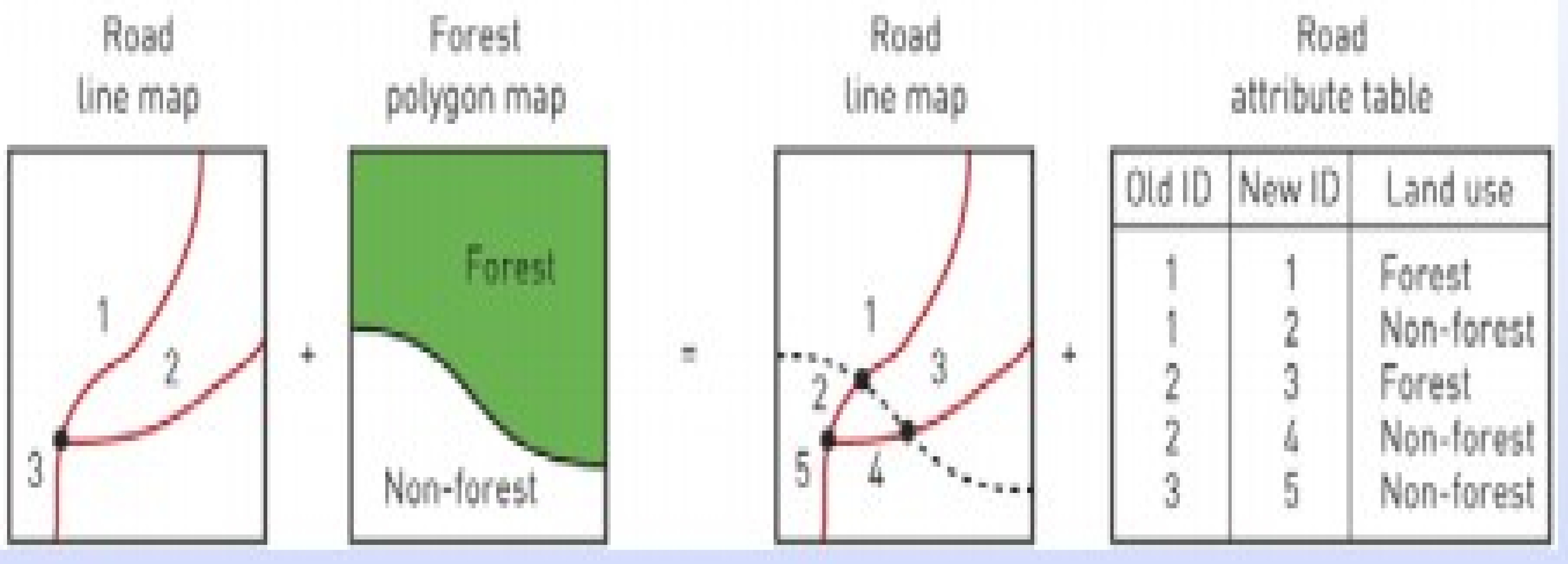
ID	County	Owner
1	Black	Dickinson
2	Cole	Murray
3	Cole	Smith
4	Fall	McBran
5	Fall	Harris

Overlay - Point in Polygon

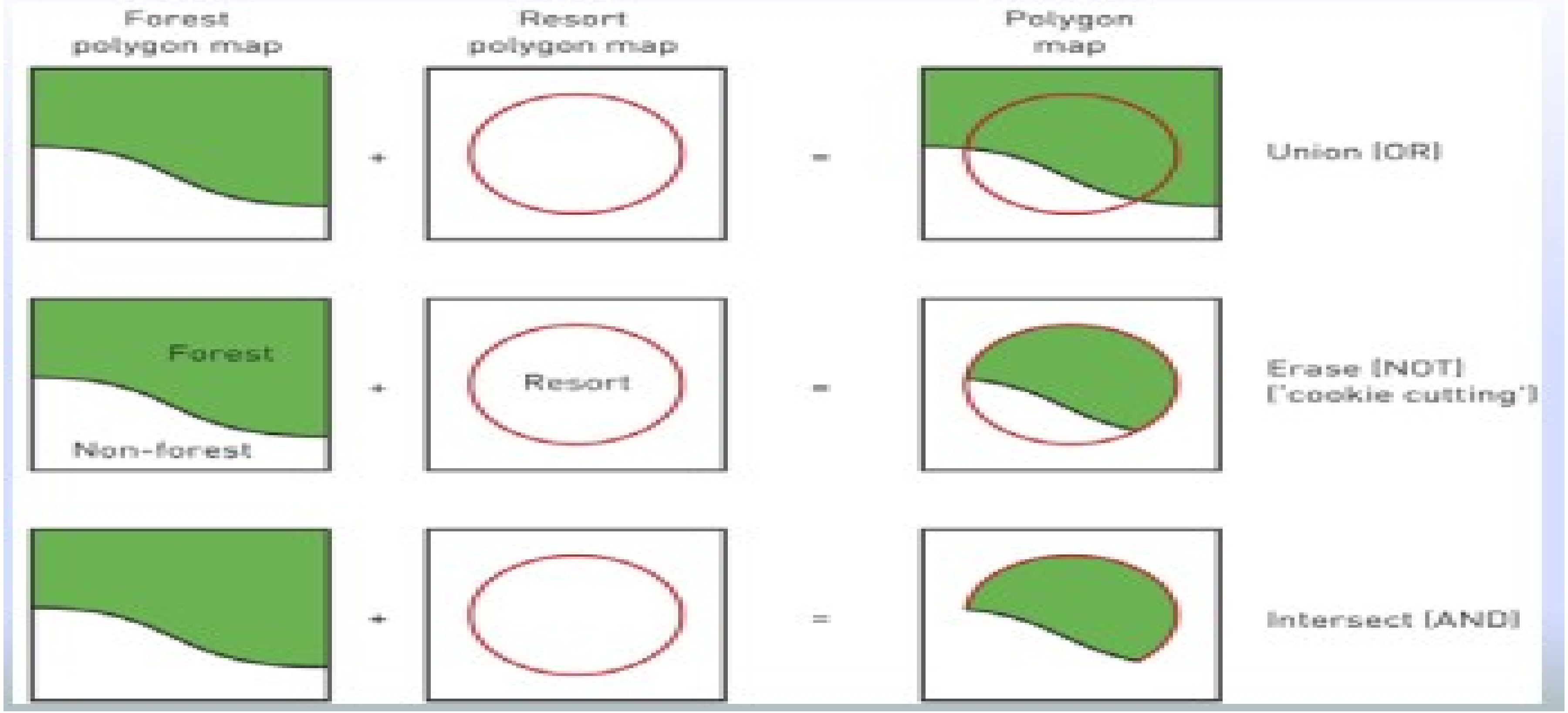
Overlay Operations- Point on Polygon



Overlay Operations- Line in Polygon

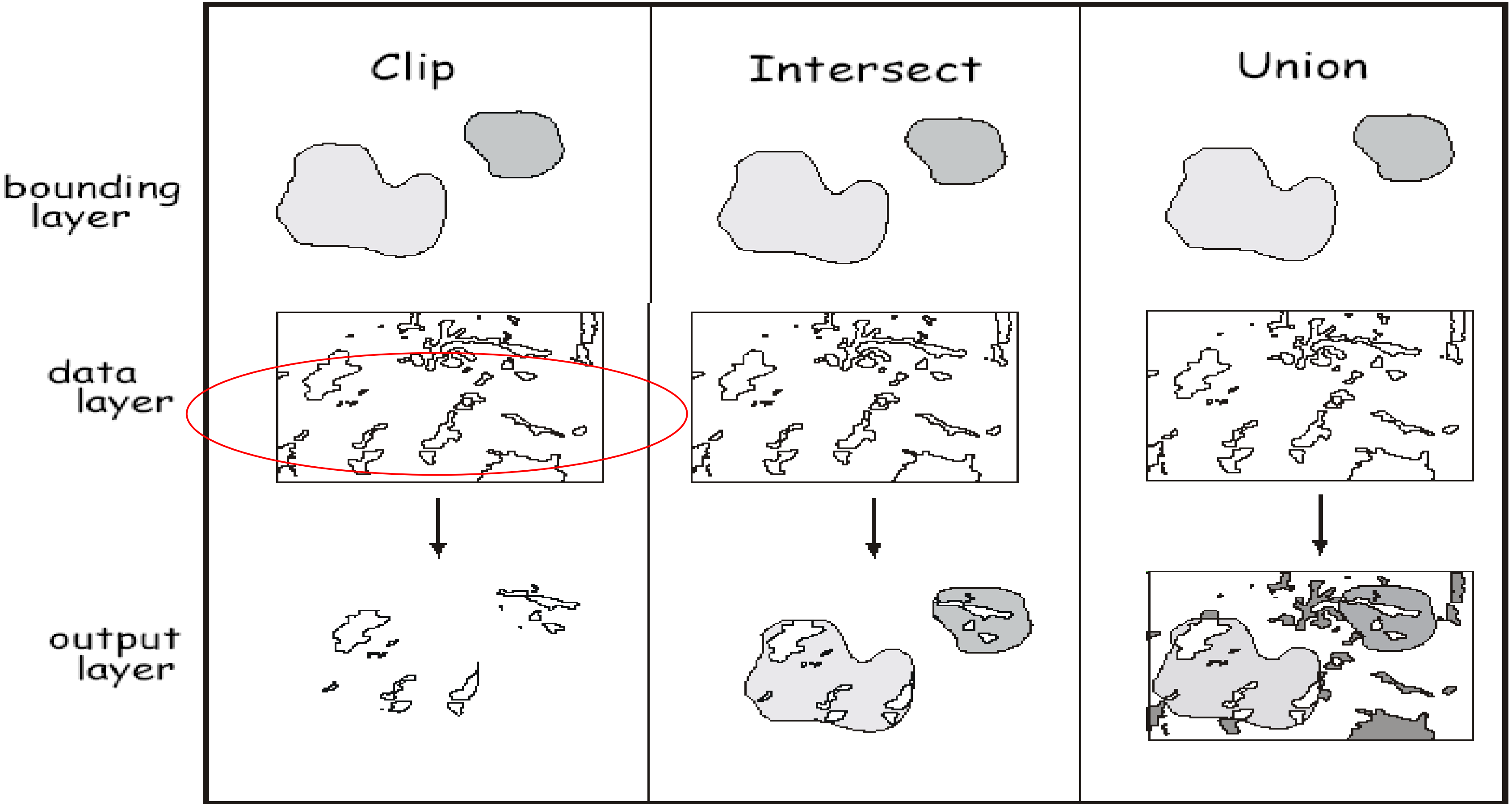


Overlay Operations- Polygon in Polygon



Basic Cases of Overlay - Clip

- Cookie cutter approach
- Bounding polygon defines the clipped second layer
- Neither the bounding polygon attributes nor geographic (spatial data) are included in the output layer


Clip
Intersect
Union
bounding layer
data layer
output layer

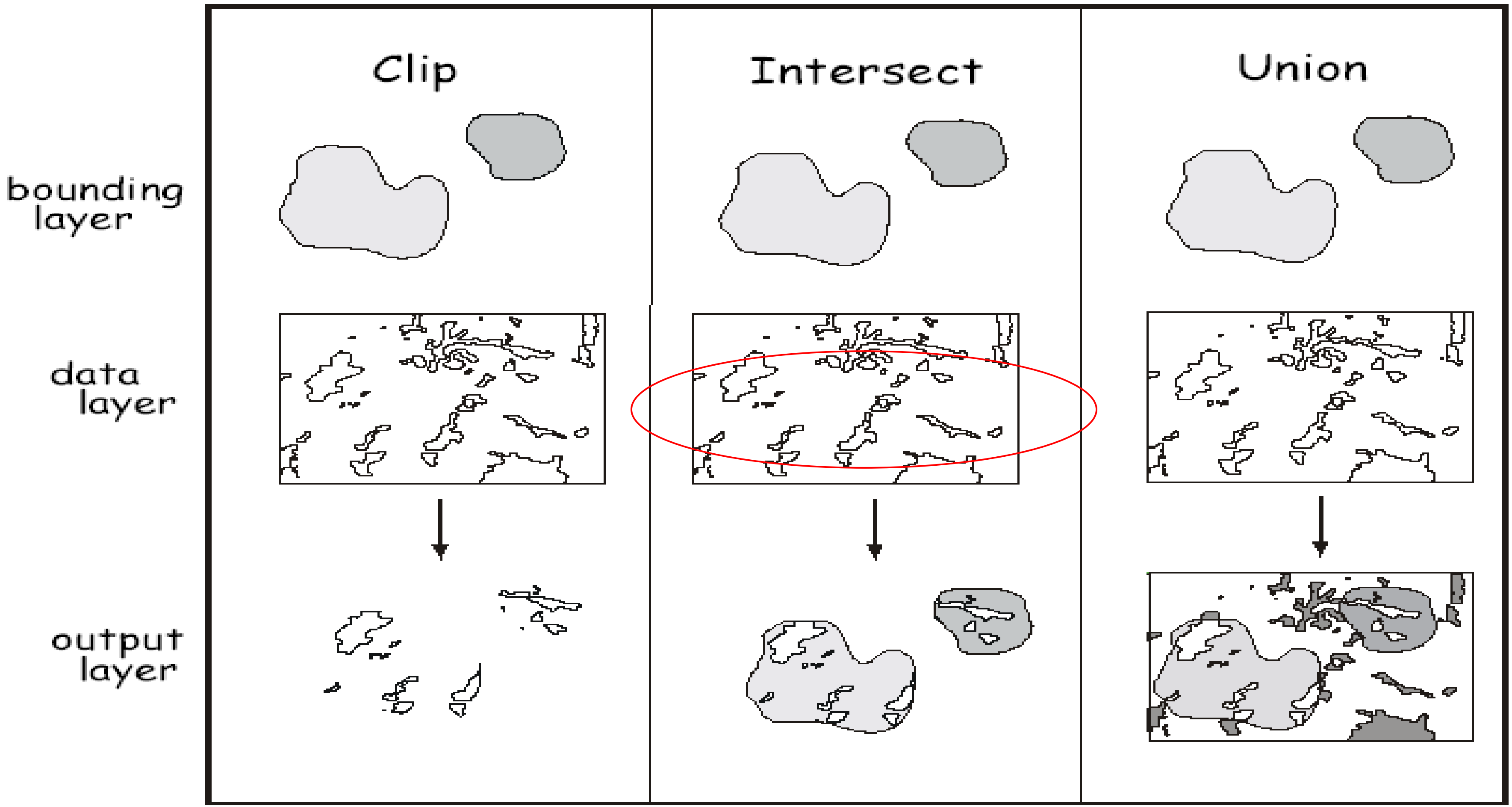
INTERSECTION

- Combines data from both layers but only for the bounding area

  (Bounding polygon also defines the output layer
  Data from both layers are combined
  Data outside the bounding layer (1st layer) is discarded)

- Order of intersection is important

(A to B   or   B to A)

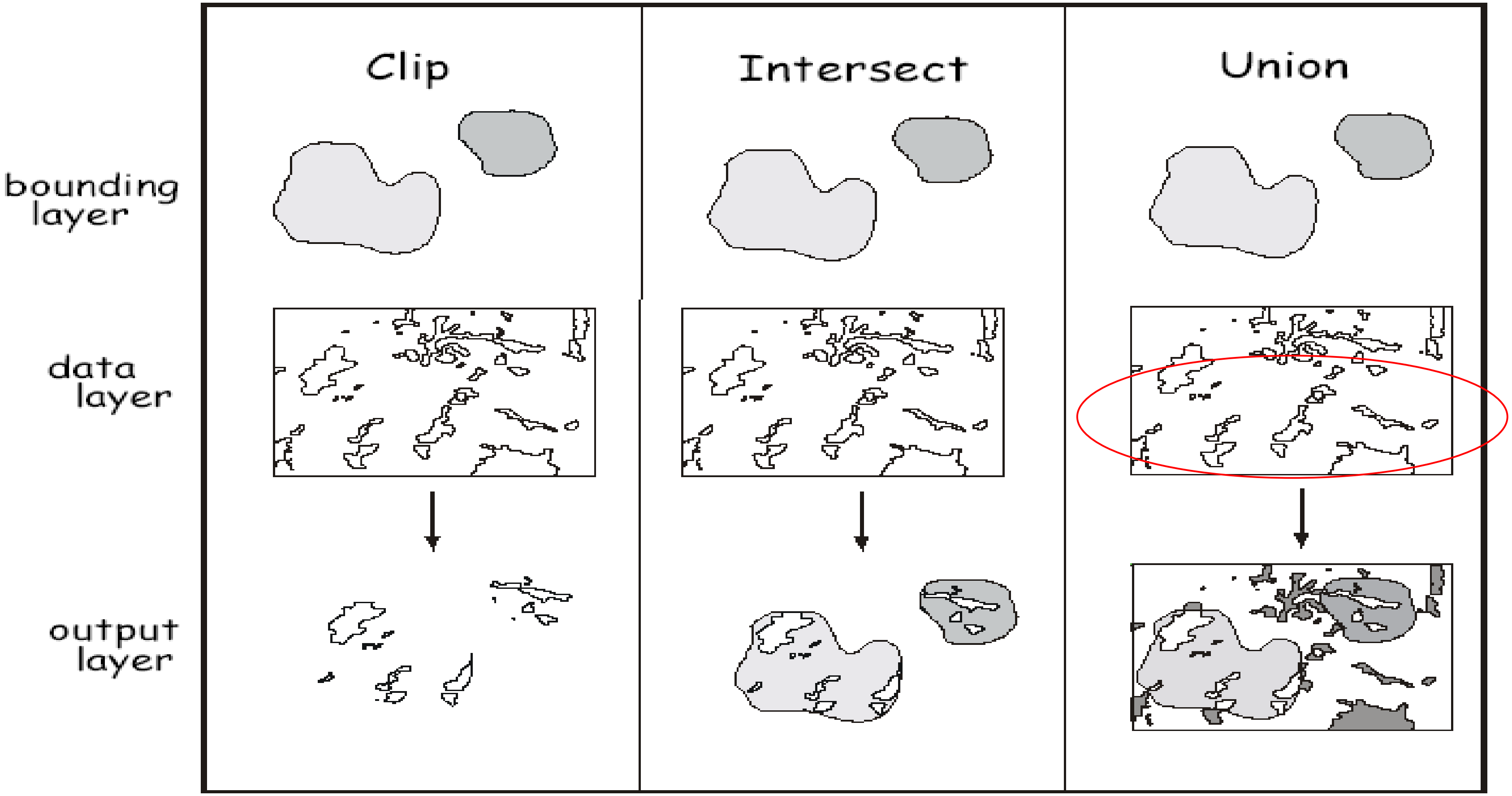


Clip
Intersect
Union
bounding layer
data layer
output layer

UNION

- Includes all data from both the bounding and data layers

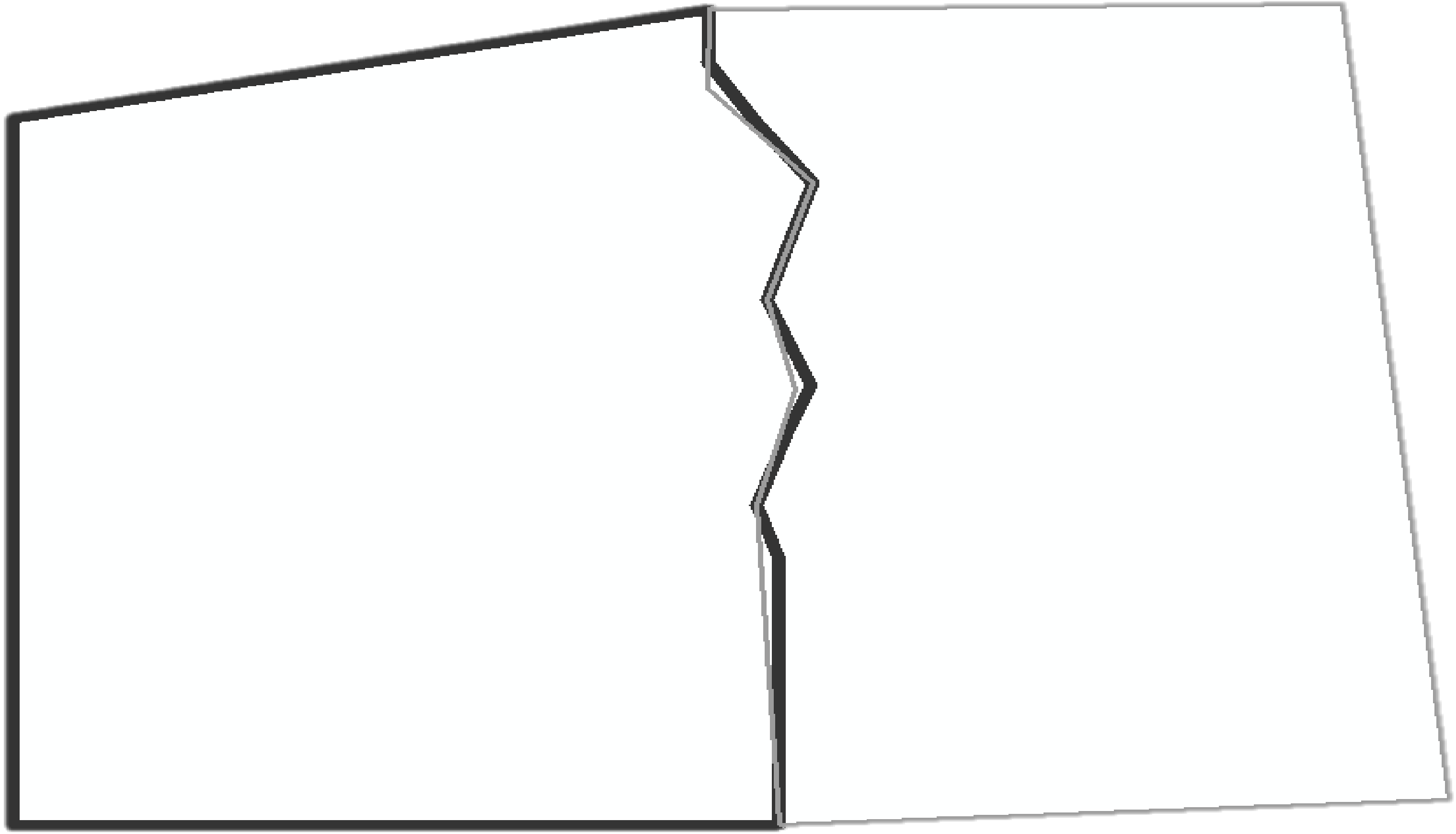
- New polygons are formed by the combinations of the coordinate data from each layer



Clip
Intersect
Union
bounding layer
data layer
output layer

Vector Overlay Problems

- <u>Common Features</u> represented in both layers, but with slightly different geometry
- This creates <u>sliver polygons</u> when the overlay operations are performed
- Several methods exist to reduce the occurrence of sliver polygons.



Raster/Image Data Analysis

Image Data Analysis

- Image data analysis is based on cells and images
- Image data analysis can be performed at the level of individual cells, or groups of cells, or cells within an entire image
- Some image data operations use a single image; others use two or more images,
- Image data analysis also depends on the type of cell value (numeric or categorical values).

Image Based Overlay: Simple Addition

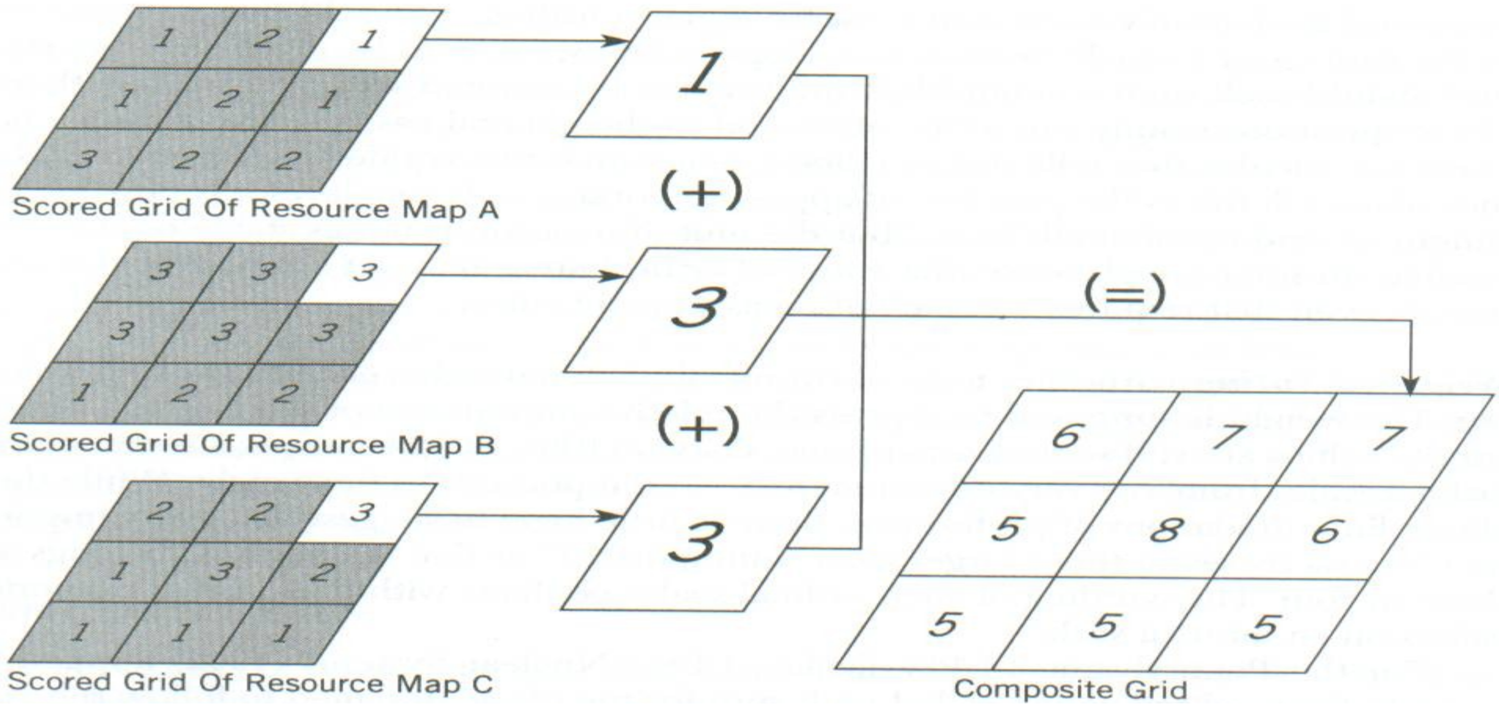


Image Source: Chrisman, Nicholas.(2002). 2nd Ed. *Exploring Geographic Information Systems*. p 144. fig. 5-12.

Image Overlay: Boolean Combine

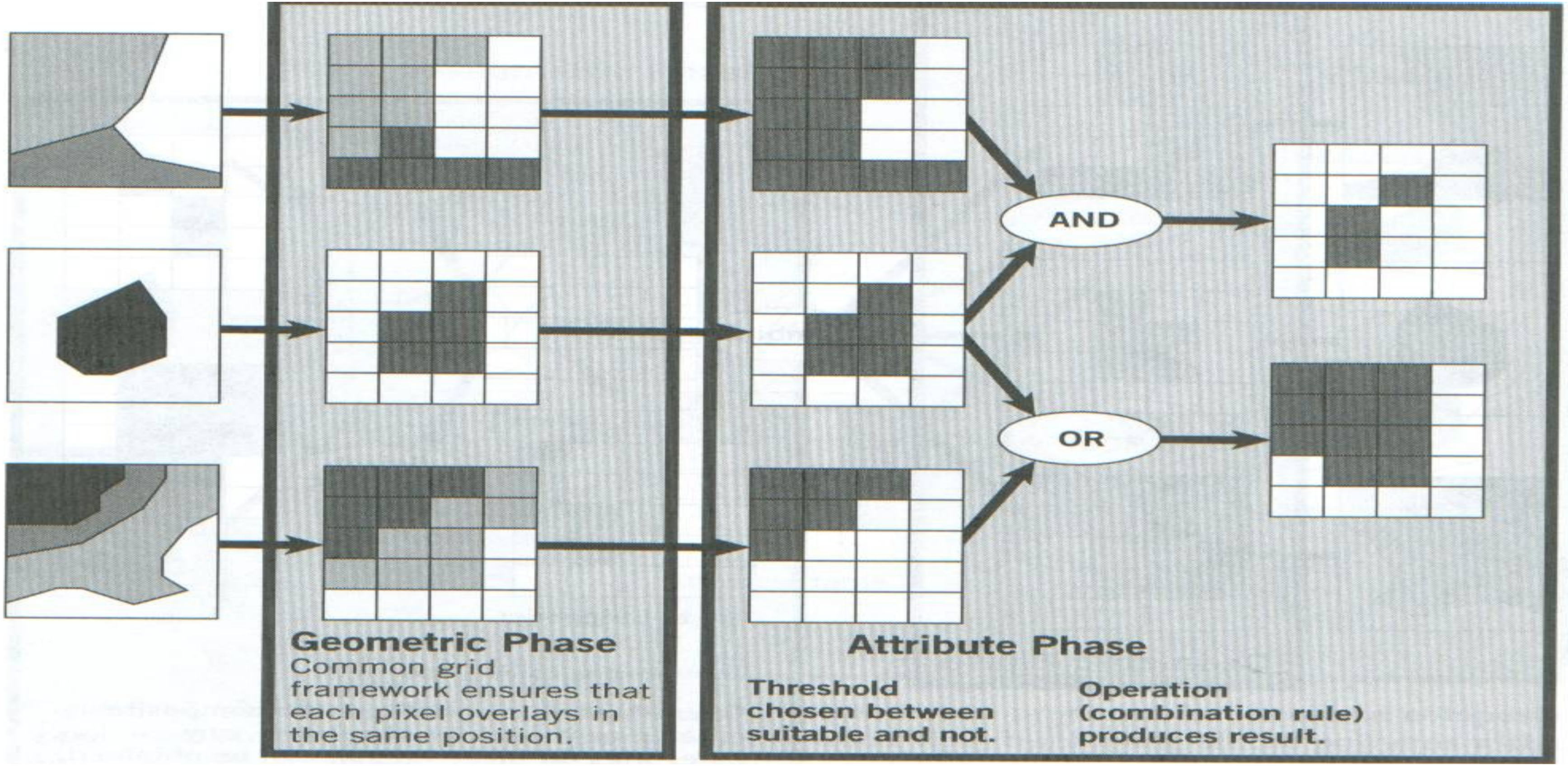
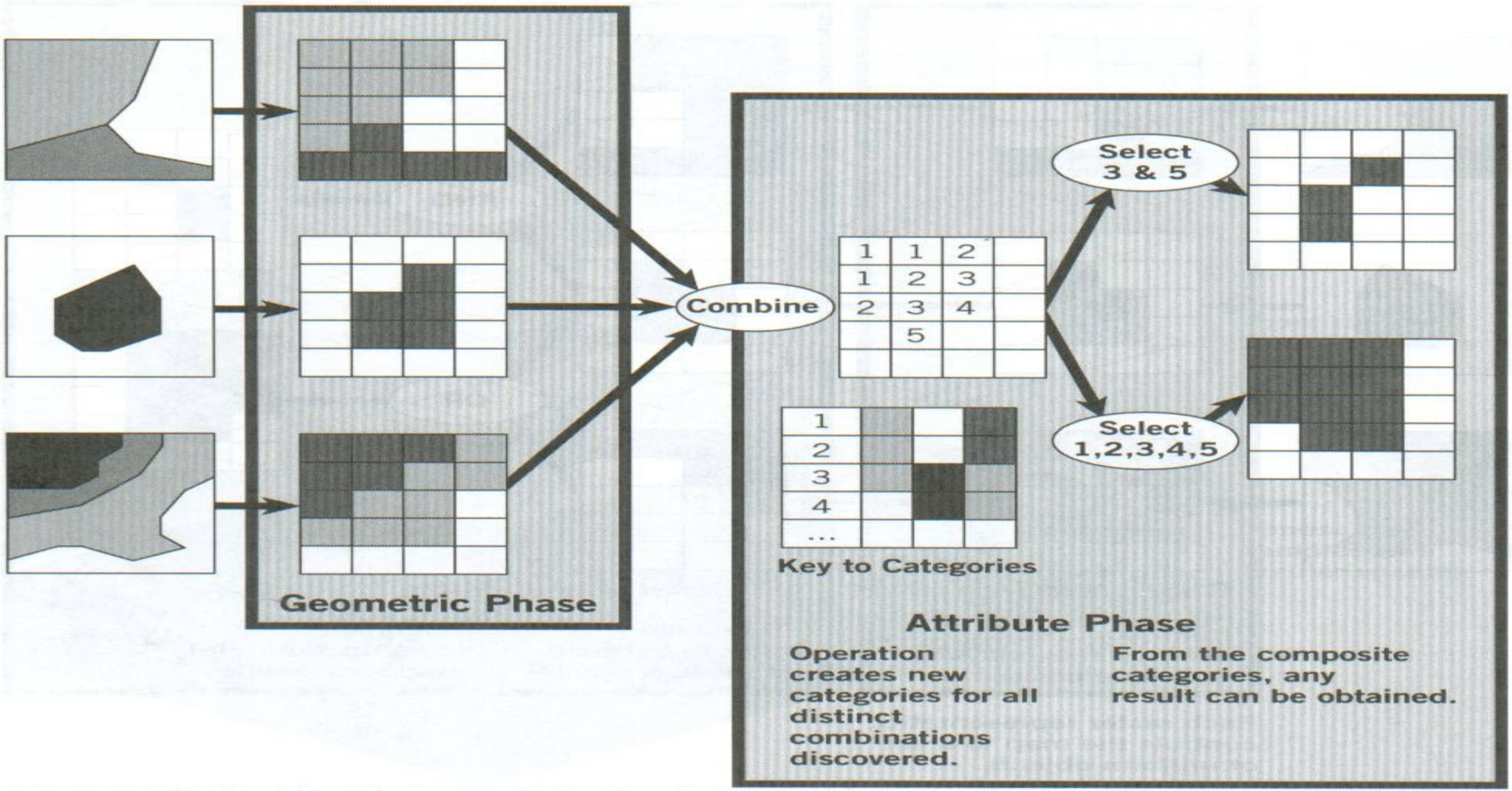


Image Source: Chrisman, Nicholas.(2002). 2nd Ed. *Exploring Geographic Information Systems*. p 125. fig. 5-3.

Image Overlay: Composite Combine



Type of Image Data Operations

- Local- Single Image; Multiple images
- Neighborhood (focal) Operations
- Zonal Operations
- **Re-sampling – by interpolation methods**
- Mosaic and clip
- Distance measurement
- Aggregate – Statistic methods (descriptive statistics)

Local Operations - Overview

- Operations performed on a cell by cell basis
- Computes output cell values as a function of the input cell values
- Can be done using single or multiple images
- “No data" cells not included in calculations
- Common uses: reclassification and overlays

Local Operations – Single Image

Arithmetic	+, -, /, *, absolute,integer,floating-point
Logarithmic	exponentials, logarithms
Trigonometric	sin,cos, tan, arcsin, arccos, arctan
Power	square, square root, power

Arithmetic, logarithmic, trigonometric, and power functions for local operations

Local Operations – Single Image

15.2	16.0	18.5
17.8	18.3	19.6
18.0	19.1	20.2

(a)

8.64	9.09	10.48
10.09	10.37	11.09
10.20	10.81	11.42

(b)

A local operation can convert a slope image from percent (a) to degrees (b).

Local Operations – Single Image

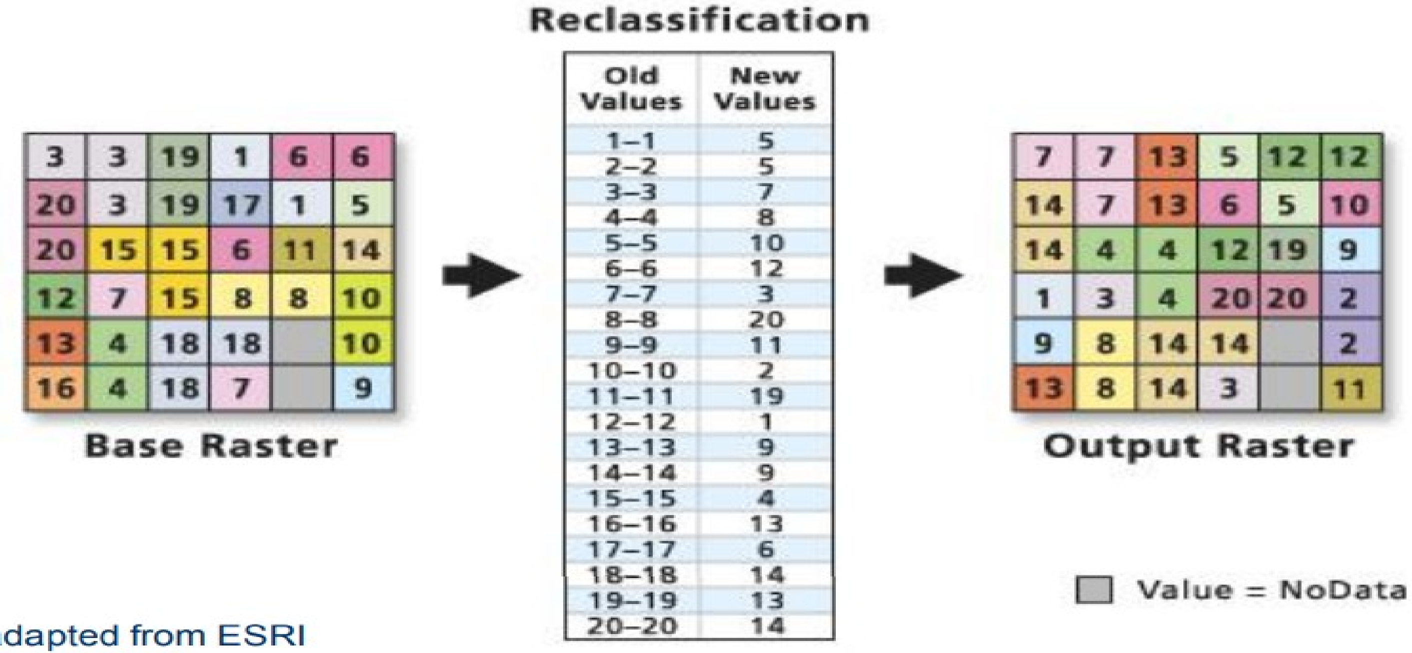


Diagram adapted from ESRI
ArcGIS 9.3 Helpdesk

One-to-one change – input raster cell value is replaced with new value in the output raster (integer rasters only)

Local Operations – Single Image

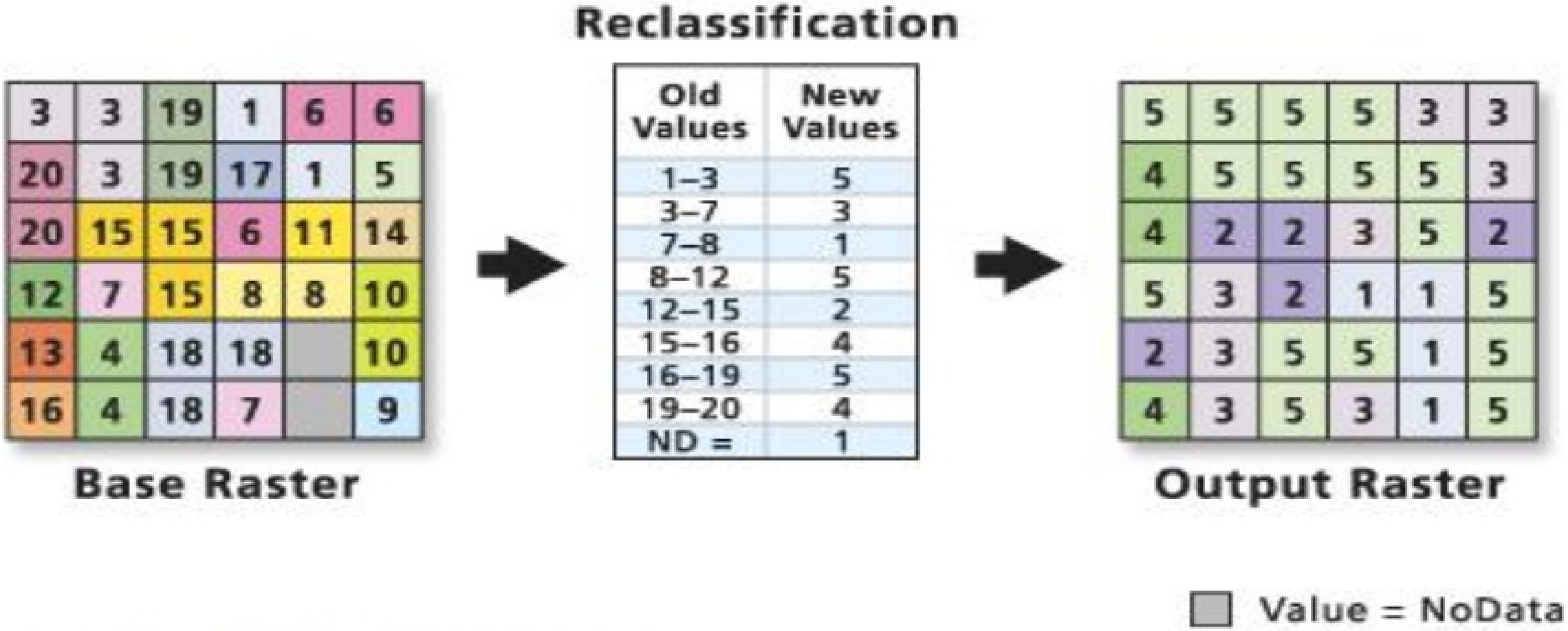


Diagram adapted from ESRI ArcGIS 9.3 Helpdesk

Range of values – a new value is given to a range of values in the input raster (integer/floating point rasters)

Local Operations: Multiple Images

- A common term for local operations with multiple input images is map algebra, a term that refers to algebraic operations with image map layers.
- Besides mathematical functions that can be used on individual images, other measures that are based on the cell values or their frequencies in the input images can also be derived and stored on the output raster of a local operation with multiple images.
- **Examples of operations: mathematical functions; summary statistics; Combine operation (Combines images by assigning a unique output value to each unique combination of input values).**

Local Operations: Multiple Images

Diagram adapted from ESRI ArcGIS 9.3 Helpdesk

Operation: add image 1 and image 2 cell values to produce an output image with the summed cell values

Local Operations: Multiple Images

(a)

5	2	3
	2	2
3	1	1

(b)

1	3	2
4	7	5
1	1	

(c)

3	4	1
4	3	2
2	1	1

(d)

3	3	2
	4	3
2	1	

The cell value in (d) is the mean calculated from three input images (a, b, and c) in a local operation. The shaded cells have no data

Local Operations: Multiple Images

(a)

3	2	1
2	1	2
1	2	3

(b)

3	2	4
3	2	4
2	4	1

(c)

1	3	6
2	4	5
4	5	7

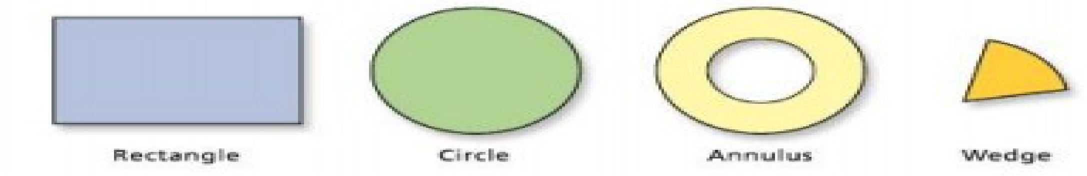
(d)

Combine code	1	2	3	4	5	6	7
(slope, aspect)	(3,3)	(2,3)	(2,2)	(1,2)	(2,4)	(1,4)	(3,1)

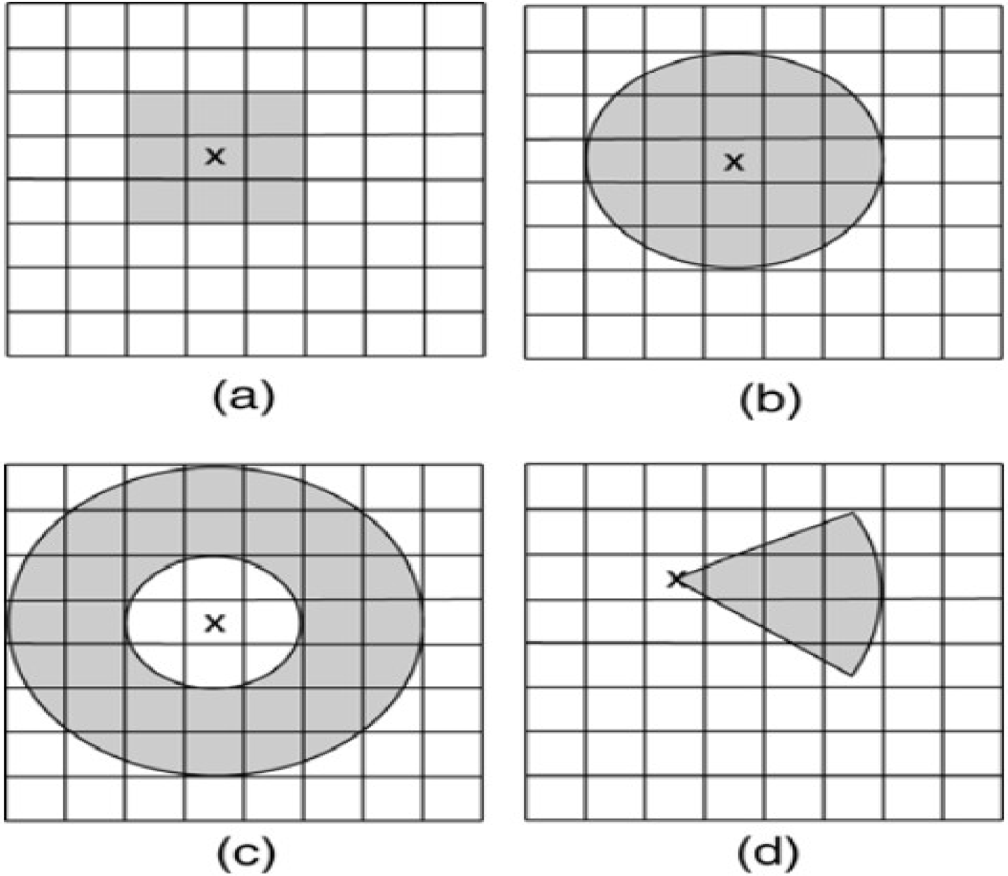
Each cell value in (c) represents a unique combination of cell values in (a) and (b). The combination codes and their representations are shown in (d).

Neighborhood (Focal) Operations

- A neighborhood operation involves a focal cell and a set of its surrounding cells. The surrounding cells are chosen for their distance and/or directional relationship to the focal cell.
- Focal cell moves from cell to cell
- Applies to single images
- Can produce summary statistics
- “No data” cells not included in analysis
- Common neighborhoods include rectangles, circles, annuluses, and wedges.



Neighborhood (Focal) Operations



Four common neighborhood types: rectangle (a), circle (b), annulus (c), and wedge (d). The cell marked with an x is the focal cell.

Neighborhood (Focal) Operations

Operation: Summation (including value of focal cell)

Neighborhood size: 3 x 3 rectangle; red circle = focal cell

Gray square = no data for that cell's value

Diagram adapted from ESRI ArcGIS 9.3 Helpdesk

Neighborhood (Focal) Operations

Operation: Summation (including value of focal cell)

Neighborhood size: 3 x 3 rectangle; red circle = focal cell

Gray squares = no data for that cell's value

Diagram adapted from ESRI ArcGIS 9.3 Helpdesk

Neighborhood (Focal) Operations

(a)

1	2	2	2	2
1	2	2	2	3
1	2	1	3	3
2	2	2	3	3
2	2	2	2	3

(b)

1.56	2.00	2.22
1.67	2.11	2.44
1.67	2.11	2.44

The cell values in (b) are the neighborhood means of the shaded cells in (a) using a 3 x 3 neighborhood. For example, 1.56 in the output raster is calculated from (1 +2 +2 +1 +2 +2 +1 +2 +1) / 9.

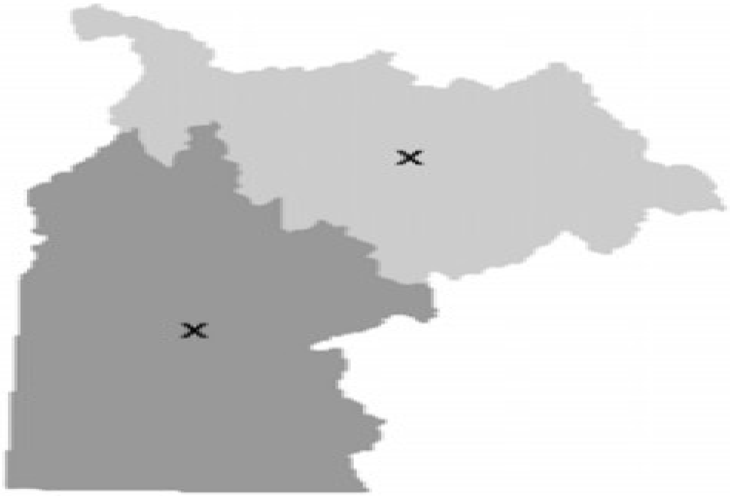
Neighborhood (Focal) Operations Common Applications

- Data simplification
- Terrain analysis
- Image processing
- Site selection

Zonal Operations

- A zonal operation works with groups of cells of same values or like features. These groups are called zones.
- Cells do not need to be contiguous to be in a zone
- Can be used with a single image or with two images
- **Single image zonal operations** – Measures the geometry of each zone (area, perimeter, centroid, thickness, etc.)
- **Two image zonal operations** Given two images in a zonal operation, one input image and one zonal image, a zonal operation produces an output image, which summarizes the cell values in the input image for each zone in the zonal image.

Zonal Operations



Zone	Area	Perimeter	Thickness
1	36,224	1,708	77.6
2	48,268	1,464	77.4

Thickness and centroid for two large zones. Area is measured in square kilometers, and perimeter and thickness are measured in kilometers. The centroid of each zone is marked with an x.

Zonal Operations

1	2	2	1
1	4	5	1
2	3	7	6
1	3	4	4

(a)

1	1	2	2
1	1	2	2
1	1	3	3
3	3	3	3

(b)

2.17	2.17	2.25	2.25
2.17	2.17	2.25	2.25
2.17	2.17	4.17	4.17
4.17	4.17	4.17	4.17

(c)

The cell values in (c) are the zonal means derived from an input image (a) and a zonal image (b). For example, 2.17 is the mean of {1, 1, 2, 2, 4, 3} for zone 1.

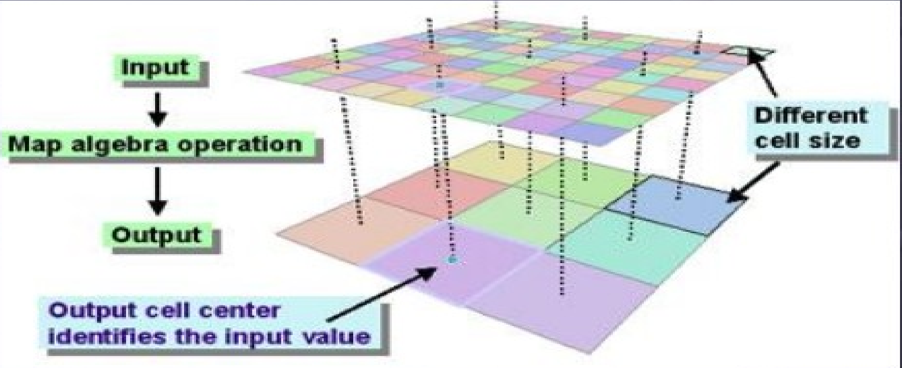
Resampling pixel values

Uses interpolation (nearest neighbor, bilinear, cubic interpolation etc.) methods on the values of the input image

deriving pixel values for a new image from an existing image

input raster will be a finer resolution

output raster will be a coarser resolution



Aggregate operation

- Uses a specified statistical aggregation method within a neighborhood to derive values in the output raster at the different resolution
- The types of statistics available to aggregate the input values are Sum, Min, Max, Mean, and Median.

1	3	2	5
1	3	2	7
1	1	2	5
2	4	3	2

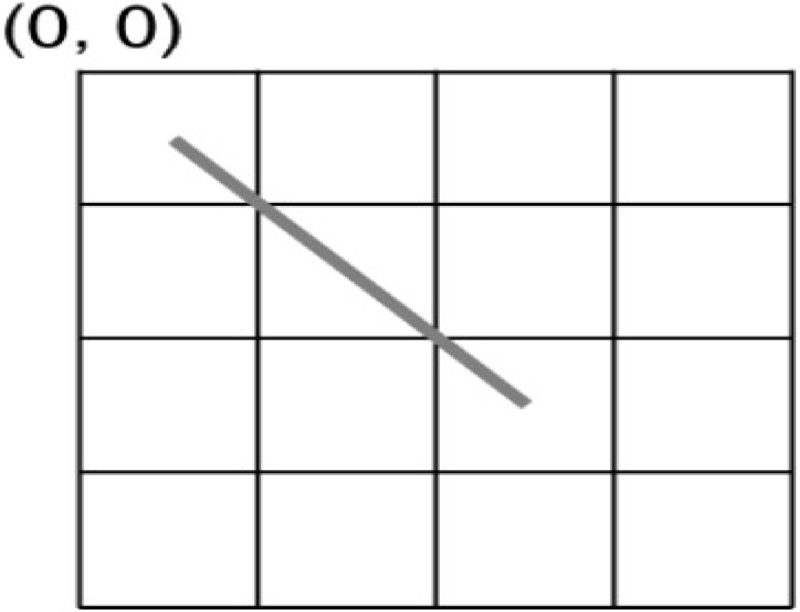
(a)

2	4
2	3

(b)

An Aggregate operation creates a lower-resolution raster (b) from the input (a). The operation uses the mean statistic and a factor of 2 (i.e., a cell in b covers 2 x2 cells in a). For example, the cell value of 4 in (b) is the mean of {2, 2, 5, 7} in (a).

Distance Measurement



A straight-line distance is measured from a cell center to another cell center. This illustration shows the straight-line distance between cell (1,1) and cell (3,3).

Clip and Mosaic Operation

(a) (b) (c)

An analysis mask (b) is used to clip an input raster (a). The output raster is (c), which has the same area extent as the analysis mask.

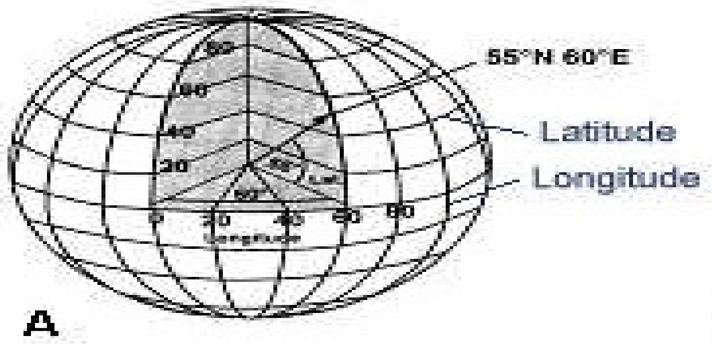
Image data extraction operation

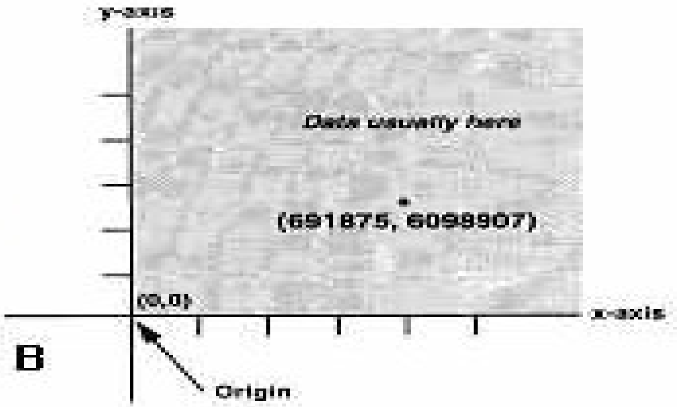
(a) (b)

A circle, shown in white, is used to extract cell values from the input image (a). The output (b) has the same area extent as the input image but has no data outside the circular area.

Coordinate System and Projection System

- Horizontal coordinate system-
  - locate data across the surface of the earth,
  - geographic, projected, or local.
- Vertical coordinate systems –
  - locate the relative height or depth of data
  - are either gravity-based or ellipsoidal.
  - Gravity-based vertical coordinate systems reference a mean sea level calculation.
  - Ellipsoidal coordinate systems reference a mathematically derived spheroidal or ellipsoidal volumetric surface.



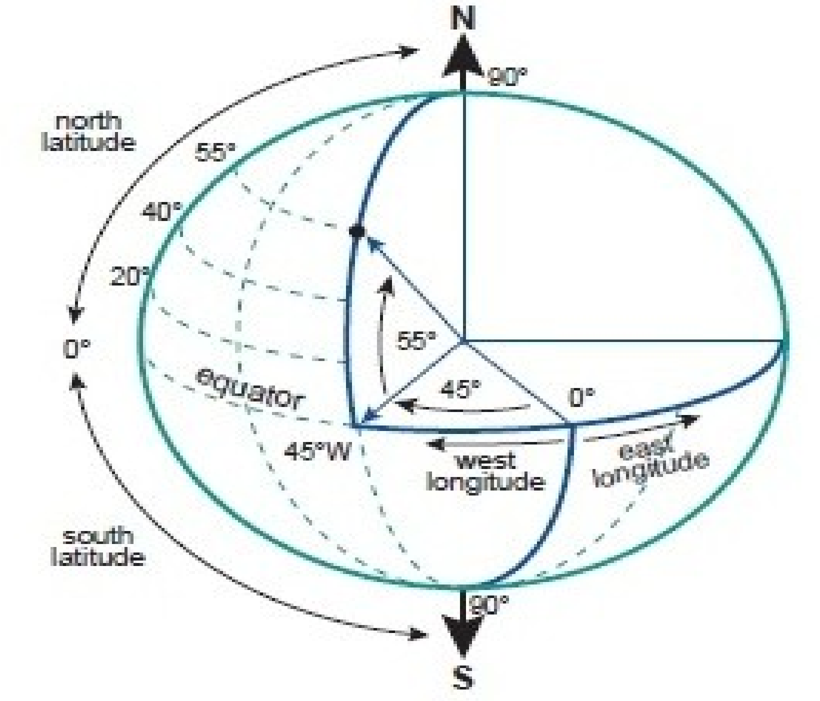


Cartesian coordinate systems

- Mutually orthogonal system of straight axes as a complete reference framework for n-dimensional spaces
- Axes intersect at system‘s origin
- Metric, continuous measurement along axes
- Projections of spherical surfaces result in 2-d cartesian systems

Geographical coordinates

- Specify position on a spherical surface relative to rotational (polar) axis and center
- Angular (polar) measurements
  - Latitude: angle from equatorial plane ±90°
  - Logitude: angle from Greenwich meridian ±180°
- For planar display on a map a "*projection transformation*" is needed

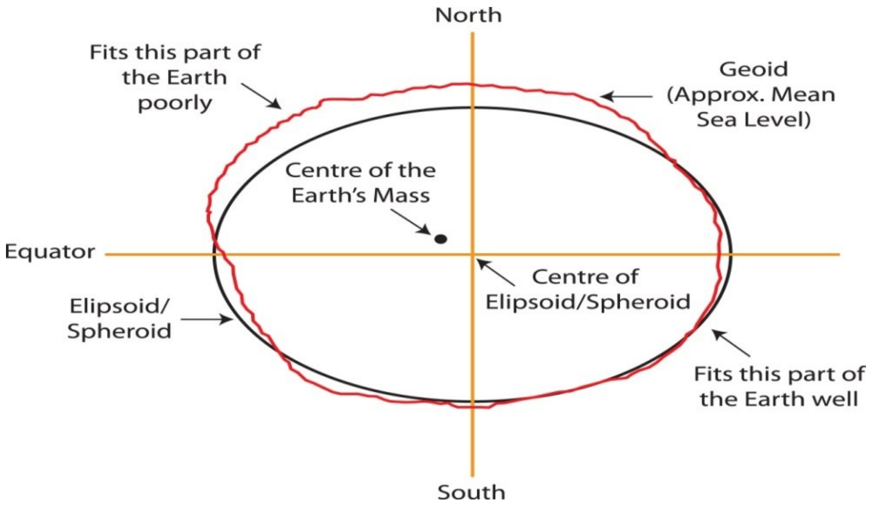


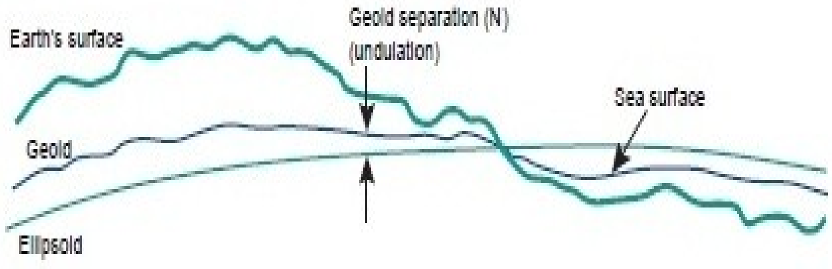
Map projections

- A map projection is defined by
  - **name** of projection
  - **type** of projection (e.g. *cylindrical* - using different reference bodies)
  - **description** (applicable parameters depend on type of projection)
  - ellipsoid / **datum** parameters

Parameters for Mapping

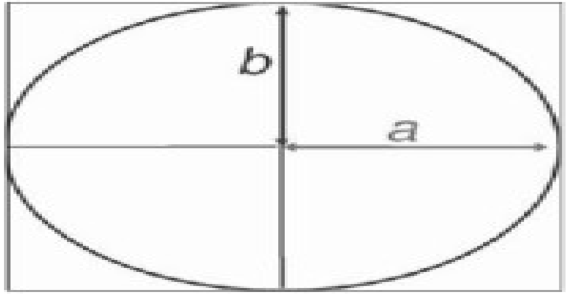
- A mathematical model of the earth must be selected- **Spheroid/Elipsoid**
- The mathematical model must be related to real-world features - **Datum**
- Real-world features must be projected with minimum distortion from a round earth to a flat map; and given a grid system of coordinates- **Projection**



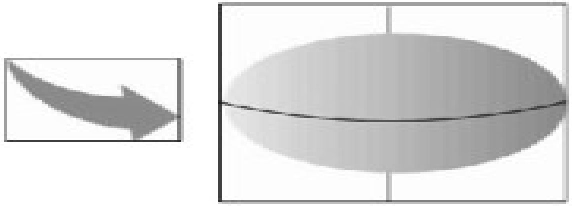


Specific Earth Ellipsoids

Ellipsoid



Rotate Ellipse in 3 Dimensions:

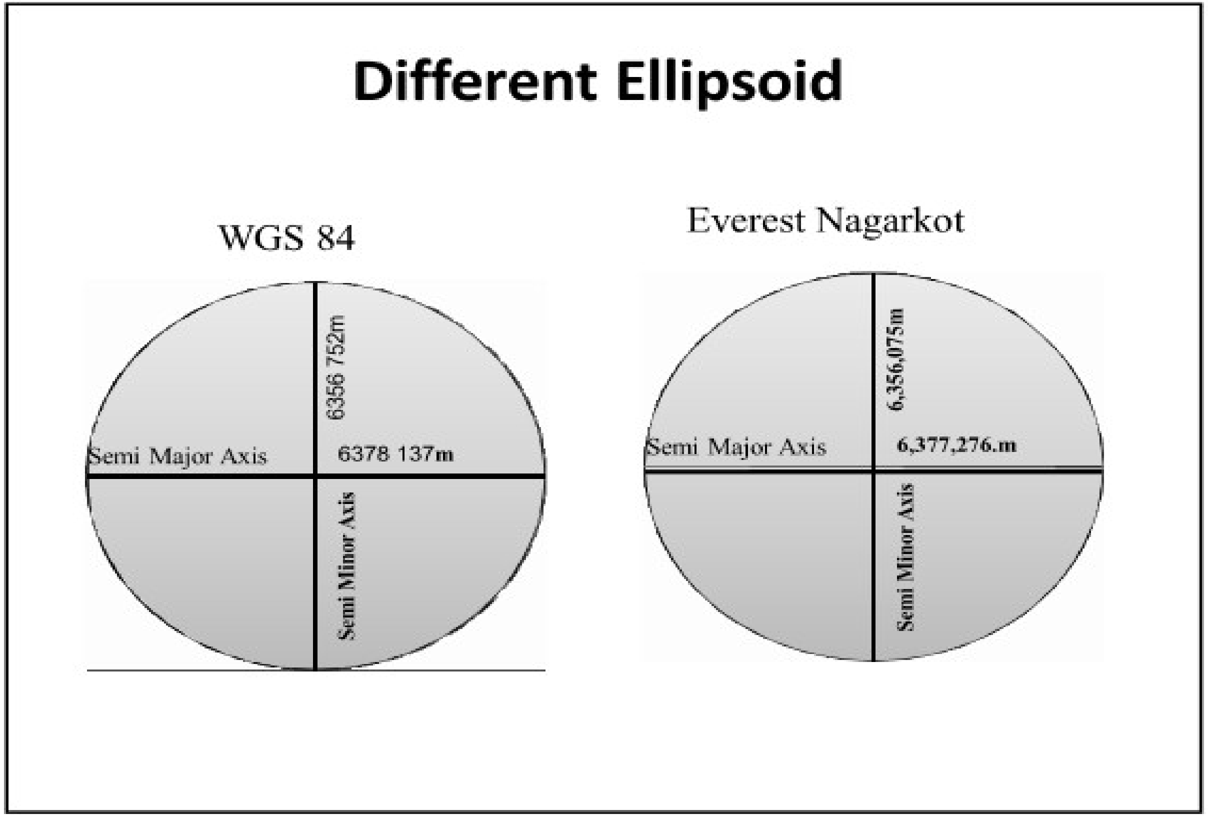


Semi-major Axis: a = 6371837 m Semi-minor Axis:
b = 6356752.3142 Flattening Ratio:
f=(a-b)/a = 1/298.257223563

Specific Earth Ellipsoids

Why use different Ellipsoid?

The earth's surface is not perfectly symmetrical, so the semi-major and semi-minor axes that fit one geographical region do not necessarily fit another.



Type of Projection System

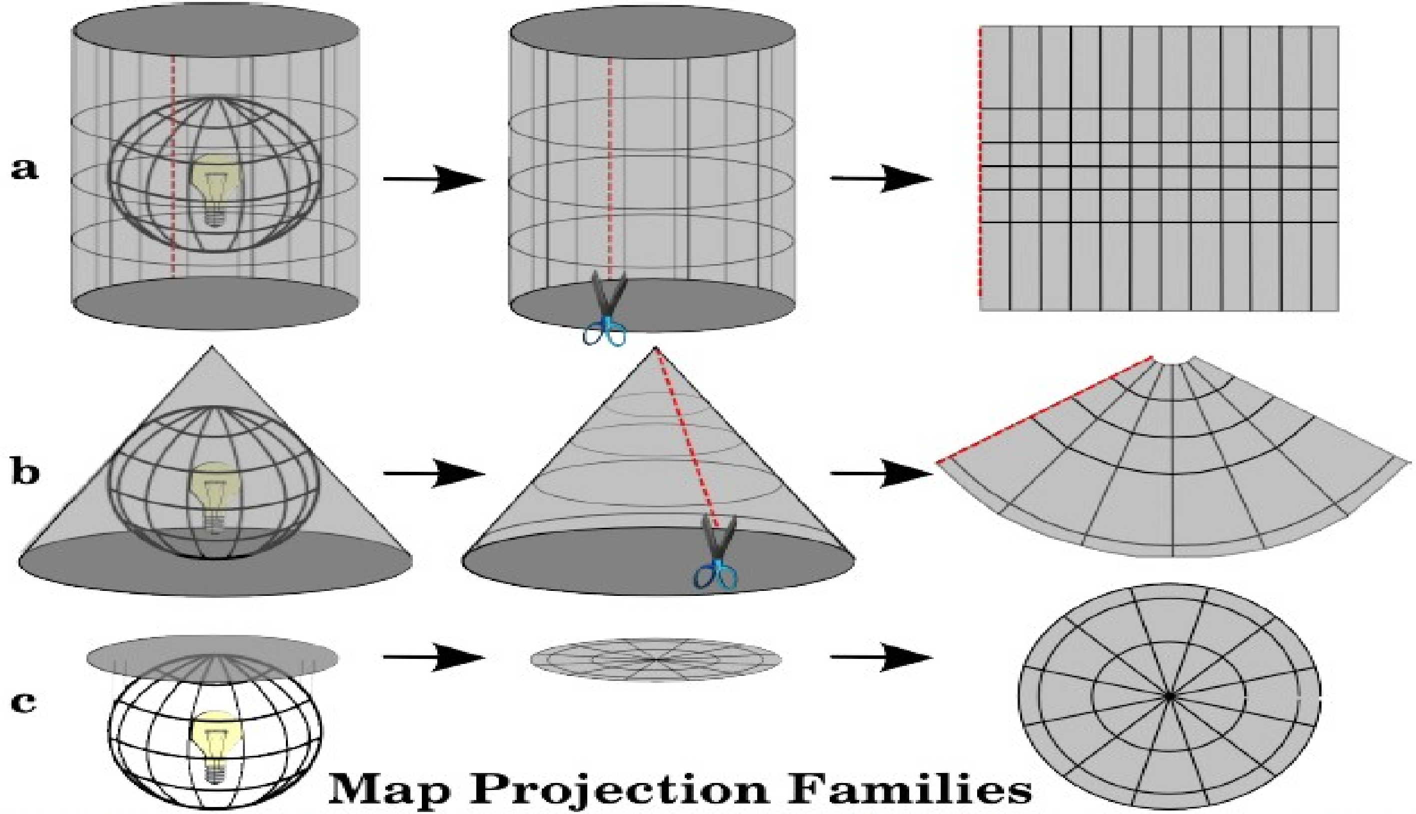


Illustration 1: The three families of map projections. They can be represented by a) cylindrical projections, b) conical projections or c) planar projections.

Geographic Coordinate System

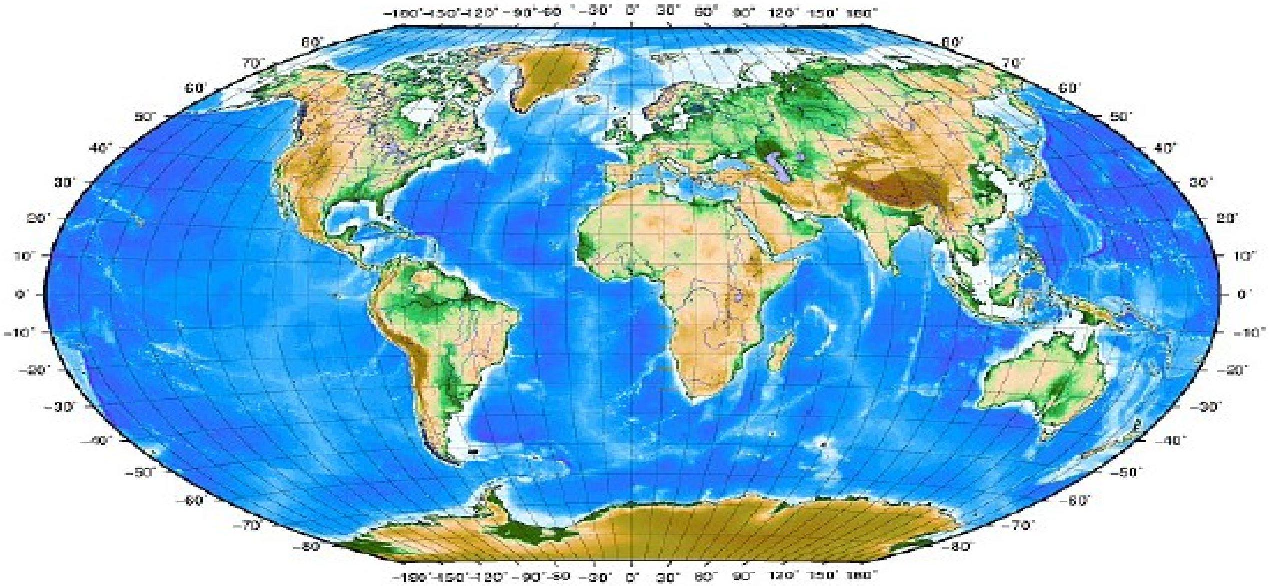
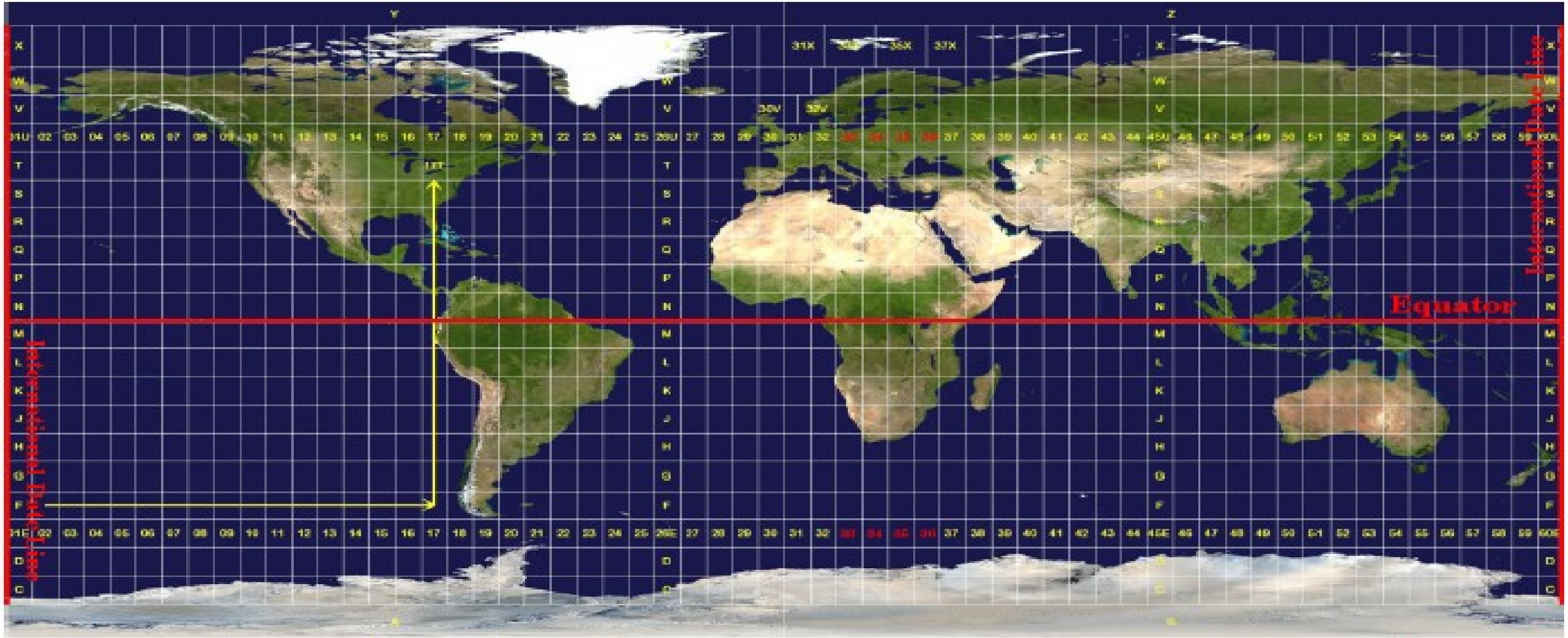


Illustration 7: Geographic coordinate system with lines of latitude parallel to the equator and lines of longitude with the prime meridian through Greenwich.

UTM: Universal Transversal Mercator System

- Worldwide the most important projection system for large scale mapping
- Transversal (horizontal) cylindrical proj.
- Cylinder is repositioned for better fit at every 6° longitude, starting from the international dateline going east:
    - Zones 1-60, each 6° wide around central meridian
    - central meridian is scaled to <1 to disperse error
    - central meridian set to constant value of 500000m

Projected Coordinate System- Universal Transverse Mercator(UTM)



Global Positioning System (GPS)

Global Navigation Satellite System (**GNSS**)

- It is a space-based navigation system (satellite navigation system) to precisely and automatically identify locations on earth.
- The GNSS of U.S., ***the United States NAVSTAR Global Positioning System (GPS), was initiated by*** U.S. Department of Defense for the military to have a precise form of world wide positioning (~$12 billion funding).

Other GNSS

- GLONASS •
  - **Global Navigation Satellite System** -the only alternative navigational system in operation with global coverage and of comparable precision to GPS
  - Russian Federation Ministry of Defense
  - Has deteriorated over time; not complete
  - Being restored to full availability in partnership with India
- GALILEO
  - EU + 6 non-EU countries: China, India, Israel, Morocco, Saudi Arabia and Ukraine
  - First 4 satellites in orbit by 09/12/2012 from Kazakhstan; 30 satellite (27 + 3)
  - Full operation expected in 2020
- The China's COMPASS (BeiDou)
  - scheduled to be operational by 2020

History: NAVSTAR Global Positioning System (GPS)

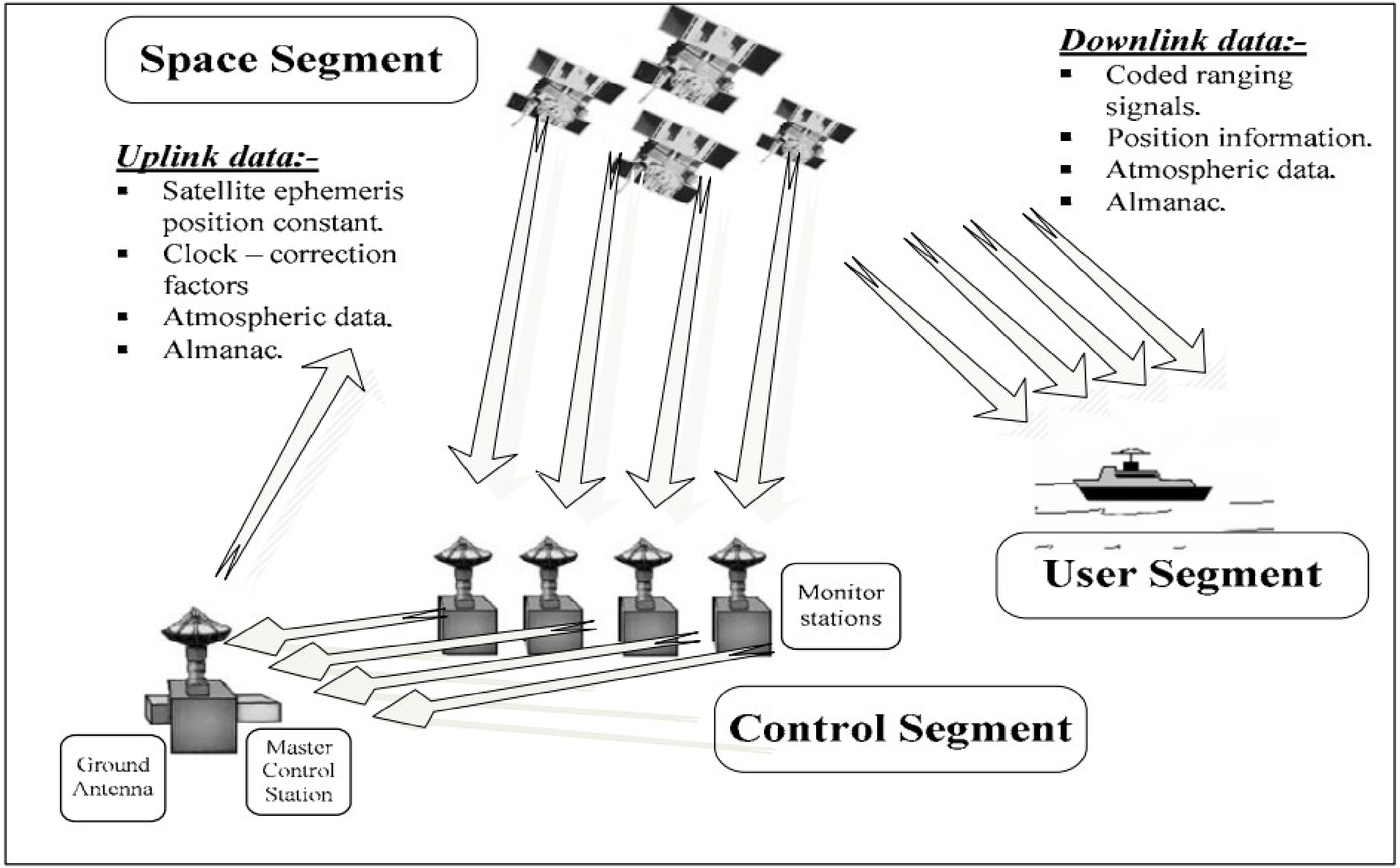
- 1973 – 1977: Proof of concept
- 1976: US Congress approved development
- 1978: First satellites launched
- Assets belongs to US Government
- Stewardship via US Dept of Defense
- First real operational test for GPS technology was the Gulf War in 1990
- June 26, 1993, the 24th satellite into orbit
- Full constellation achieved in 1995
- Selective Availability turned off by President Clinton in May 1st , 2000
- But also authorization of GPS III modernization, starting 2017
- Currently 31 satellites in orbit of various ages and type (?)
- Ultimately 62 are planned for
- 12,000 miles above Earth
- Orbit twice daily

Four Primary Functions of GPS

- Position and coordinates.
- The distance and direction between any two waypoints, or a position and a waypoint.
- Travel progress reports.
- Accurate time measurement.

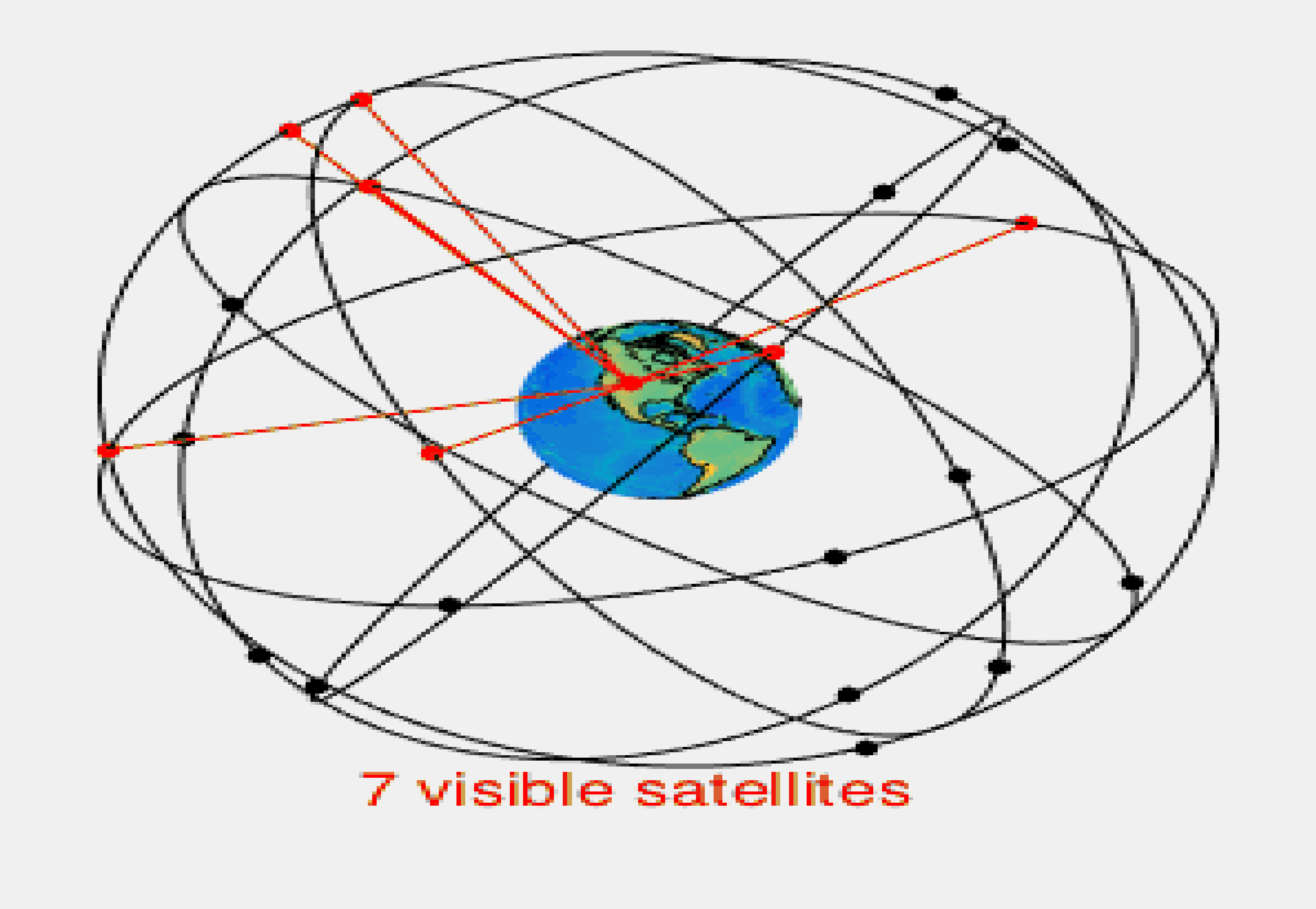
Components of GPS

- ## Space Segment (GPS satellites)
  - Navigation Satellites, which have an average 8.5 years lifespan, are renewed and evolve with technology. As of February 2016, there are 32 satellites at 20,200 kilometers (12,600 miles) above the earth in the GPS constellation, 31 of which are in use. The additional satellites improve the precision of GPS receiver calculations by providing redundant. The satellites are spaced so that from any point on earth, at least four satellites (typically 5 to 8) will be above the horizon. There are four active satellites in each of six-orbital planes. Satellites orbit with a period of 11h58’ at an angle of 55° to the Equator to ensure coverage of polar regions and 60° to other orbits. Powered by solar cells, the satellites continuously orient themselves to point their solar panels toward the Sun and their antennas toward Earth. Each satellite contains one computer, four atomic clocks and a radio and is able to continually broadcast its changing position and time.
- ## Control Components (GPS ground control stations)
  - The ground control component includes the master control station at Falcon Air Force Base, Colorado Springs , Colorado and monitor stations at Falcon AFB, Hawaii , Ascension Island in the Atlantic , Diego Garcia in the Indian Ocean , and Kwajalein Island in the South Pacific. The control segment uses measurements collected by the monitor stations to predict the behavior of each satellite's orbit and atomic clocks. The prediction data is linked up to the satellites for transmission to users. The control segment also ensures that GPS satellite orbits remain within limits and that the satellites do not drift too far from nominal orbits.
- ## User Component (GPS receivers)
  - When we buy a GPS, we are actually buying only the GPS receiver and get free use of the other two main components, worth billions of dollars. The user segment (also called GPS receiver) is composed of hundreds of thousands of U.S. and allied military users of the secure GPS Precise Positioning Service, and tens of millions of civil, commercial and scientific users of the Standard Positioning Service. In general, GPS receivers are composed of an antenna, tuned to the frequencies transmitted by the satellites, receiver-processors, and a highly stable clock (often a crystal oscillator). They may also include a display for providing location and speed information to the user.



GPS segments (Source: Aerospace Corporation, 2003)

Space Segment



Control Segment

Locations of GPS ground monitoring stations. These stations controls and monitors the satellite orbits and function.

User Segment

GPS receivers come in a variety of formats, from devices integrated into cars, phones, and watches, to dedicated devices such as these.

Hand-held receivers

A taxi equipped with GPS

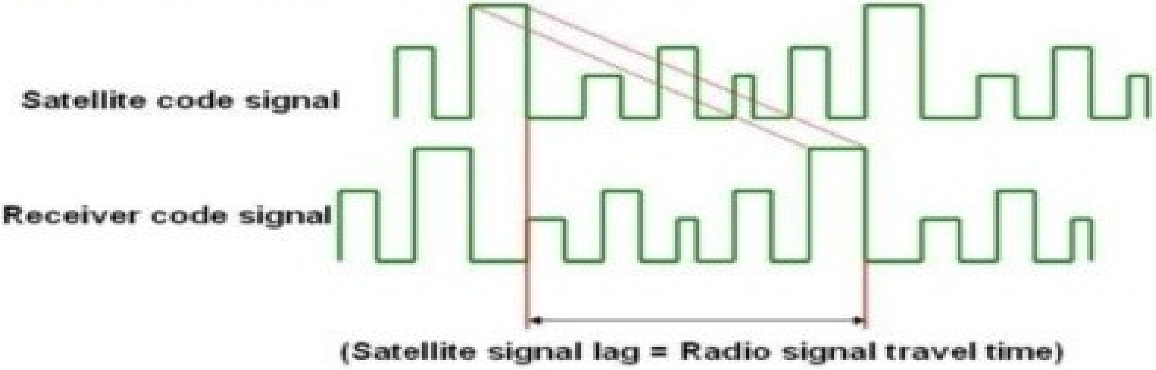
How GPS works?

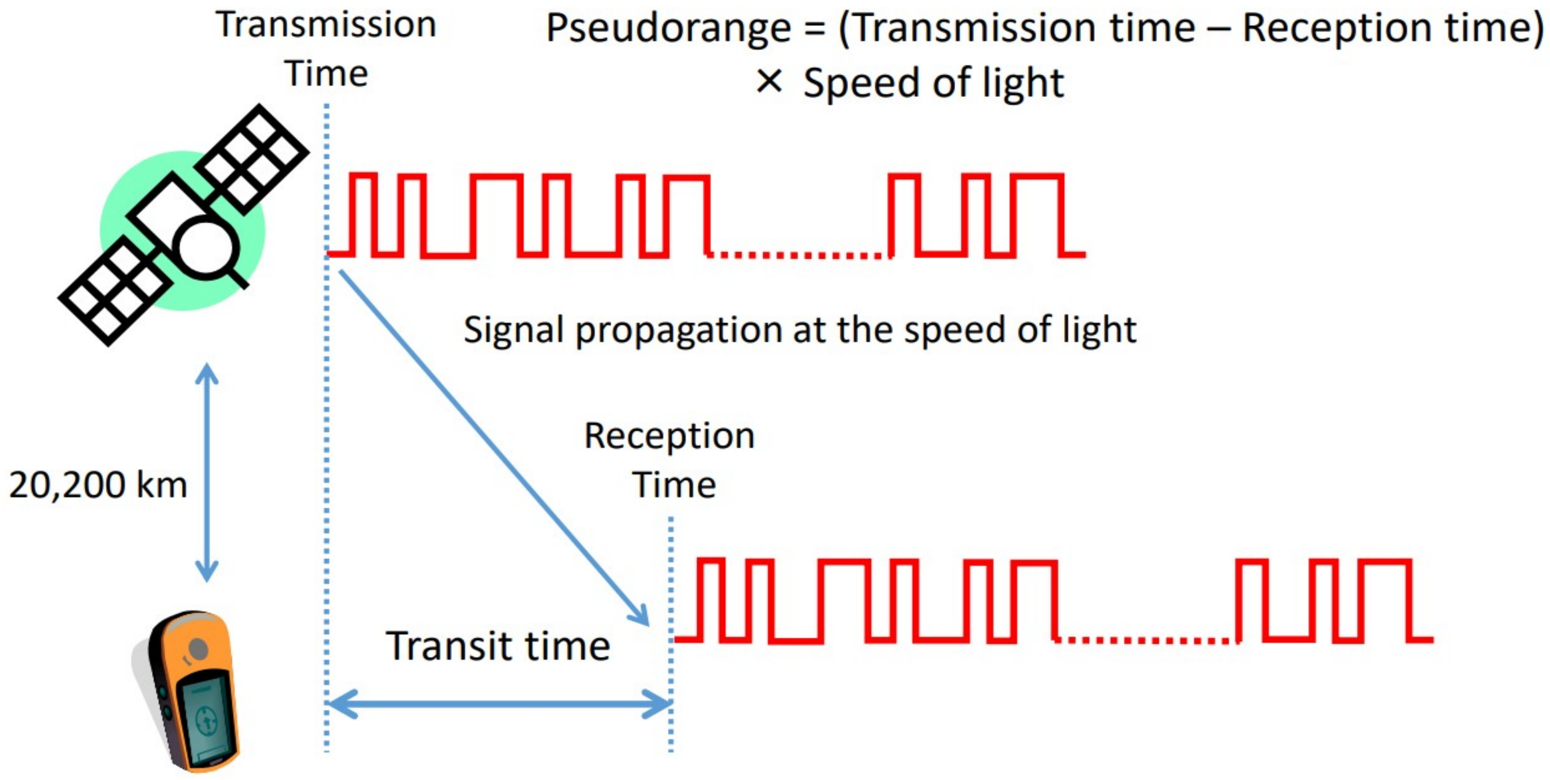
GPS uses **trilateration** to determine a user's position.

Distance = Speed x Travel Time

1. GPS signals are a radio signal, therefore they travel at the speed of light
2. If we know the time the signal was sent and the time the signal was received we can work out travel time.
3. By subtracting the sent time from the received time, we can determine the travel time
4. Now we can multiply travel time by the speed of light and we can determine distance

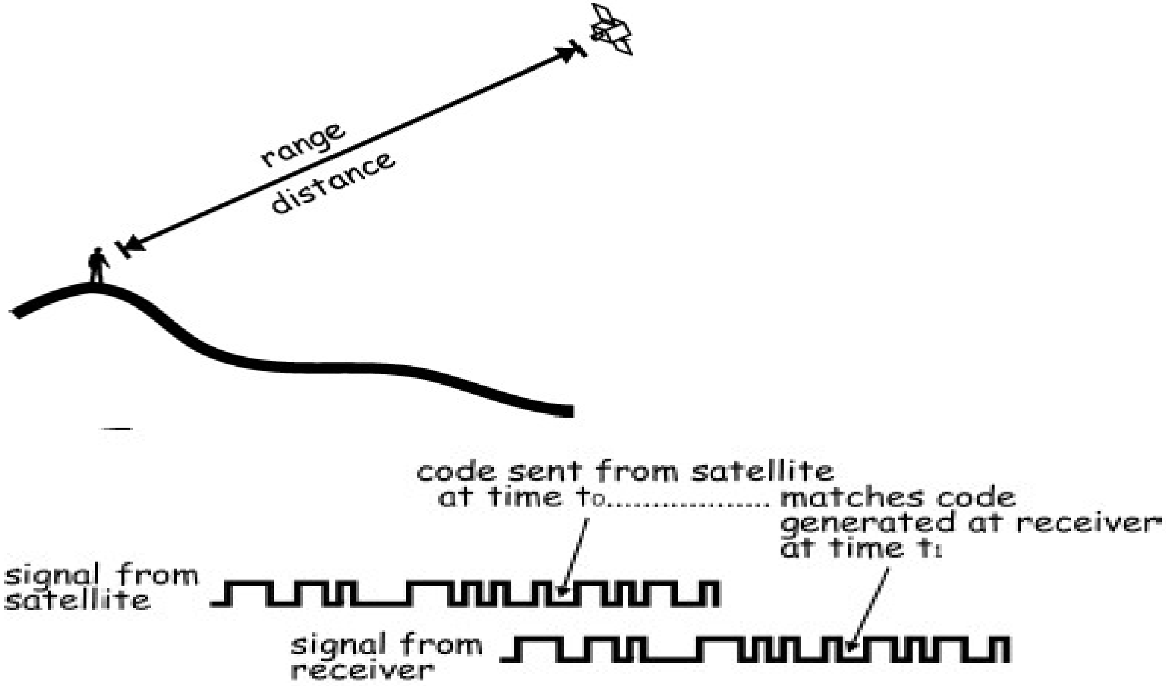
To determine distance, both the satellite and GPS receiver generate the same pseudocode at the same time. The satellite transmits the pseudocode which is received by the GPS receiver. The receiver is still producing the pseudocode while the satellite's code is travelling through the sky. The 2 signals are eventually compared and the difference between the 2 signals is the travel time.





A GPS receiver measures the signal transmission time from the code phase at signal reception time.

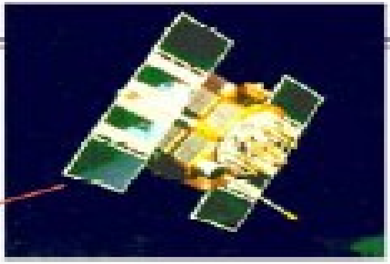
How GPS works?



range distance from satellite,

$$d = \text{speed of light} \times (t_1 - t_0)$$

How GPS works ?

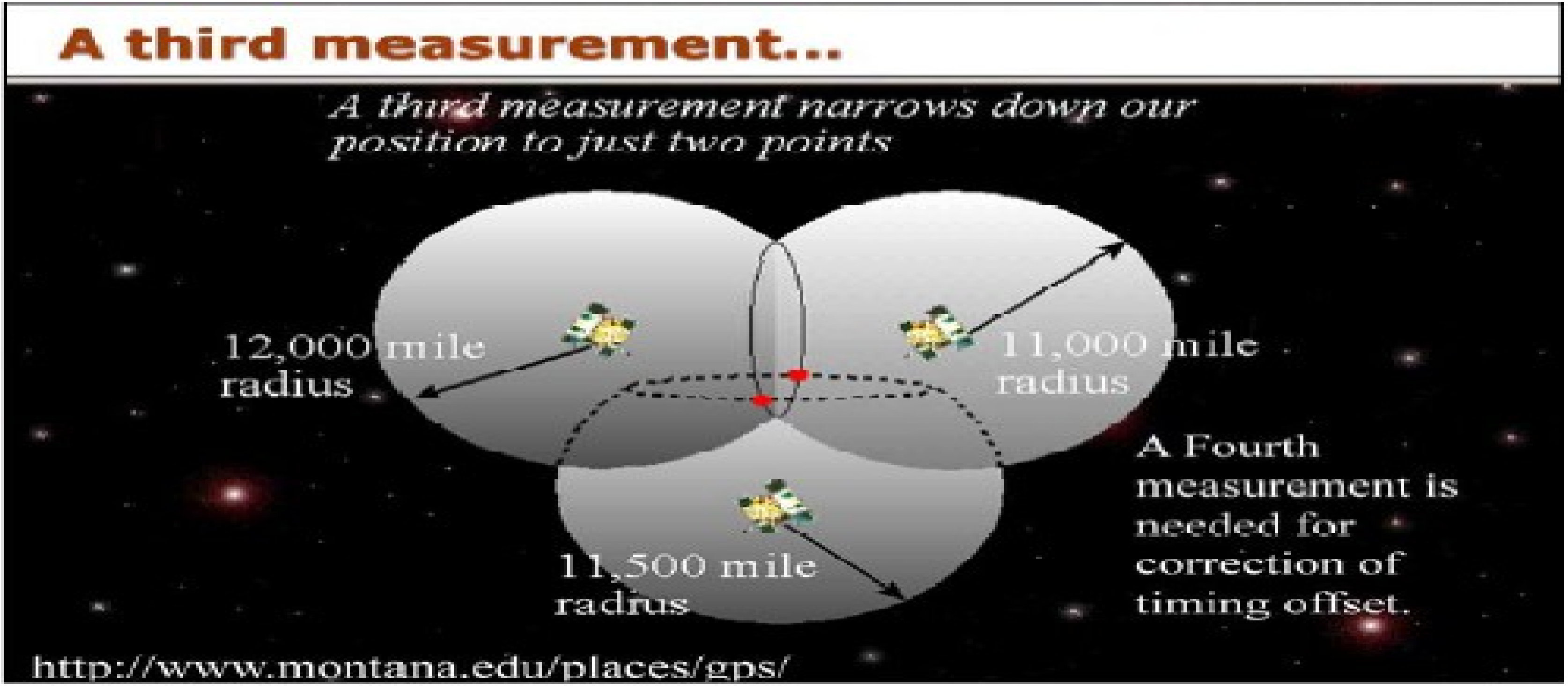


- GPS receivers calculate their position by measuring the time it takes for the signal to travel from the satellites to the receiver
- Satellite signals require a direct line to the GPS receiver
- Signals can not go through water, soil, walls or others

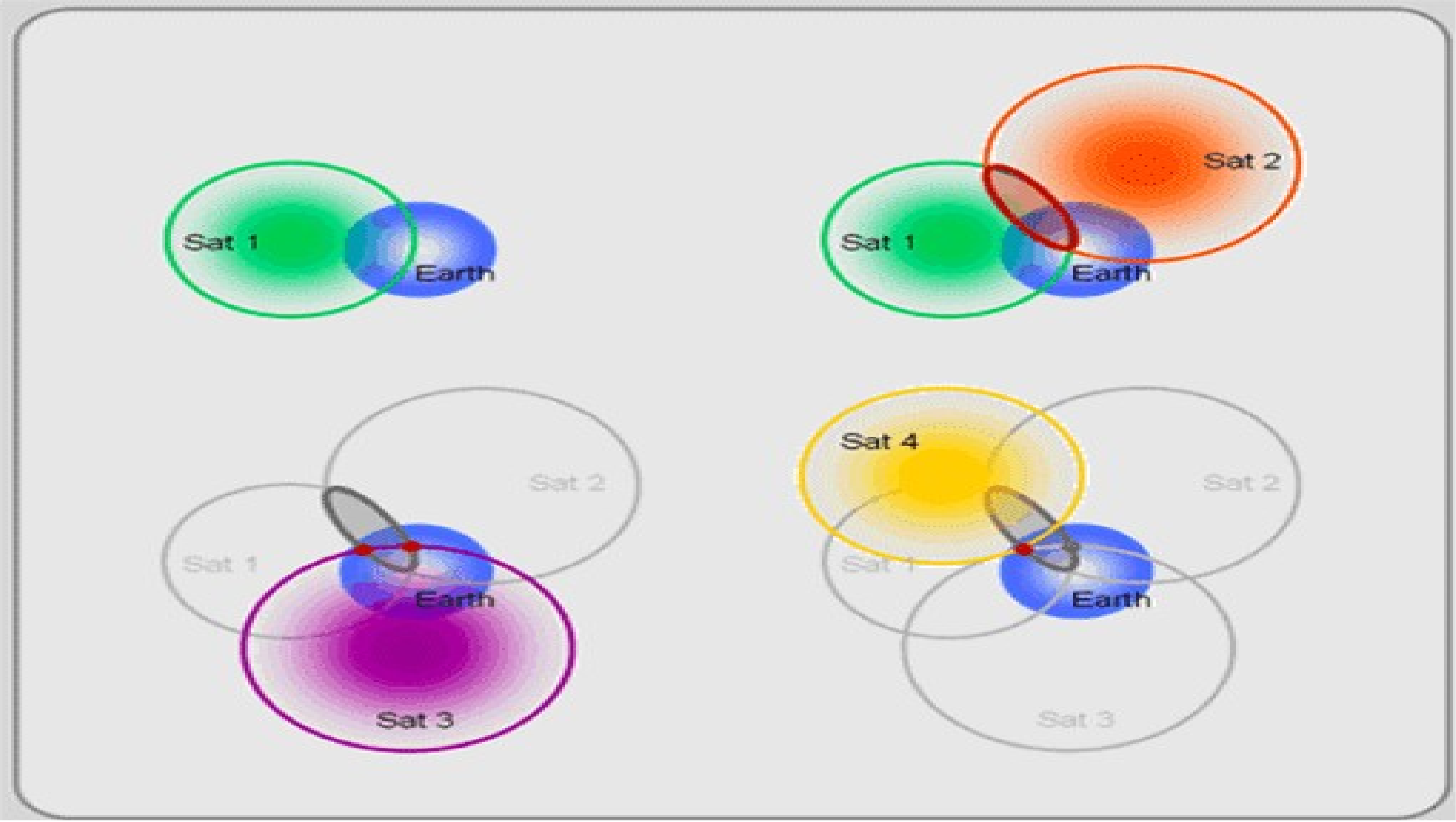
How GPS works - 5 steps

- Accurate measure of time for signal to travel from *satellite* to receiver
- Speed of *light* X *travel time* = distance
- Distance measurements to 4 satellites is necessary to compute a 3-D position through triangulation
- Knowledge of satellite positioning
- Corrections due to atmospheric influences and other errors

The time it takes from the GPS signal to travel from the satellite to the receiver is measured and then converted to distance by multiplying with the speed of light. Distance measurements form 4 satellites is necessary to compute a 3-d position (including a reasonably accurate measure of elevation). A lower accuracy 2-D position can be computed from distance measurements from three satellites. Differential correction can be applied to the signal to correct for atmospheric and other errors. We will talk more about differential correction later in this lecture.



A third measurement narrows down the position to only two points. A fourth measurement narrows down the location to only one location. You can get a reasonable (less accurate) estimate of location with only three satellite measurements, however four satellite measurements are necessary for computation of altitude.



Sat 1
Earth
Sat 2
Sat 1
Earth
Sat 2
Sat 1
Earth
Sat 3
Sat 4
Sat 2
Sat 1
Earth
Sat 3

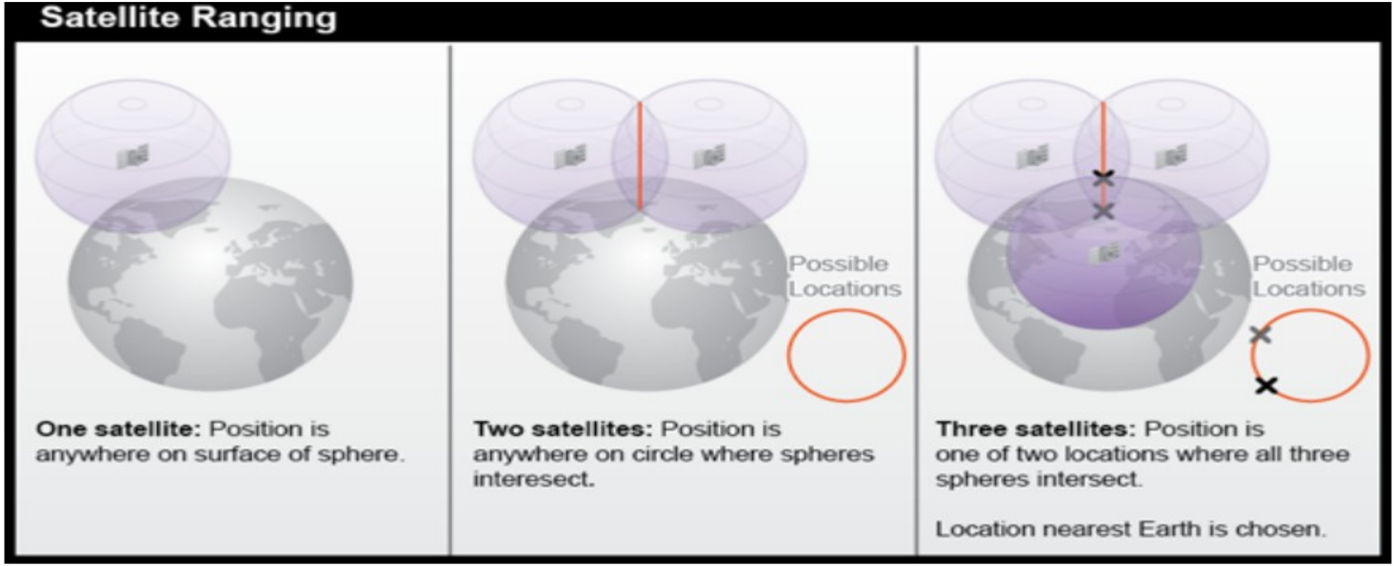


Figure 5.8: A 2-dimensional location fix requires three satellites. Adding a fourth satellite allows 3-dimensional location (horizontal + elevation).

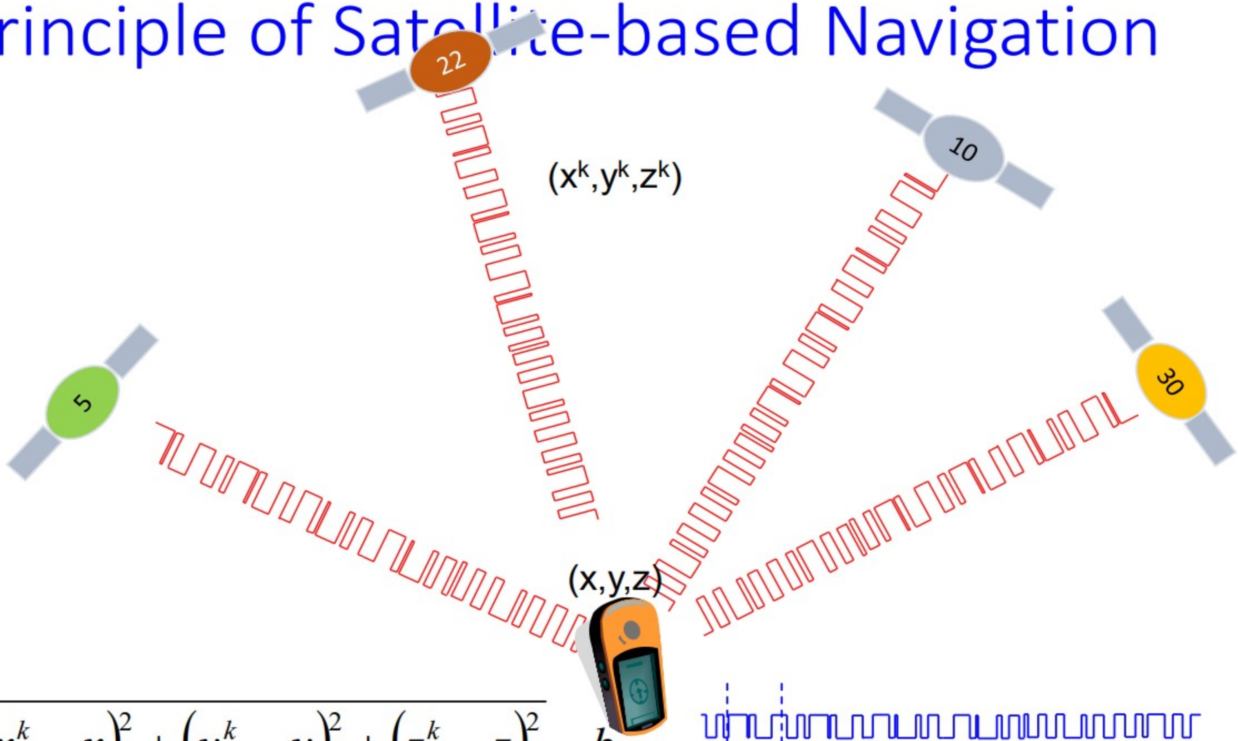
Click for a text description of Figure 5.8.

Three graphics of Satellite Ranging:

- **One satellite: position is anywhere on surface of sphere.**
- **Two satellites: position is anywhere on circle where spheres intersect.**
- **Three satellites: Position is one of two locations where all three spheres intersect. Location nearest Earth is chosen.**

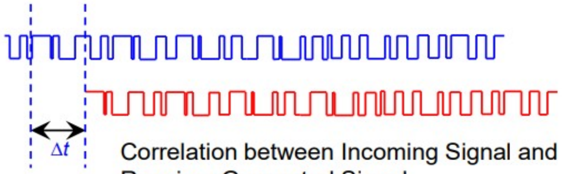
Credit: Joshua Stevens, Department of Geography, The Pennsylvania State University.

Principle of Satellite-based Navigation



$$\rho^k = \sqrt{\left(x^k - x\right)^2 + \left(y^k - y\right)^2 + \left(z^k - z\right)^2} - b$$

If k ≥ 4, solve for x, y, z and clock bias, b



Correlation between Incoming Signal and Receiver Generated Signal

Credit: Dinesh. Manandhar, CSIS, The University of Tokyo

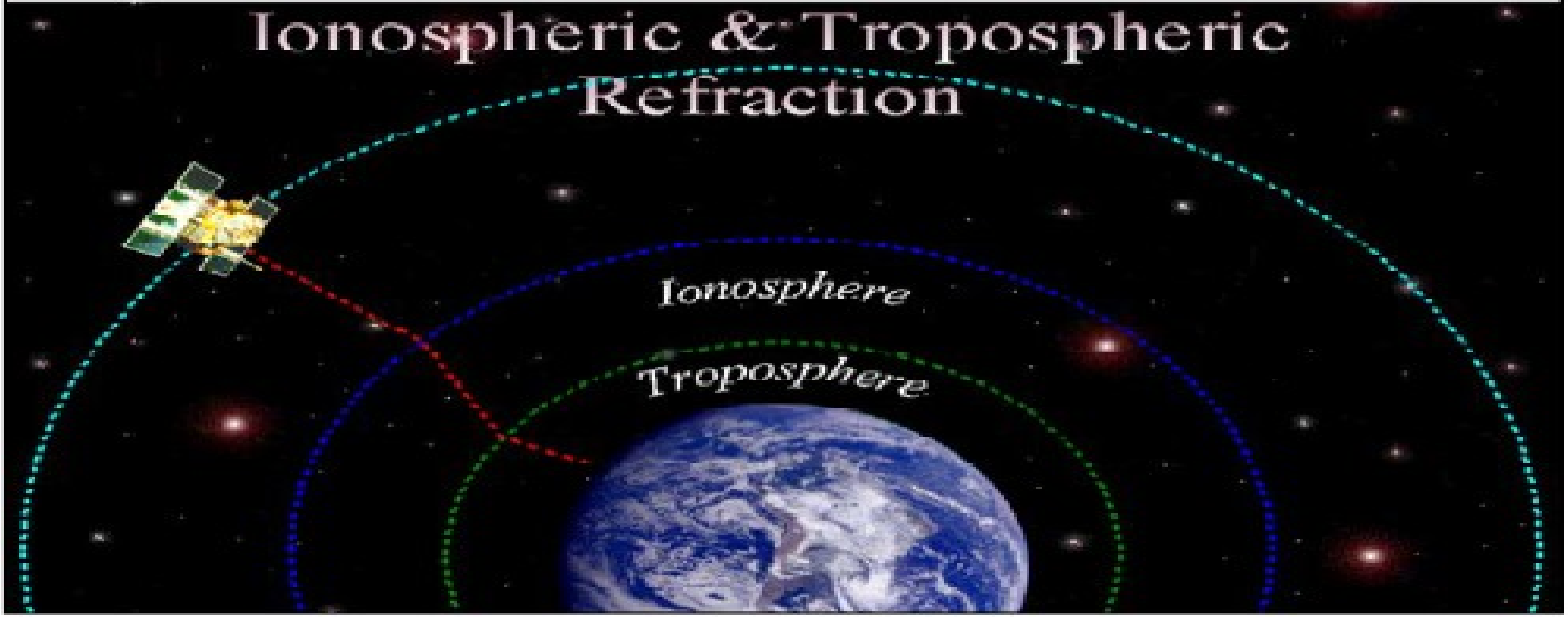
GPS errors

- Atmospheric effects
- Measurement noise
- Ephemeris errors
- Satellite clock drift
- Multi-path effects
- Satellite geometry
- Selective Availability (turned off May 2000)

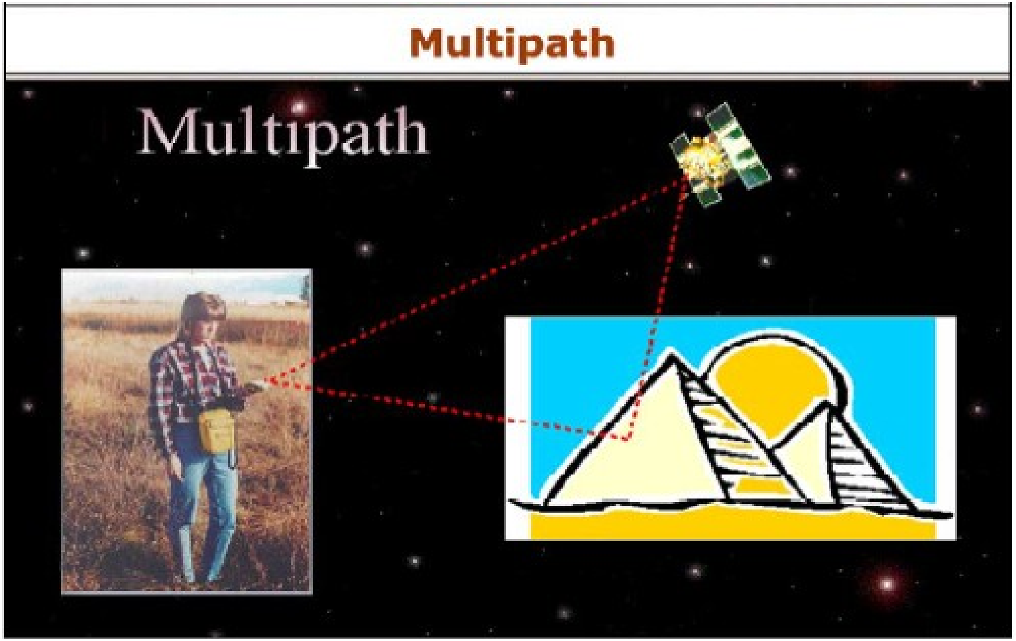
Many contributing factors add to the error associated with acquisition of a GPS location. In the next few slides you will explore the sources and influence of the different errors on the total GPS error.

The last bullet in the slide addresses the error introduced by 'Selective Availability'. Selective Availability was a ~100 m error introduced to the GPS signal by the Department of Defense. Selective Availability was turned off in May 2000, and is currently not affecting the accuracy of GPS receivers.

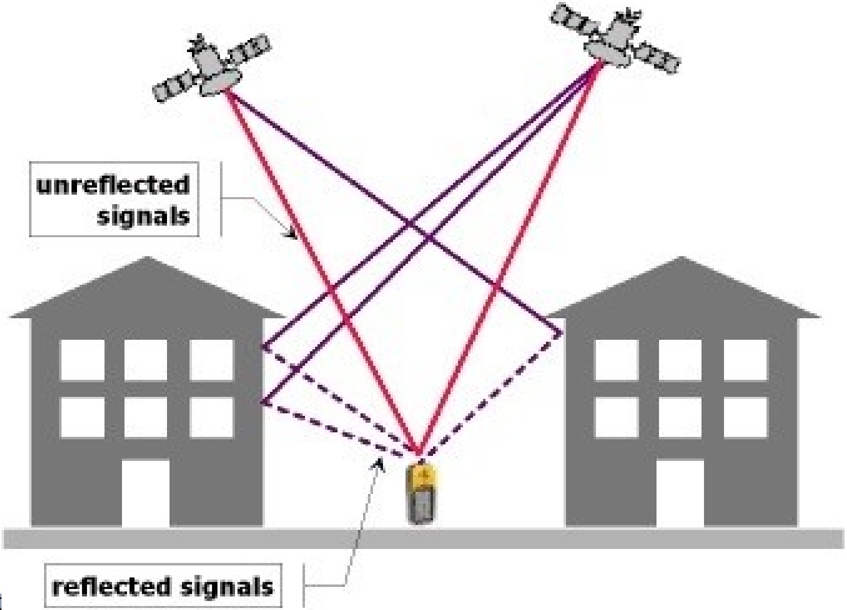
Atmospheric refraction

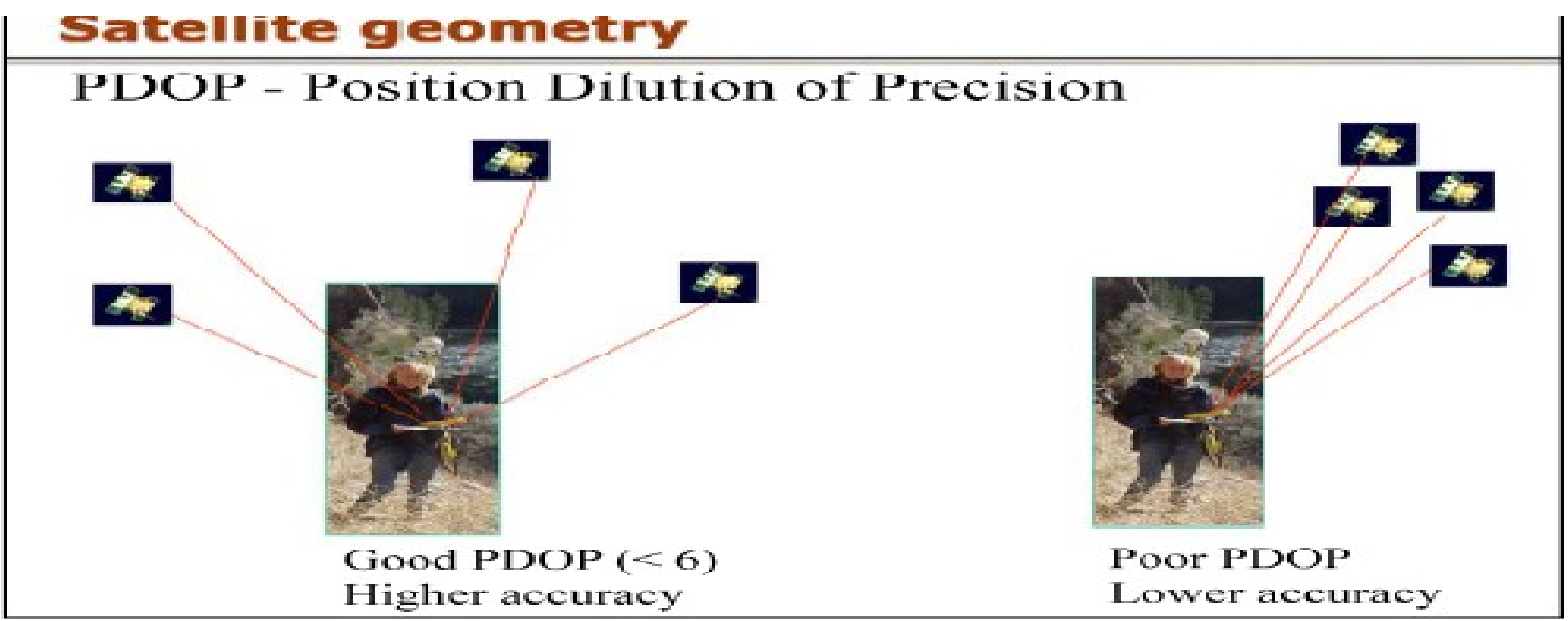


The ionosphere and troposphere both refract the GPS signals. This causes the speed of the GPS signal in the ionosphere and troposphere to be different from the speed of the GPS signal in space. Therefore, the distance calculated from "Signal Speed x Time" will be different for the portion of the GPS signal path that passes through the ionosphere and troposphere and for the portion that passes through space.



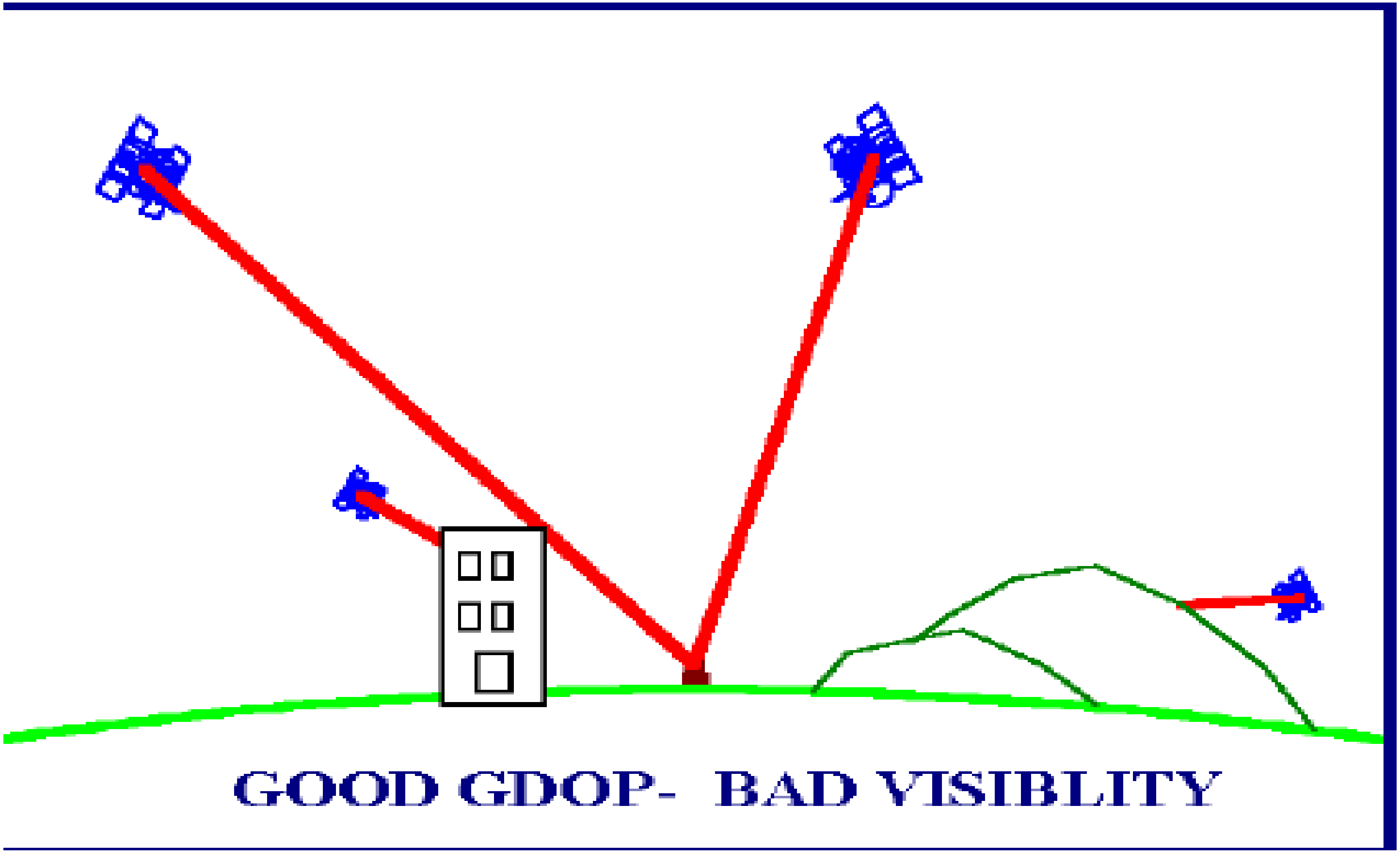
A GPS signal bouncing off a reflective surface prior to reaching the GPS receiver antenna is referred to as multipath. Because it is difficult to completely correct multipath error, even in high precision GPS units, multipat error is a serious concern to the GPS user.





PDOP is an indicator of the quality of the geometry of the satellite constellation. Your computed position can vary depending on which satellites are used for the measurement. Different satellite geometries affect the errors. A greater angle between the satellites lowers the PDOP, and provides a better measurement. A higher DOP indicates poor satellite geometry, and an inferior measurement configuration.

PDOP under good conditions is below 6. The accuracy specification for a high end GPS unit is only valid when the PDOP is below a specified value (usually 6).


GOOD GDOP- BAD VISIBLITY

GPS Error Budget

- Ionosphere................................5.0 meters
- Troposphere..............................0.5 meters
- Ephemeris data..........................2.5 meters
- Satellite clock drift......................1.5 meters
- Multipath...................................0.6 meters
- Measurement noise......................0.3 meters
- ~~Selective availability.................30-100 meters~~

- Total.......................................~ 10 meters

The error levels for different sources of GPS error are listed in the table above. Selective Availability was an error introduced by the Department of Defense, however this error was turned off in May of year 2000.

Ephemeris data refers to imperfections in the satellite orbits.

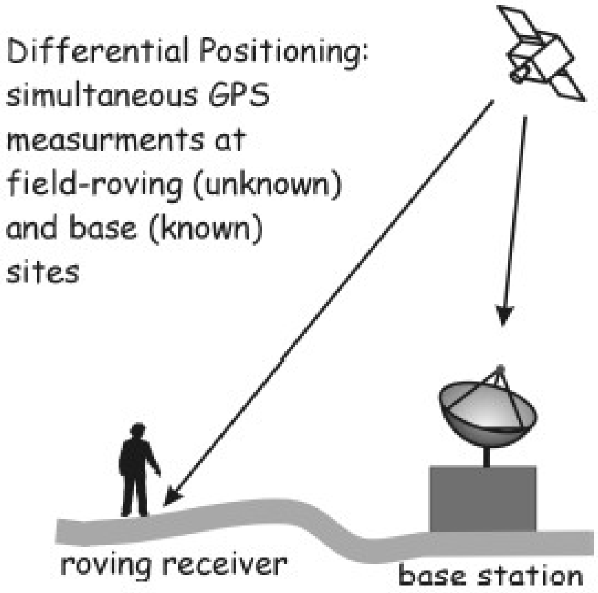
Differential GPS

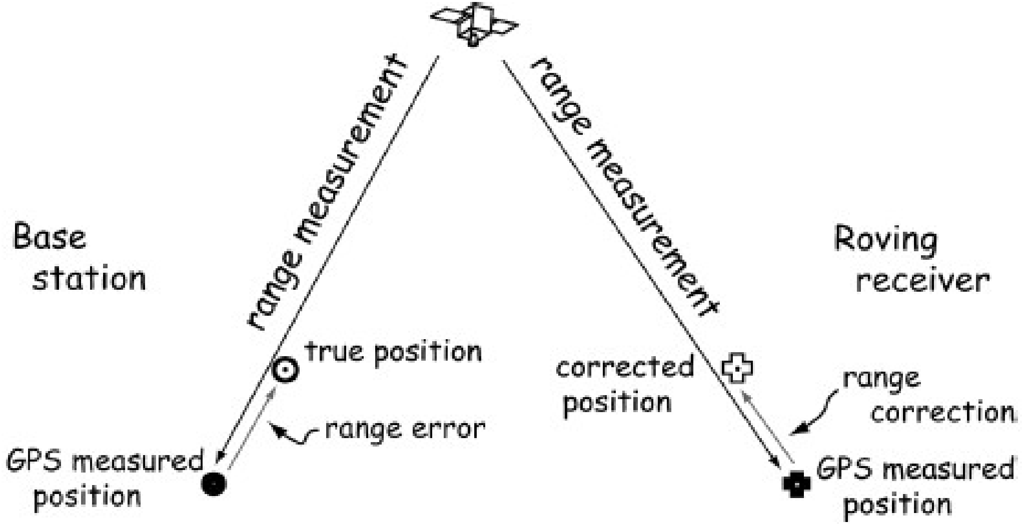
....is used to correct for errors

1) Real-time differential correction

2) Post-processing

Differential GPS (DGPS) incorporates a series of techniques to account for some of the GPS errors. Differential GPS can be applied 'on the fly' (real-time differential GPS) or post-processing differential correction (correction applied to the GPS data after it has been collected).





*Good correction is found when the roving receiver is within 300 km (180 miles) of the base station.

Differential GPS

- Involves use of two receivers - one that's stationary (reference) and another rover
- errors are a compounding of factors, but receivers within 100km usually have same errors
- stationary receiver sits on a known location and back calculates what the timing should be, compares with what they are and develops "error correction" factor
- corrections are transmitted to rovers
- or differential corrections are made after field data collection - post-processing differential correction

Visual Image Interpretation

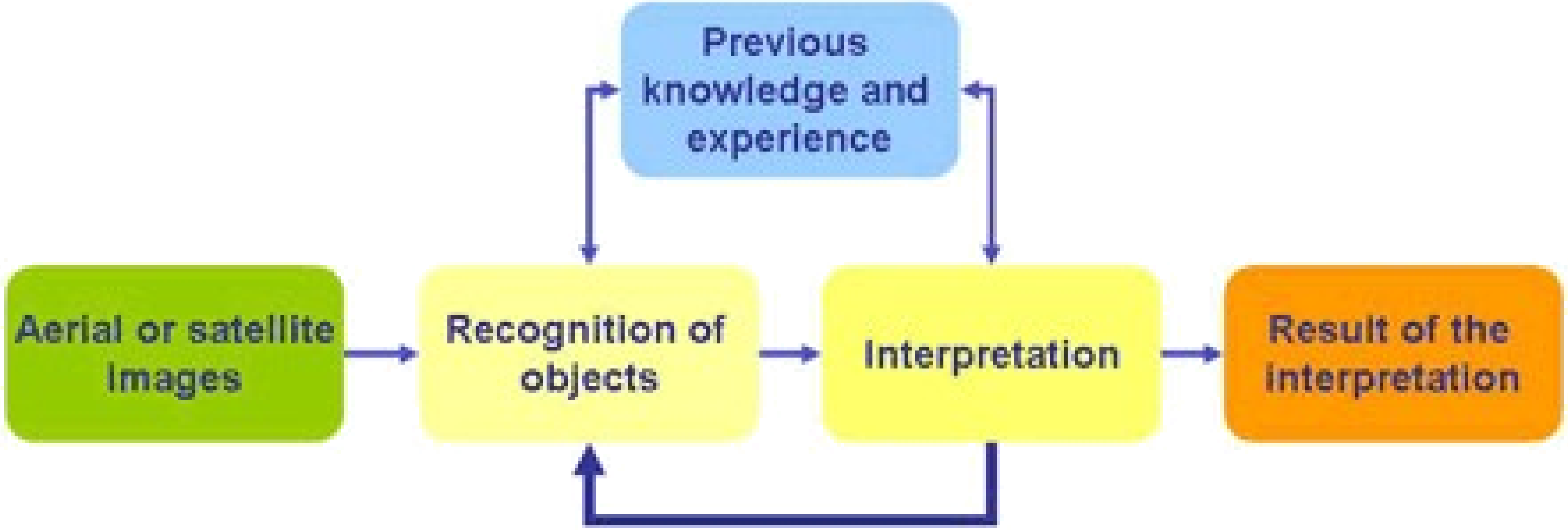
Visual Image Interpretation

- **Visual perception** is the ability to interpret information and surroundings from the effects of visible light reaching the eye,
- **Interpretation** is the process of extraction of qualitative and quantitative information of objects from aerial photographs or satellite images.
- Visual image interpretation is very useful in various fields; geography, geology, agriculture, forestry, environment, ocean studies, wetlands, conservation of natural resources, urban and regional planning, defense and many other purposes.

Visual Image Interpretation

- Image interpretation and Aerial photo interpretation,
- Based on the mode of the interpretation, interpretation can be categorised into visual and digital interpretation.
- Much interpretation and identification of targets in remote sensing imagery is performed manually or visually, i.e. by a human interpreter
- When remote sensing data are available in digital format, **digital processing and analysis** may be performed using a computer

Visual Image Interpretation



Source: Albertz 2007 with modifications

Visual Image Interpretation

Manual interpretation

- Manual interpretation and analysis dates back to the early beginnings of remote sensing for air photo interpretation.
- Manual interpretation requires little, if any, specialized equipment
- Manual interpretation is often limited to analyzing only a single channel of data or a single image at a time due to the difficulty in performing visual interpretation with multiple images
- Manual interpretation is a subjective process, meaning that the results will vary with different interpreters

Digital processing

- Digital processing and analysis is more recent with the advent of digital recording of remote sensing data and the development of computers.
- digital analysis requires specialized, and often expensive, equipment
- digital analysis is useful for simultaneous analysis of many spectral bands and can process large data sets much faster than a human interpreter
- Digital analysis is based on the manipulation of digital numbers in a computer and is thus more objective, generally resulting in more consistent result

Elements of Visual Interpretation

- Image interpretations employ combination of the following eight elements
  - **tone,**
  - **shape,**
  - **size,**
  - **texture,**
  - **Site**
  - **shadow**
  - **association,**

Image elements

  - **pattern**

Terrain element

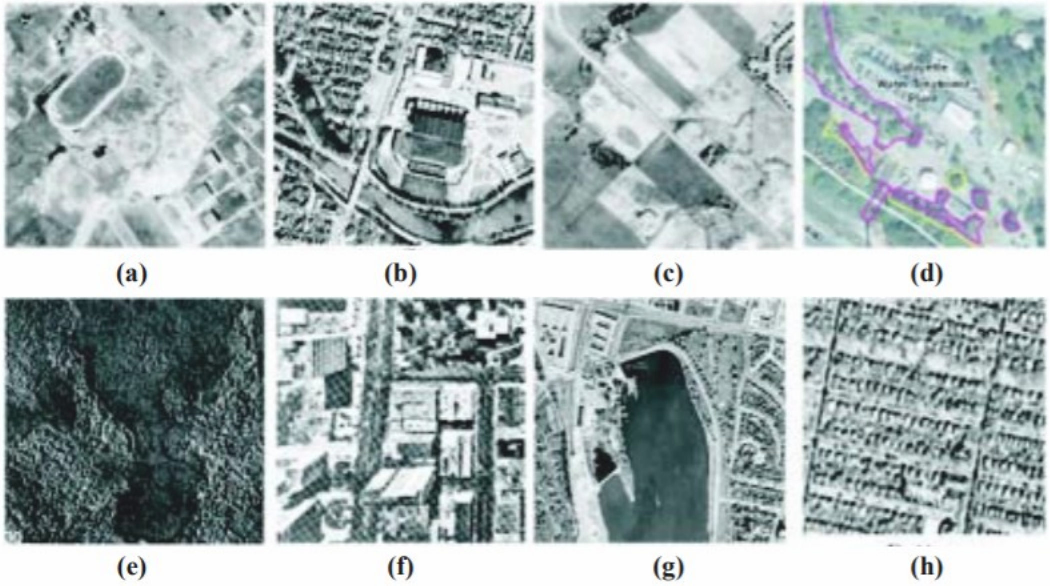
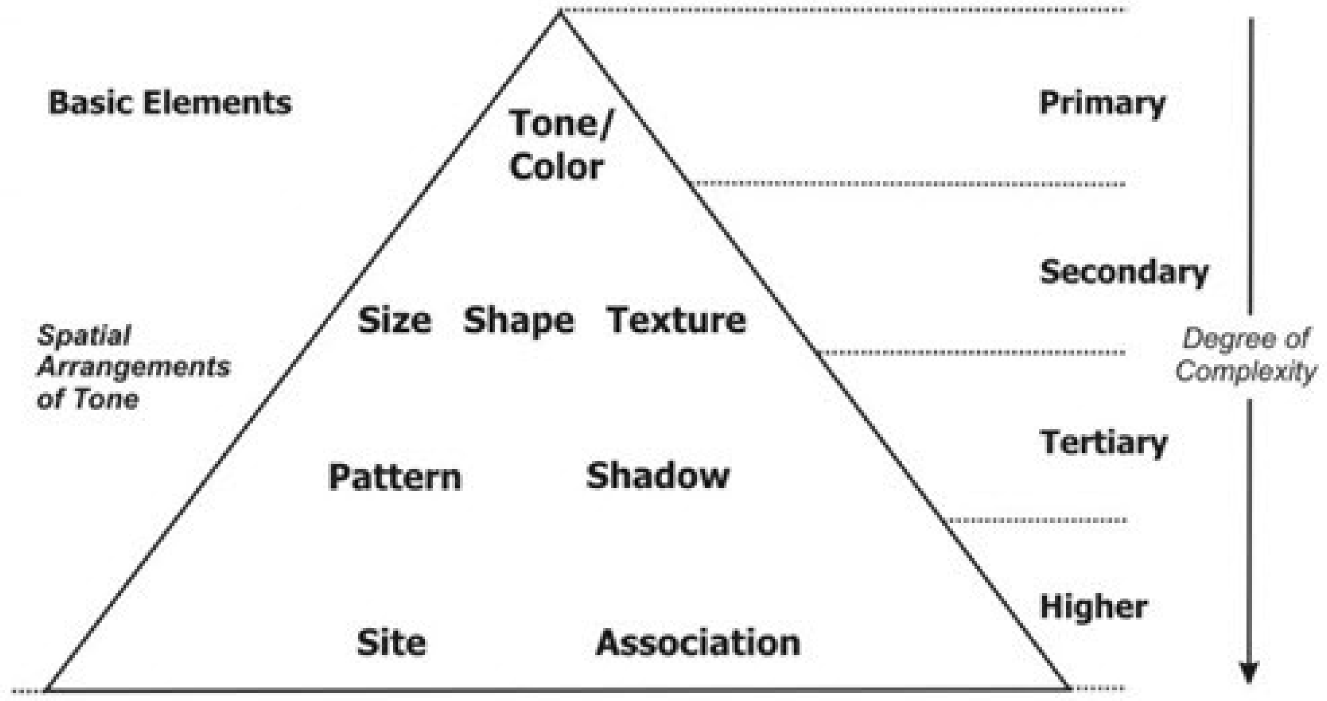


Fig. 7.4: Representative examples of the eight elements of visual image interpretation. (a) Shape, (b) size, (c) tone, (d) site, (e) texture, (f) shadow, (g) association and (h) pattern (source: http://ccrs.nrcan.gc.ca)

Ordering of image elements in image interpretation



Tone or colour

- refers to the relative brightness or colour of objects in an image
- Tone is the fundamental element for distinguishing between different targets or features
- variations in the tone or the colour depend upon the orientation of incoming radiations, surface properties and the composition of the objects.
- Example: smooth and dry object surfaces reflect more energy in comparison to the rough and moist surfaces

7.13 (a) Turbid river

7.13 (b) River with fresh water

a fresh water body absorbs much of the radiations received by it and appears in dark tone or black colour, whereas the turbid water body appears in light tone or light bluish colour

Colour Signatures on Standard False Colour Composite of Earth Surface Features

S. No.	Earth Surface Feature	Colour(In Standard FCC)
1.	**Healthy Vegetation and Cultivated Areas**	
	Evergreen	Red to magenta
	Deciduous	Brown to red
	Scrubs	Light brown with red patches
	Cropped land	Bright red
	Fallow land	Light blue to white
2.	**Waterbody**	
	Clear water	Dark blue to black
	Turbid waterbody	Light blue
3.	**Built – up area**	
	High density	Dark blue to bluish green
	Low density	Light blue
4.	**Waste lands/Rock outcrops**	
	Rock outcrops	Light brown
	Sandy deserts/River sand/ Salt affected	Light blue to white
	Deep ravines	Dark green
	Shallow ravines	Light green
	Water logged/Wet lands	Motelled black

Shape

- refers to the general form, structure, or outline of individual objects.
- Shape can be a very distinctive clue for interpretation. Straight edge shapes typically represent urban or agricultural (field) targets, while natural features, such as forest edges, are generally more irregular in shape, except where man has created a road or clear cuts.
- Farm or crop land irrigated by rotating sprinkler systems would appear as circular shapes.

Figure 7.16 Curvilinear shape of the Railway Tract is Distinctly different from Sharp Bending Roads.

Size of objects in an image is a function of scale. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target.
A quick approximation of target size can direct interpretation to an appropriate result more quickly.

Site

- **s**ite refers to the topographic position, for example, sewage treatment facilities are positioned at low topographic sites near stream or river
- certain tree species located in areas of specific altitudes.

Texture

- refers to the arrangement and frequency of tonal variation in particular areas of an image.
- Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation.
- Smooth textures are most often the result of uniform, even surfaces, such as fields, asphalt, or grasslands.

Figure 7.14 (a) Coarse texture image of mangroves

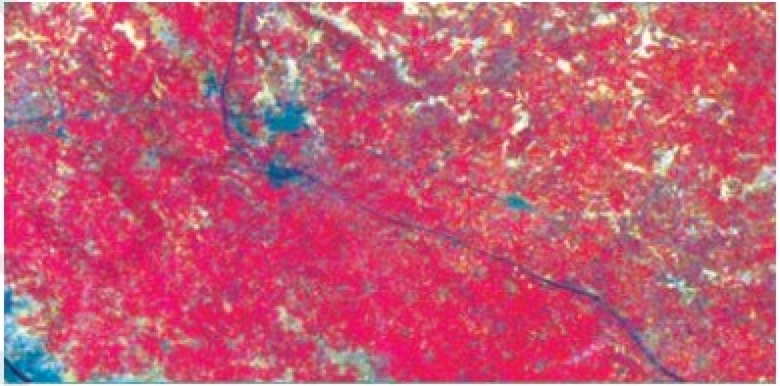


Figure 7.14 (b) Fine texture of cropped land

- A target with a rough surface and irregular structure, such as a forest canopy, results in a rough textured appearance.
- Texture is one of the most important elements for distinguishing features in radar imagery.

Shadow

- Shadow of an object is a function of the sun's illumination angle and the height of the object itself
- The shape of some of the objects is so typical that they could not be identified without finding out the length of the shadow they cast.
  - For example, the Dharahara in KMC, the Qutub Minar located in Delhi, overhead water tanks, electric or telephone lines, and similar features can only be identified using their shadow,

Fig. 7.9: Taller objects such as the Qutub Minar cast larger shadow than smaller objects such as buildings and trees (source:earth.google.com)

- the shadow as an element of image interpretation is of less use in satellite images. However, it serves a useful purpose in large-scale aerial photography

Association

- refers to the relationship between the objects and their surroundings along with their geographical location.
  - For example, an educational institution always finds its association with its location in or near a residential area as well as the location of a playground within the same premises
  - commercial properties may be associated with proximity to major transportation routes, whereas residential areas would be associated with schools, playgrounds, and sports fields.

In the given image, a lake is associated with boats, a marina, and adjacent recreational land.

Pattern

- The spatial arrangements of many natural and man–made features show repetitive appearance of forms and relationships.
- Typically an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern.
- Orchards with evenly spaced trees, and urban streets with regularly spaced houses are good examples of pattern.

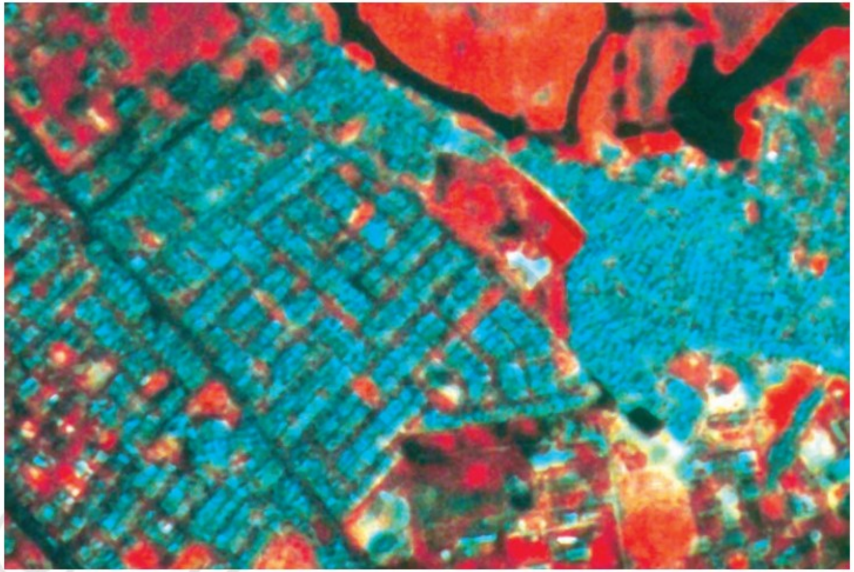


Figure 7.17 *Planned residential areas are easily identifiable using the pattern they form*

- Urban and rural settlement areas can be easily identified based on the patterns created by the rows of houses or buildings

Typical adjectives associated with interpretation elements

(source: Bhatta, 2010)

Element	Common adjectives (quantitative and qualitative)
Location	x,y coordinates: longitude and latitude or meters, easting and northing in a map grid
Size	Length, width, perimeters, area: small, medium (intermediate) and large
Shape	An object's geometric characteristics: linear, curvilinear, circular, elliptical, radial, square, rectangular, triangular, hexagonal, pentagonal, amorphous, etc
Shadow	A silhouette caused by solar illumination from the side
Tone/colour	Gray tone: light (bright), intermediate (gray), dark (black) colour = intensity, hue, saturation
Texture	Characteristics placement and arrangement of repetition of tone or colour; smooth, intermediate (medium), rough (coarse), mottled, stippled
Pattern	The spatial arrangement of objects on the ground; systematic, unsystematic or random, linear, curvilinear, rectangular, circular, elliptical, parallel, centripetal, serrated, striated, braided
Height/depth/volume/aspect	Z-elevation (height), depth (bathymetry), volume, slope, aspect
Site/situation/association	Site: elevation, slope, aspect, exposure, adjacency to water, transportation, utilities Situation: objects are placed in a particular order or orientation relative to one another association: related phenomena are usually present

Typical Examples of Image Interpretation

Example of Image Interpretation

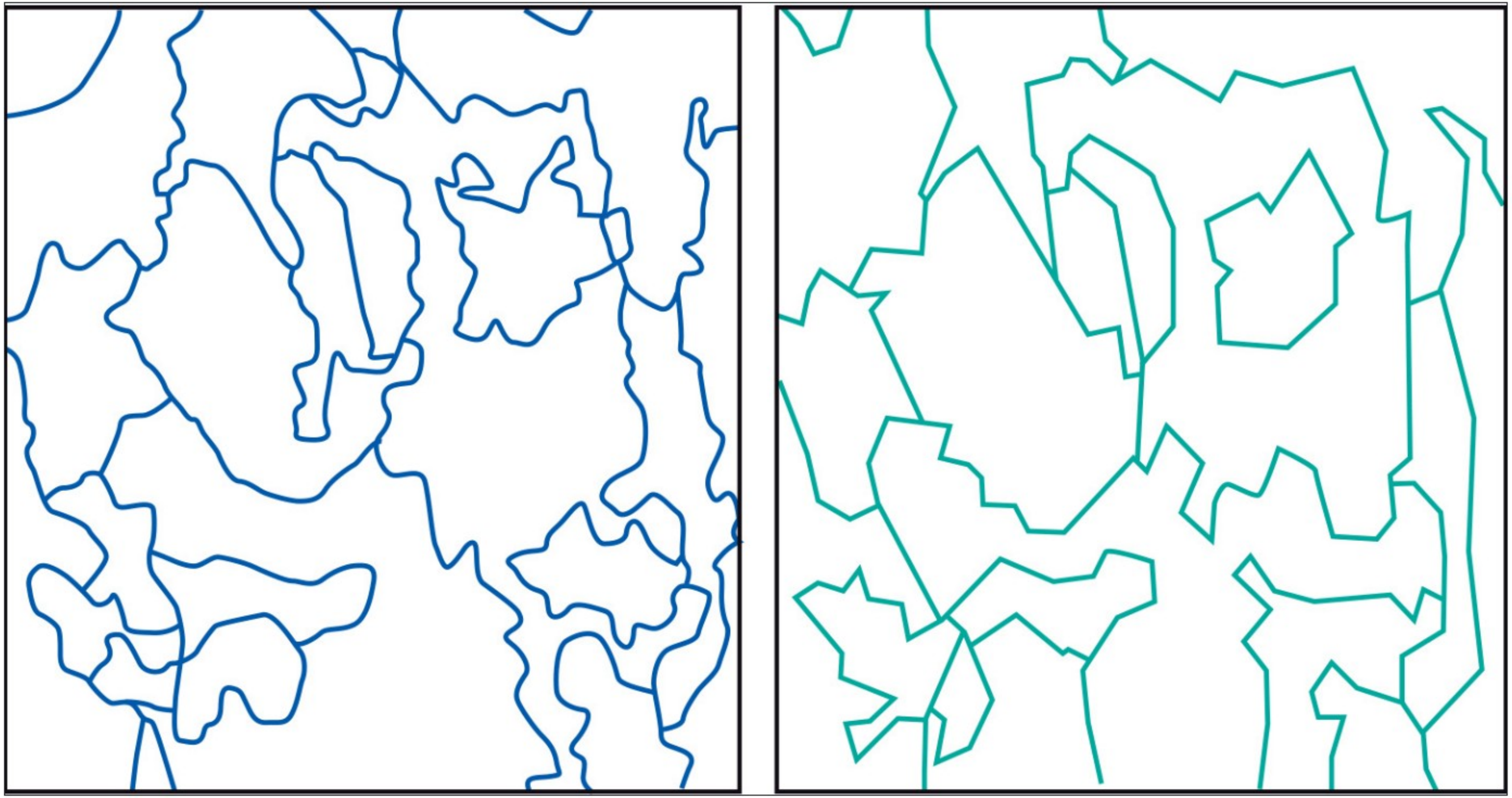


Figure A. Two interpretation results derived by two photo-interpreters analysing the same image (Middelkoop, H. 1990).

Image Interpretation Keys

- The eight interpretation elements (size, shape, shadow, tone, color, texture, pattern and associated relationship), as well as the time the image/photograph is taken, season, film type and image/photo-scale should be carefully considered when developing interpretation keys
- It is the criteria for identification of an object with interpretation elements and it can be one of two generic types:
- **Selective keys** contain numerous example images with the supporting text. The interpreter selects the example that most closely resembles the feature or condition found on the image being studied.

- **Elimination keys** are composed of word descriptions ranging through various levels of broad to specific characteristic discrimination. Interpretation proceeds step by step from general to specific and leads to elimination of all features or conditions except the one being identified.

Image Interpretation Keys

Table 7.3: An example of interpretation keys for forest mapping, Japan Association of Forestry (source: http://stlab.iis.u-tokyo.ac.jp/~wataru /lecture/rsgis/rsnote/cp7/t7-5-1.gif)

Feature	Tone	Crown shape	Edge of crown	Pattern	Texture
Cedar	Dark	Conical with sharp spear	Circular and sharp	Spotted grain	Hard and coarse
Cypress	Dark but lighter than cedar	Conical with round crown	Circular	Spotted	Hard and fine
Pine	Light and unclear	Cylindrical with shapeless	Circular but unclear	Irregularly spotted	Soft but coarse
Larch	Lighter than cypress	Conical with unclear crown	Circular with unclear edge	Spotted	Soft and fine
Fir/spruce	Dark and clear	Conical with wider crown	Circular with zigzag edge	Irregular	Coarse
Deciduous	Lighter	Irregular	Unclear	Irregular	Coarse

Image Interpretation Keys

Table 7.4: A sample of image interpretation keys used for interpreting for landcover mapping (source: http://stlab.iis.u-tokyo.ac.jp/~ wataru /lecture/rsgis/rsnote/cp7/t7-5-2.gif). PW-Pure White, W-White, DRG-Dark Gray, R-Red, B-Blue, P-Pink, G-Green, LB-Light Blue, RP-Reddish Purple, GR-Gray, BL-Black, BY-Brandish Yellow and BP-Bluish Purple

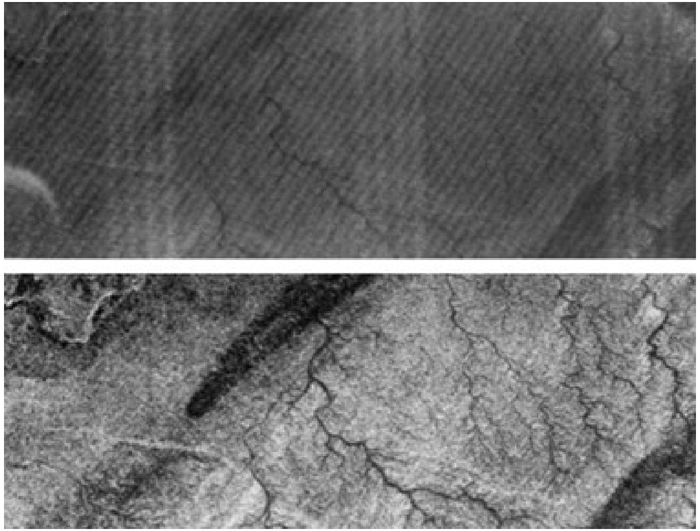
	Band 4	Band 5	Band 6	Band 7	457 (BGR)	457(RGB)
Snow	PW	PW	PW	PW	PW	PW
Cloud	W	W	W	W	W	W
Haze	W	W	—	—	W	W
Forest	DGR	BL	W	W	R	G
Grass	GR	DG	W	W	P	BY
Bare land	GR	W	W	W	W	W
Wet land	GR	W	GR	DGR	LB	RP
Urban	GR	W	GR	DGR	LB	RP
Water	DGR	BL	BL	BL	B	BP
Shadow	BL	BL	BL	BL	BL	BL

Digital Image Processing

- Digital image processing may involve numerous procedures including formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer.
- most of the common image processing functions available in image analysis systems can be categorized into the following four categories:
  - Preprocessing
  - Image Enhancement
  - Image Transformation
  - Image Classification and Analysis

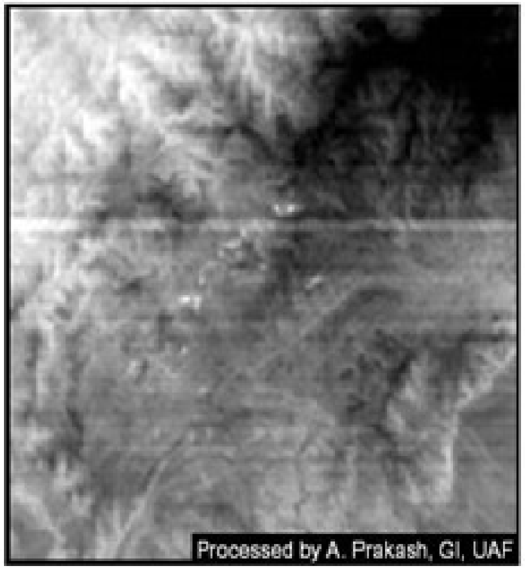
Digital Image Processing

- **Preprocessing** functions involve those operations that are normally required prior to the main data analysis and extraction of information, and are generally grouped **as radiometric and geometric corrections**
- Radiometric corrections include correcting the data for sensor irregularities and unwanted sensor or atmospheric noise, and converting the data so they accurately represent the reflected or emitted radiation measured by the sensor.
  - Noise correction
  - Sun angle correction
  - Correction for atmospheric scattering

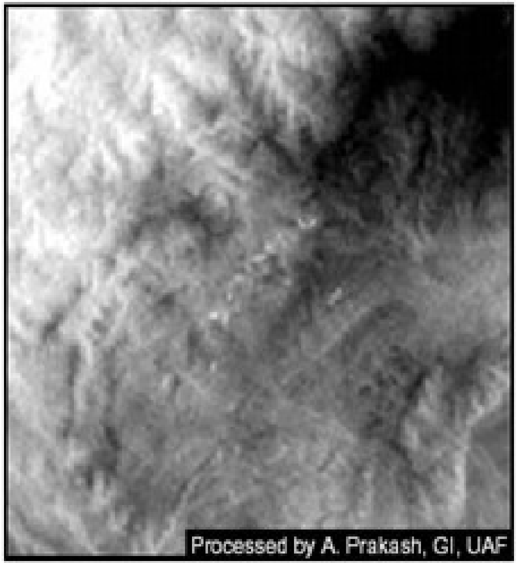


SAR B Radar image before and after noise correction

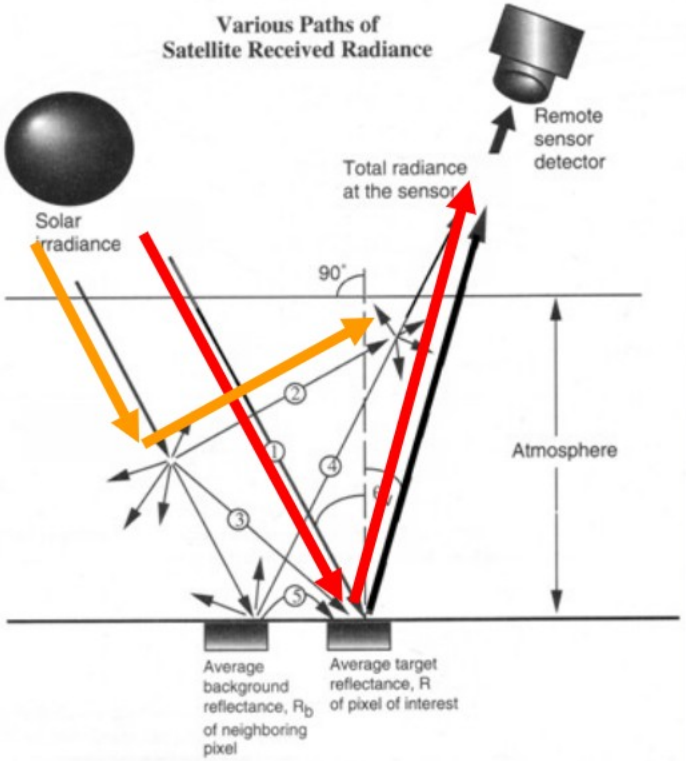
Striping –Landsat image



Striping



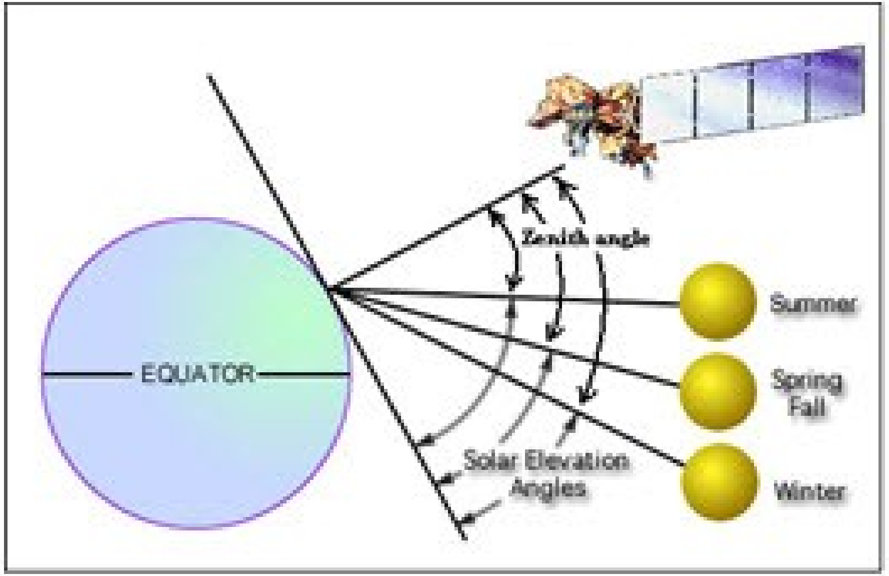
De-striped



Direct and scattered illumination

Sun angle correction

- Position of the sun relative to the earth changes depending on time of the day and the day of the year
- Solar elevation angle: Time- and location dependent
- In the northern hemisphere the solar elevation angle is smaller in winter than in summer
- The solar zenith angle is equal to 90 degree minus the solar elevation angle
- Irradiance varies with the seasonal changes in solar elevation angle and the changing distance between the earth and sun

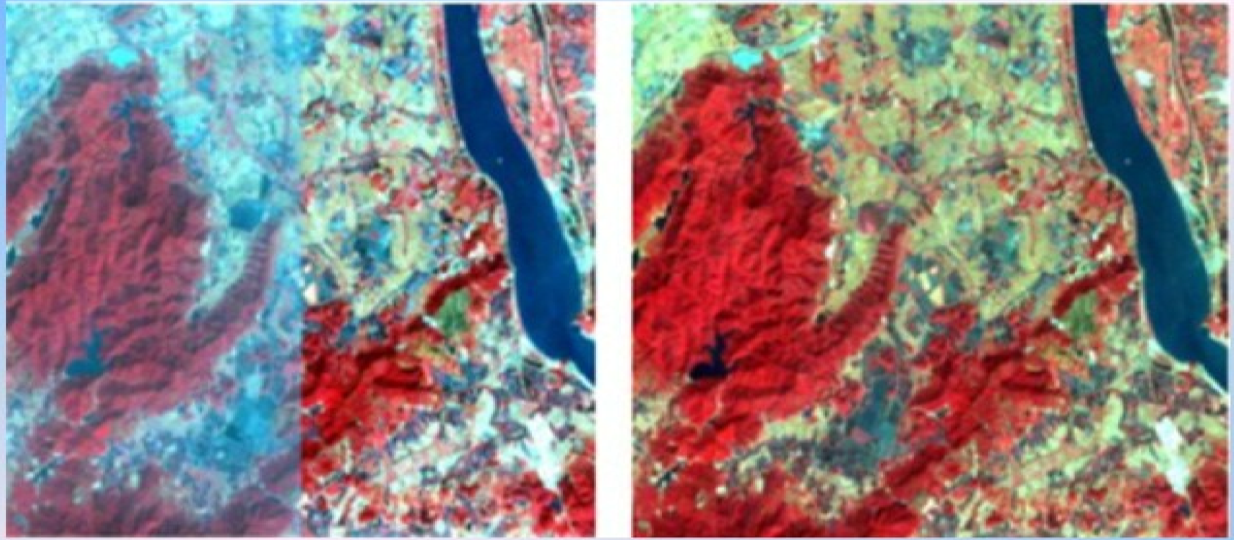


Sun angle correction

- An absolute correction involves dividing the DN-value in the image data by the sine of the solar elevation angle
- Size of the angle is given in the header of the image data

$$DN_{corr} = \frac{DN}{\sin \alpha}$$

Sun angle correction

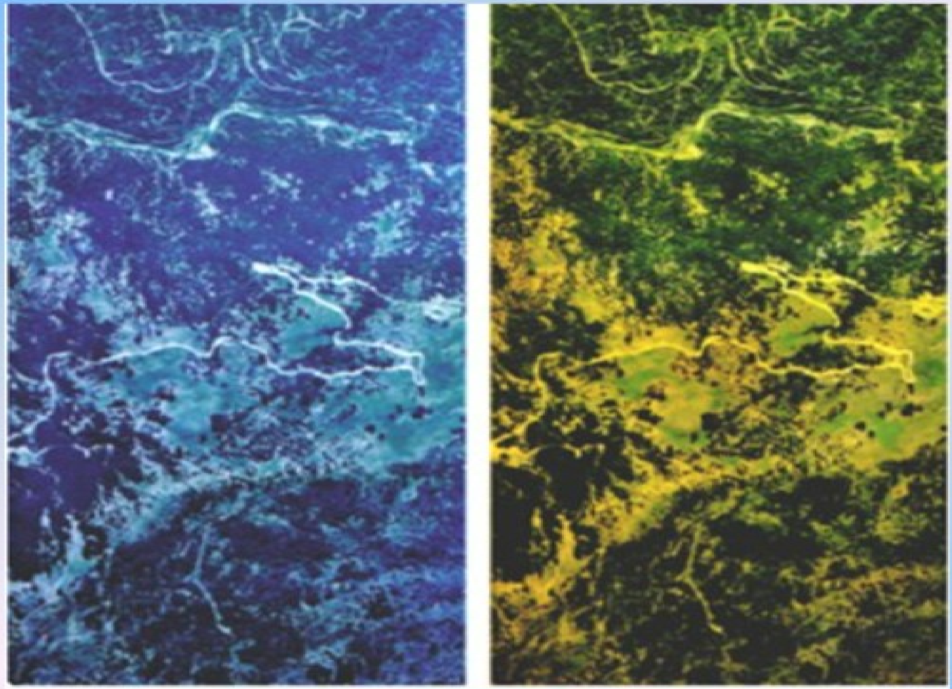


Landsat 7 ETM+ color infrared composites acquired with different sun angle.
(A) The left image was acquired with a sun elevation of 37° and right image
(B) with a sun elevation of 42°. The difference in reflectance is clearly shown.
(C) (B) The left image was corrected to meet the right image.

Haze Reduction

- Aerial and satellite images often contain haze. Presence of haze reduces image contrast and makes visual examination of images difficult.
- Due to Rayleigh scattering
  - Particle size responsible for effect smaller than the radiation's wavelength (e.g. oxygen and nitrogen)
- Haze has an additive effect resulting in higher DN values
- Scattering is wavelength dependent
- Scattering is more pronounced in shorter wavelengths and negligible in the NIR

Haze Reduction



(a) Before haze removal (b) After haze removal

High-altitude normal color air photo of redwood stands and open grass areas in Redwood Creek Basin, California.

Haze removal

The aerial image before haze removal (b) The aerial image after haze removal (a)

- Geometric corrections include correcting for geometric distortions due to sensor-Earth geometry variations, and conversion of the data to real world coordinates (e.g. latitude and longitude) on the Earth's surface.

Digital Image Processing

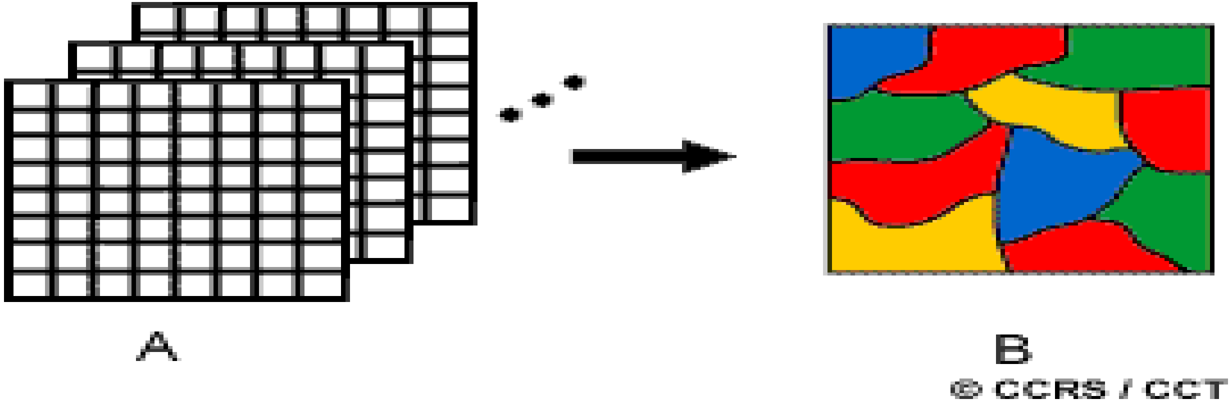
Image enhancement

- is solely to **improve the appearance of the imagery** to assist in visual interpretation and analysis.
- Examples of enhancement functions include contrast stretching to increase the tonal distinction between various features in a scene, and **spatial filtering** to enhance (or suppress) specific spatial patterns in an image.

Digital Image Processing

Image transformations

- are operations similar in concept to those for image enhancement. However, unlike image enhancement operations which are normally applied only to a single channel of data at a time, image transformations usually involve combined processing of data from multiple spectral bands.
- Arithmetic operations (i.e. subtraction, addition, multiplication, division) are performed to combine and transform the original bands into "new" images which better display or highlight certain features in the scene.
- We will look at some of these operations including various methods of **spectral or band** ratioing, and a procedure called **principal components analysis** which is used to more efficiently represent



Digital Image Processing

Image classification and analysis

- are used to digitally identify and classify pixels in the data.
- **Classification** is usually performed on multi-channel data sets (A) and this process assigns each pixel in an image to a particular class or theme (B) based on statistical characteristics of the pixel brightness values.
- There are a variety of approaches taken to perform digital classification.
- There are two generic approaches which are used most often, namely **supervised** and **unsupervised** classification.

WHAT IS A "DN"?

DN stands for Digital Number. It is a function of:

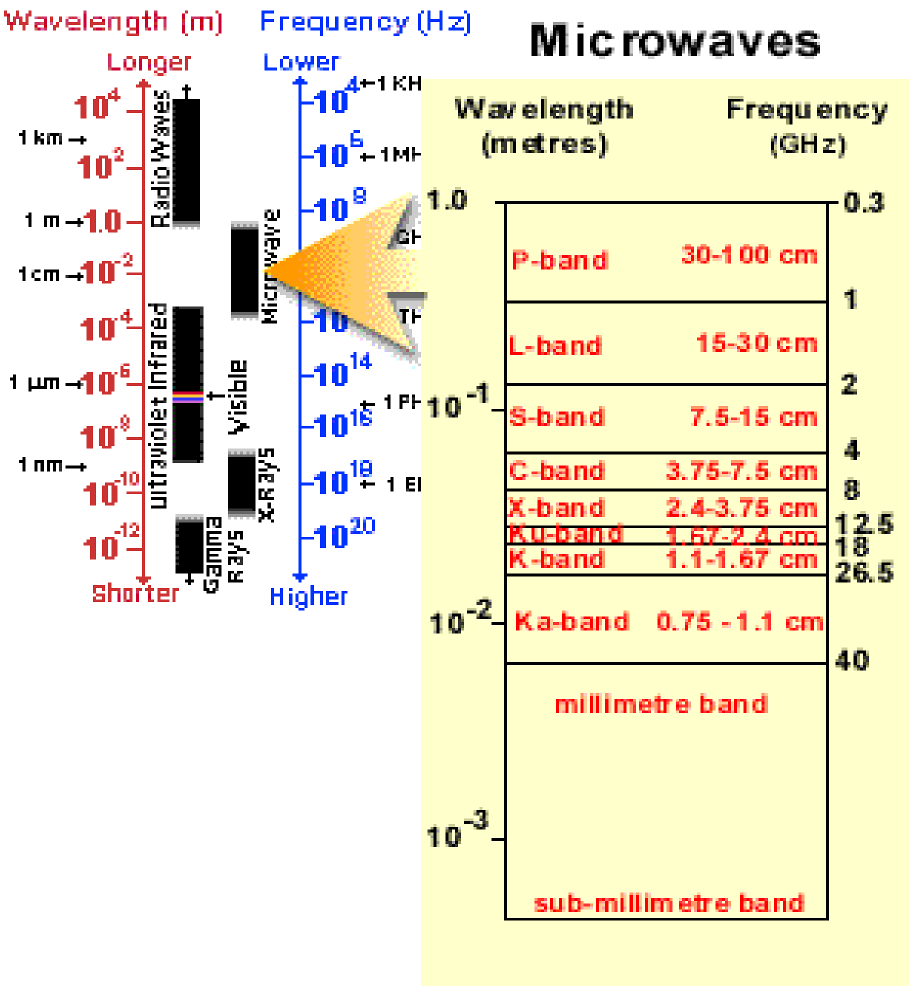
- The reflectance of the target material
- Solar distance
- Atmospheric scattering and absorption
- Slope and aspect of reflecting surface relative to solar azimuth
- Angle of view of the sensor, relative to the local terrain orientation
- Gain setting of the scanner

Microwave Remote Sensing

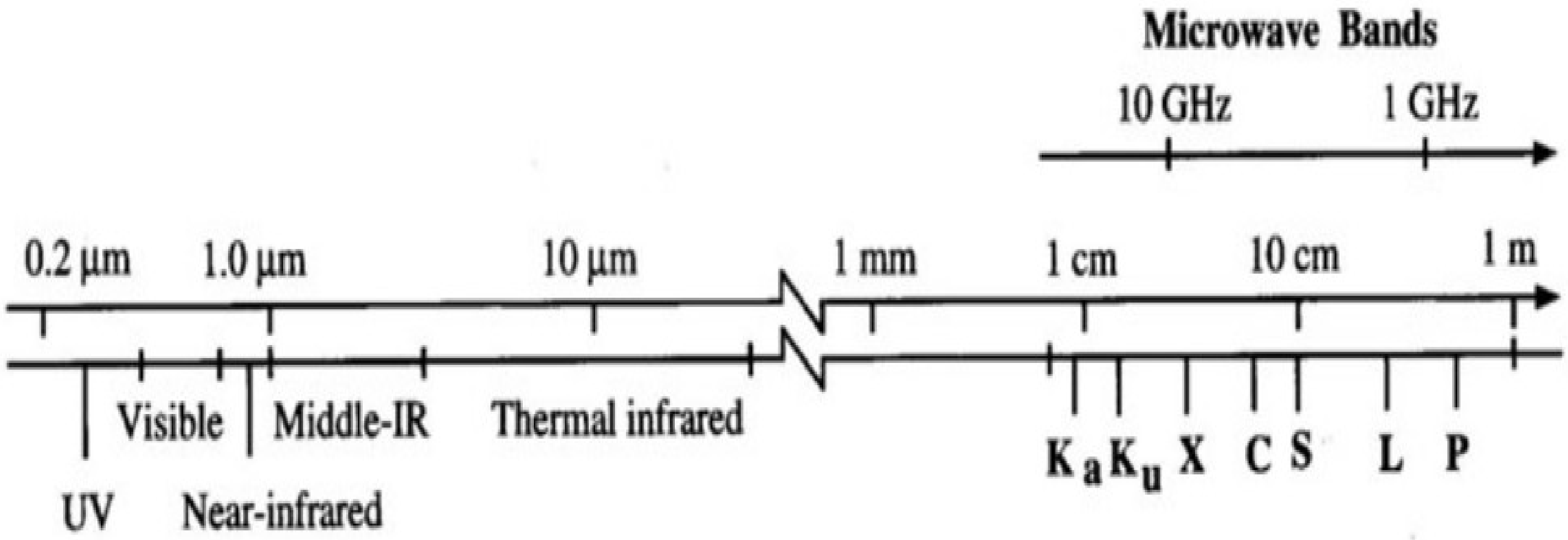
Microwave Remote Sensing

- Microwave remote sensing, using microwave radiation using wavelengths from 1cm – 1m enables observation in all weather conditions without any restriction by cloud or rain.
- Whereas shorter wavelengths (e.g., visible and infrared) provide information on the upper layers of vegetation, the longer wavelengths of microwave and RF signals penetrate deeper into the canopy and substructure providing additional information
- So, this is an advantage that is not possible with the visible and/or infrared remote sensing.

- **Microwave region** from about 1 cm to 1 m and covers the longest wavelengths used for remote sensing
  - Ka, K, and Ku bands: very short wavelengths used in early airborne radar systems but uncommon today.
  - X-band: used extensively on airborne systems for military reconnaissance and terrain mapping



Microwave Remote Sensing

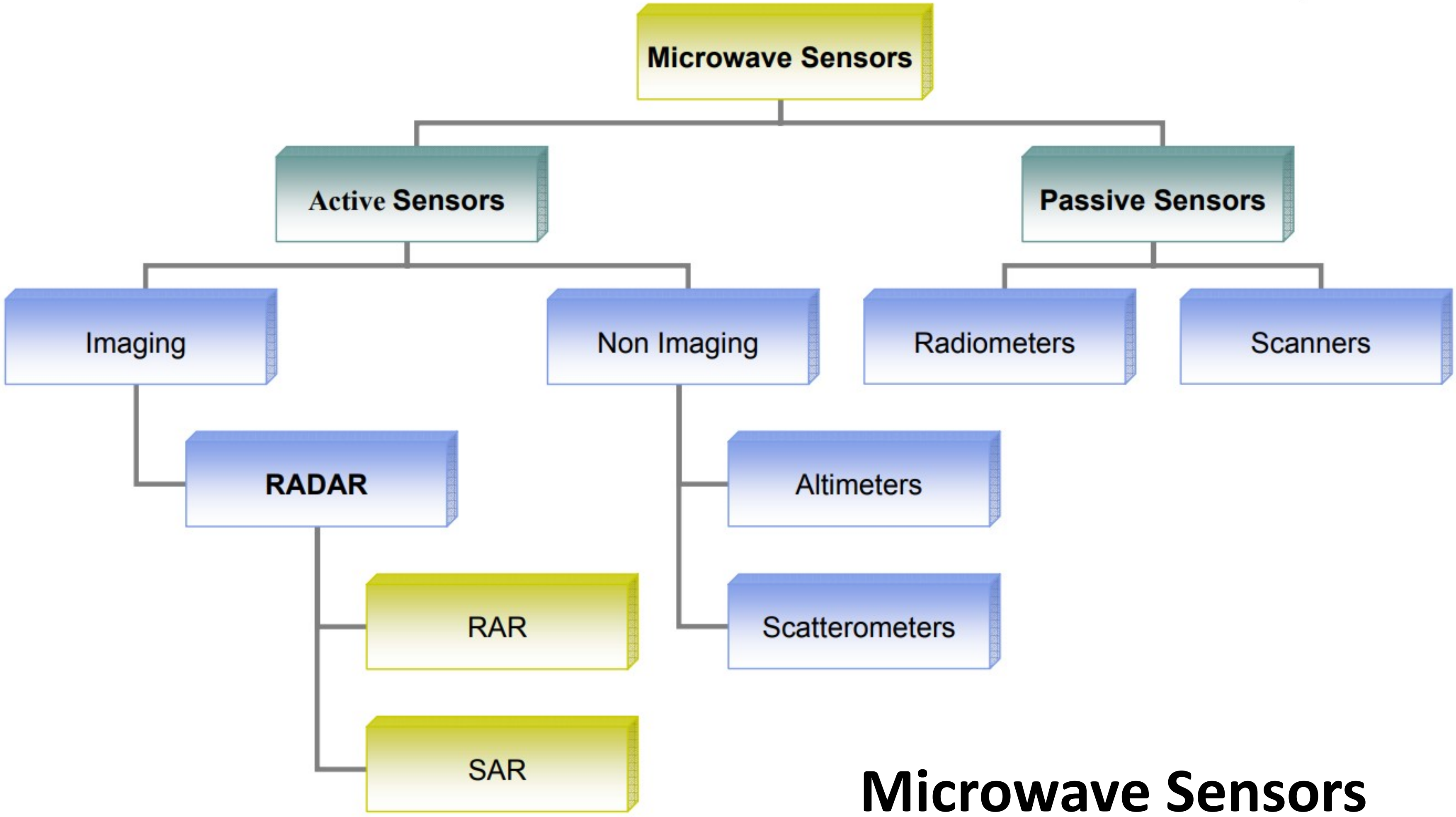


Microwave Remote Sensing

- C-band: common on many airborne research systems (CCRS Convair-580 and NASA AirSAR) and space borne systems (including ERS-1 and 2 and RADARSAT).
- S-band: used on board the Russian ALMAZ satellite.
- L-band: used onboard American SEASAT and Japanese JERS-1 satellites and NASA airborne system
- P-band: longest radar wavelengths, used on NASA experimental airborne research system.

Advantages of Microwave Remote Sensing

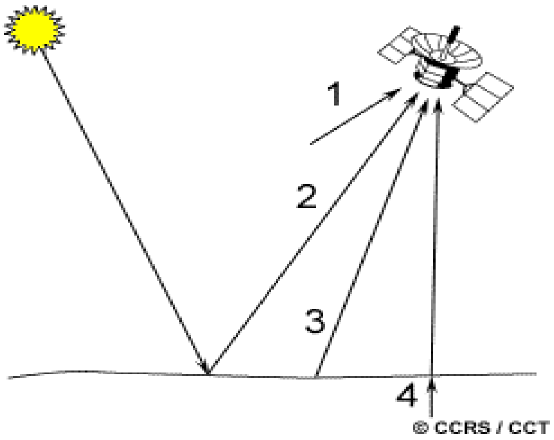
- Time independent.
- Weather independent.
- Sensitive to moisture in soil, vegetation and snow.
- Enhancement of surface roughness / relief.
- Penetration of soil and vegetation cover.
- Ability to collect data which are far away from flight path.



Microwave Sensors

Passive Microwave Remote Sensing

- A passive microwave sensor detects the naturally emitted microwave energy within its field of view.
- This emitted energy is related to the temperature and moisture properties of the emitting object or surface.
- **The microwave energy recorded by a passive sensor**
- emitted by the atmosphere (1), reflected from the surface (2), emitted from the surface (3), or transmitted from the subsurface (4)



Passive Microwave Remote Sensing

- Applications of passive microwave remote sensing include meteorology, hydrology, and oceanography.
- Used for determine water and ozone content in the atmosphere
- measure soil moisture
- mapping sea ice, currents, and surface winds as well as detection of pollutants, such as oil slicks.

Active Microwave Remote Sensing

- Active microwave sensors provide their own source of microwave radiation to illuminate the target.
- Operates in day and night, and largely immune to smoke, haze, fog, rain, snow,
- Active microwave sensors are generally divided into two distinct categories: **imaging and non-imaging**.
- The most common form of imaging active microwave sensors is RADAR **RA**dio **D**etection **A**nd **R**anging)

RADAR Imaging

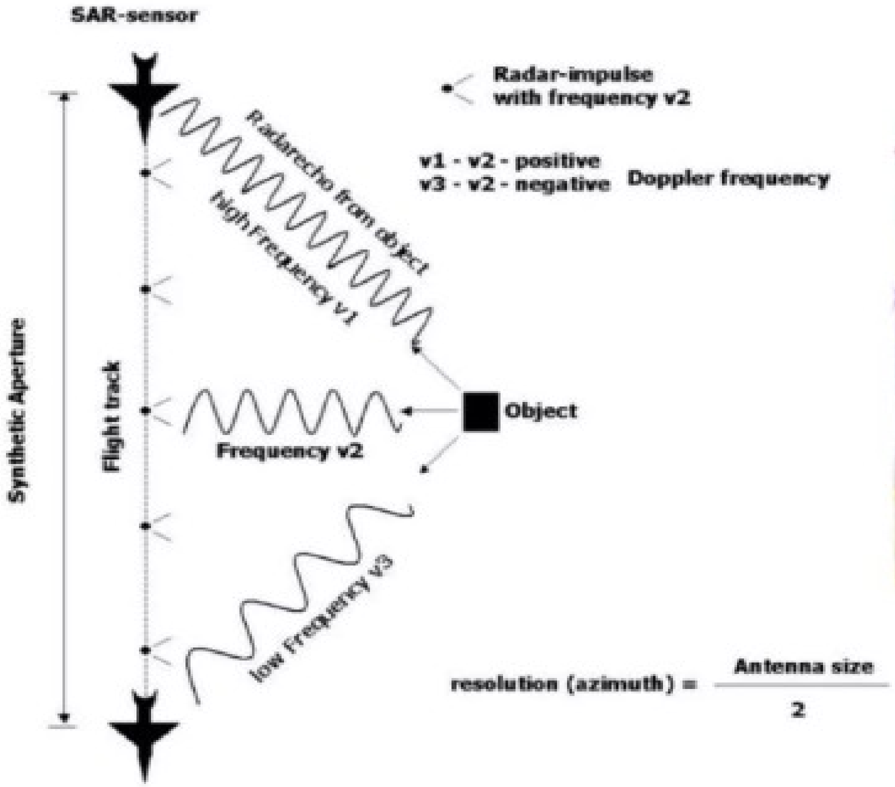
- is the capability of the radiation to penetrate through cloud cover and most weather conditions.
- Because radar is an active sensor, it can also be used to image the surface at any time, day or night. These are the two primary advantages of radar: **all-weather and day or night** imaging.
- consists fundamentally of a transmitter, a receiver, an antenna, and an electronics system to process and record the data

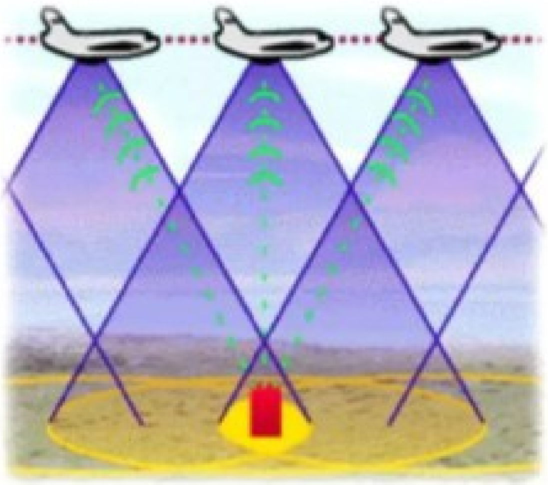
RADAR Imaging- Types

- **SLAR (Side-Looking Airborne Radar)**
  - develop in the 1950's
  - airborne, fixed antenna width, sends one pulse at a time and measures what gets scattered back
  - resolution determined by wavelength and antenna size (narrow antenna width = higher resolution)

- **SAR (Synthetic Aperture Radar)**
  - also developed by those responsible for SLAR, but this configuration is not dependent on the physical antenna size although to achieve higher resolution the receiving antenna components and transmitter components need to be separated.
  - "synthesizes" a very broad antenna by sending multiple pulses

RADAR Imaging- SAR



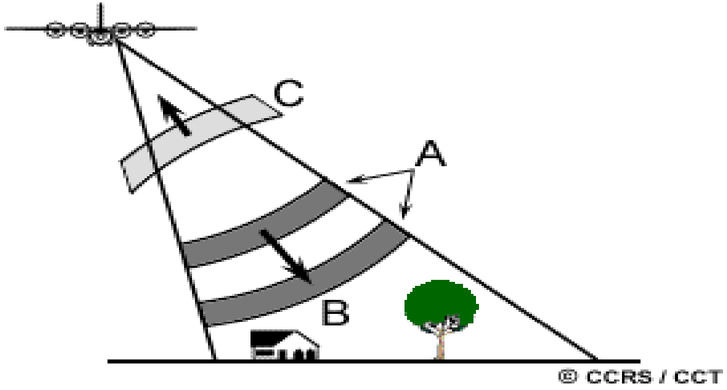


Key Components of a Radar System

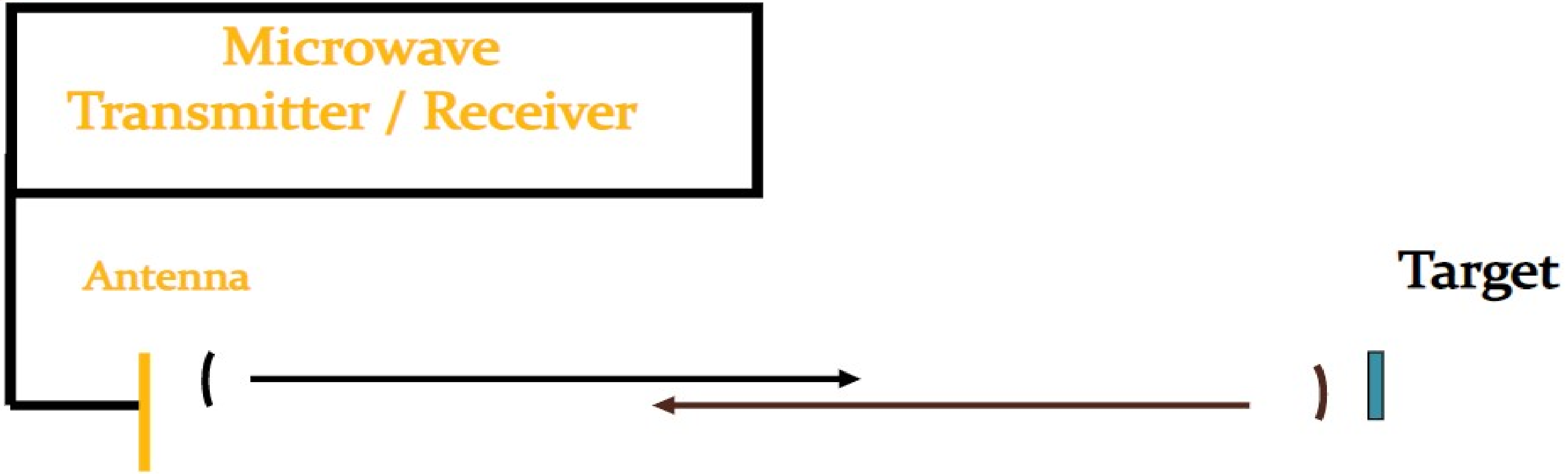
- **Microwave Transmitter** – electronic device used to generate the microwave EM energy transmitted by the radar
- **Microwave Receiver** – electronic device used to detect the microwave pulse that is reflected by the area being imaged by the radar
- **Antenna** – electronic component through which microwave pulses are transmitted and received

RADAR Imaging

- The transmitter generates successive short bursts (or **pulses** of microwave (A) at regular intervals which are focused by the antenna into a beam (B).
- The radar beam illuminates the surface obliquely at a right angle to the motion of the platform. The antenna receives a portion of the transmitted energy reflected (or **backscattered**) from various objects within the illuminated beam (C).

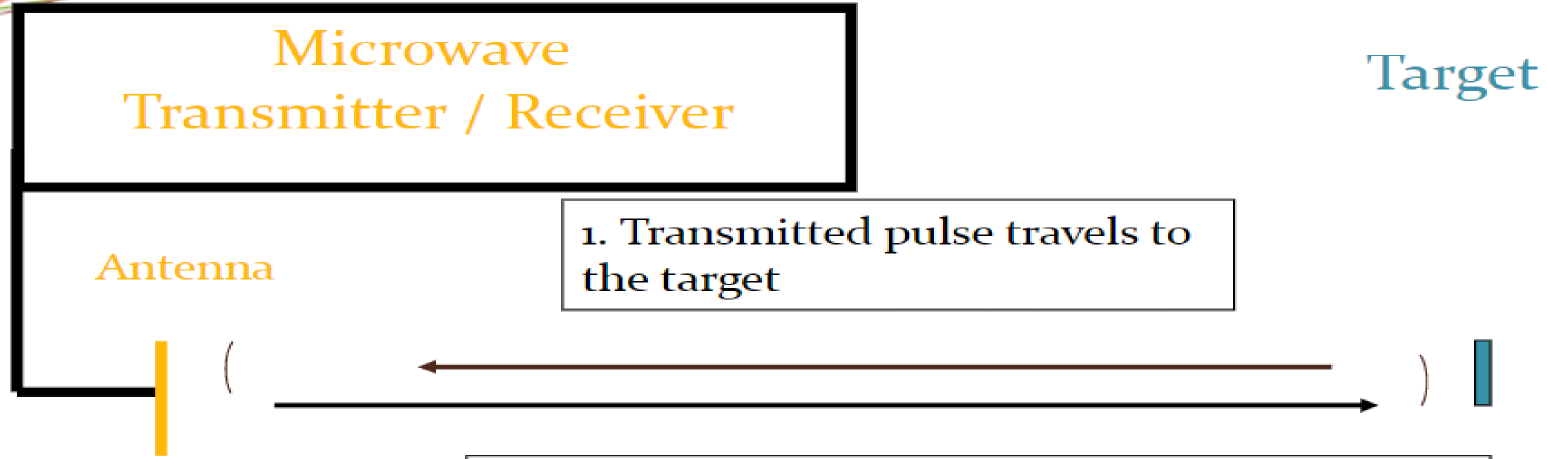


- By measuring the time delay between the transmission of a pulse and the reception of the backscattered "echo" from different targets, their distance from the radar and thus their location can be determined.



Microwave EM energy pulse transmitted by the radar

Microwave EM energy pulse reflected from a target that will be detected by the radar



2. The target reflects the pulse, and the reflected pulse travels back to the microwave antenna / receiver

3. The radar measures the time (t) between when the pulse was transmitted and when the reflected signal reaches the receiver

4. The distance, R, from the antenna to the target is calculated as ct / 2, where c is the speed of light

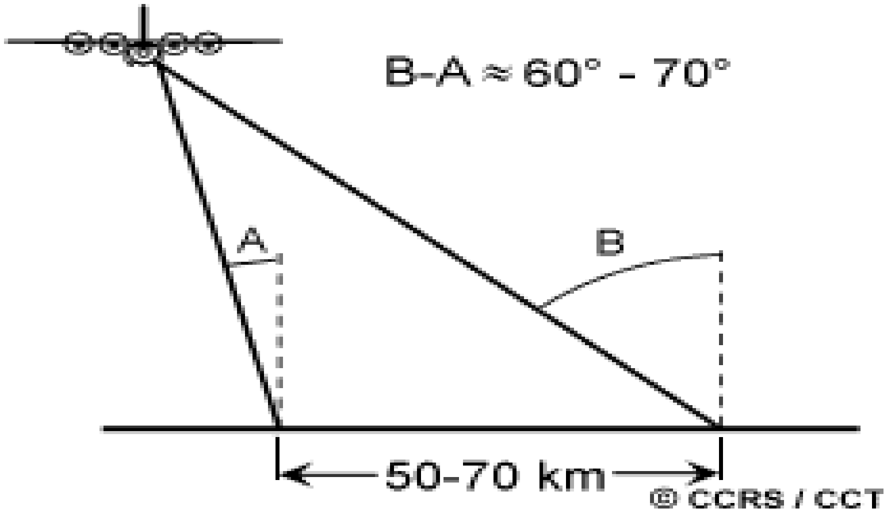
Airborne Radars

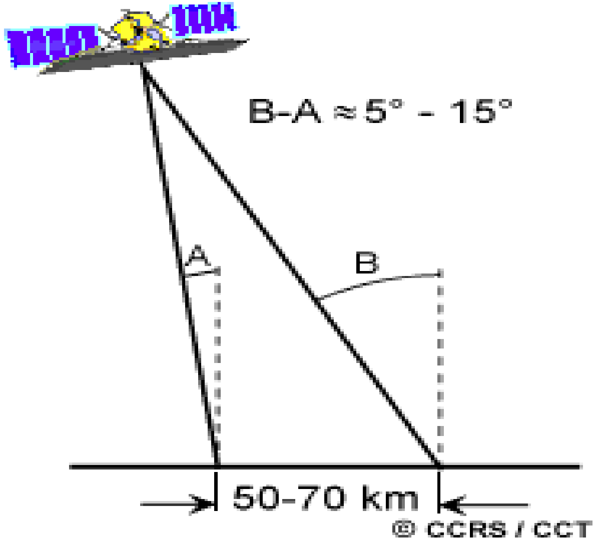
- Due to wider ranges of incidence angle (look angle), imaging geometry problems,
- flexible in their capability to collect data from different look angles and look directions. Additionally, an airborne radar is able to collect data anywhere and at any time (as long as weather and flying conditions are acceptable!).
- As with any aircraft, an airborne radar will be susceptible to variations in velocity and other motions of the aircraft as well as to environmental (weather) conditions.

Space-borne Radars

- Avoid imaging geometry problems since they operate at altitudes up to one hundred times higher than airborne radars.
- A space-borne radar does not have this degree of flexibility, as its viewing geometry and data acquisition schedule is controlled by the pattern of its orbit. However, satellite radars do have the advantage of being able to collect imagery more quickly over a larger area than an airborne radar, and provide consistent viewing geometry.
- Space-borne radars are not affected by motion of this type. Indeed, the geometry of their orbits is usually very stable and their positions can be accurately calculated.

Airborne Versus Space-borne Radars

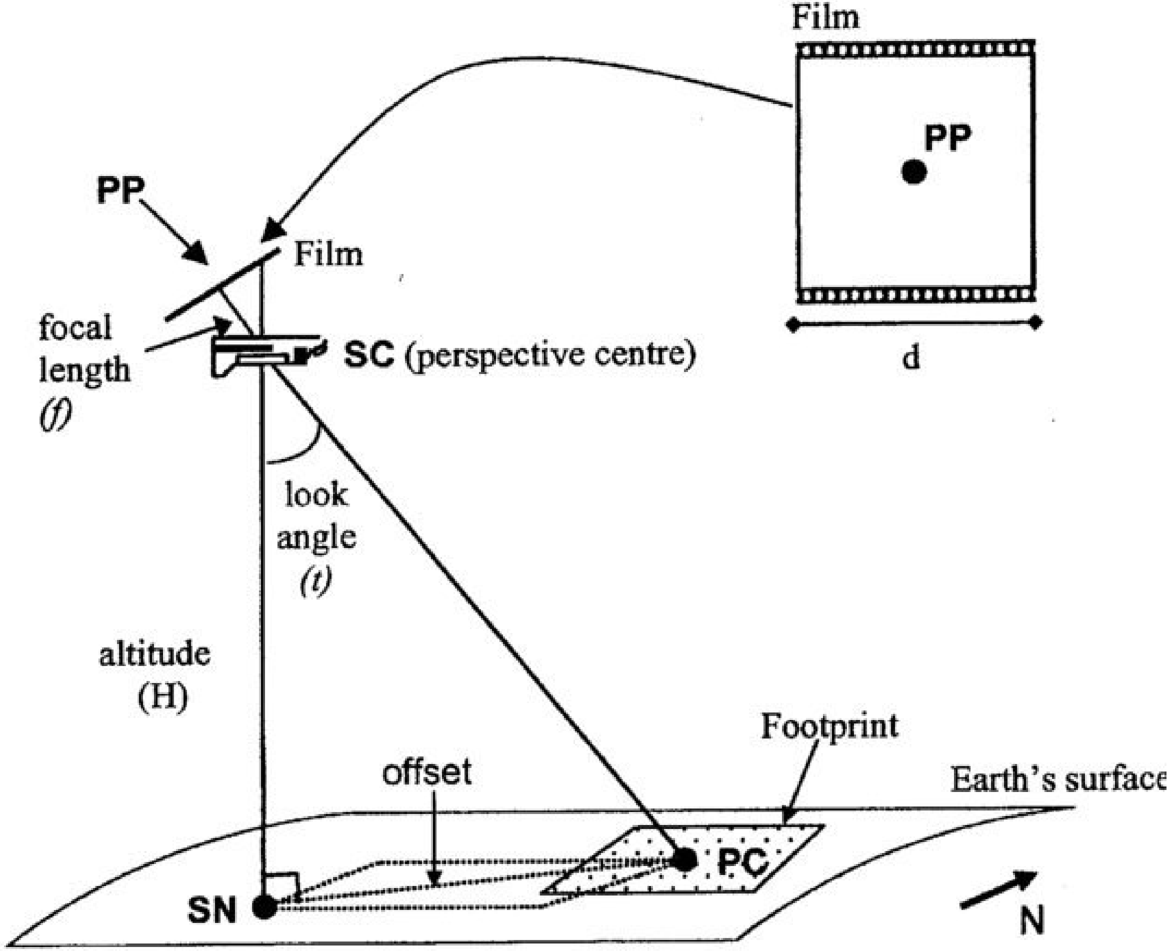




In airborne radar, wide range of incidence angles, perhaps as much as 60 or 70 degrees, in order to achieve relatively wide swaths (let's say 50 to 70 km)

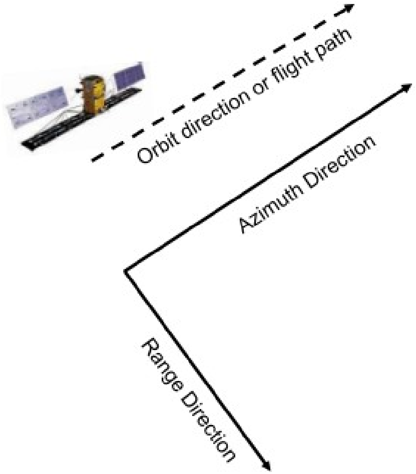
At altitudes of several hundred kilometres, space-borne radars can image comparable swath widths, but over a much narrower range of incidence angles, typically ranging from five to 15 degrees.

Geometric relationship between look angle (t), spacecraft nadir point (SN), photograph centre point (PC), and photograph principal point (PP).



https://www.researchgate.net/publication/228992093_Astronaut-acquired_orbital_photographs_as_digital_data_for_remote_sensing_Spatial_resolution/figures?lo=1

Radar Geometry



Radars are side looking – a requirement in order to range the target

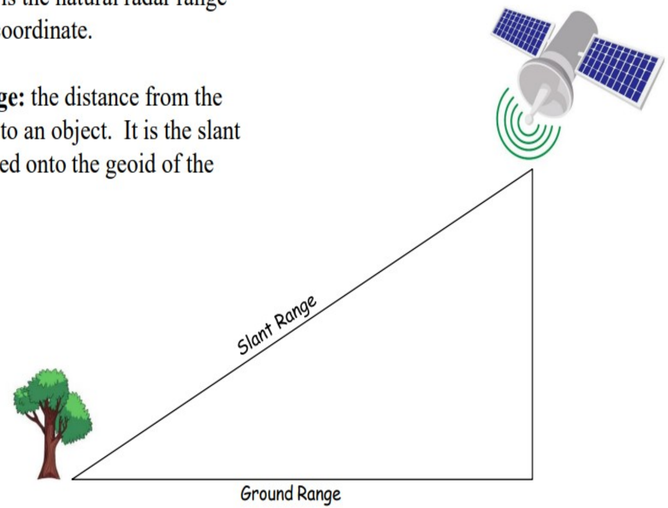
Azimuth: the direction parallel to the flight path of the aircraft or orbit of the satellite

Range: the direction perpendicular to the flight or orbital path

Slant Range? Ground Range?

Slant range: the distance measured along a line between the antenna and the target. It is the natural radar range observation coordinate.

Ground range: the distance from the ground track to an object. It is the slant range projected onto the geoid of the Earth.

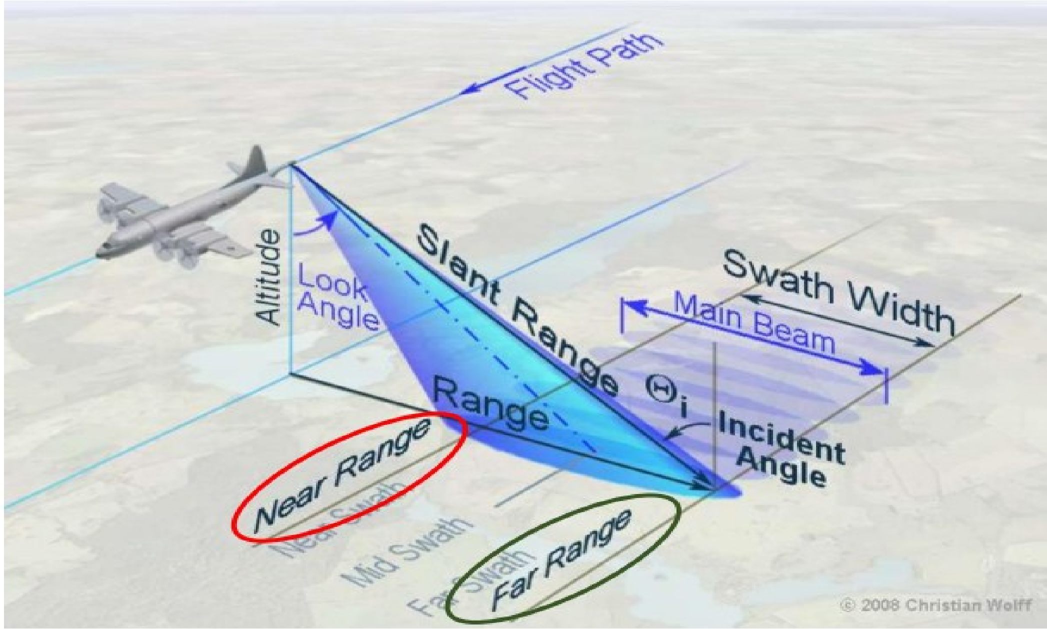


Radar Geometry

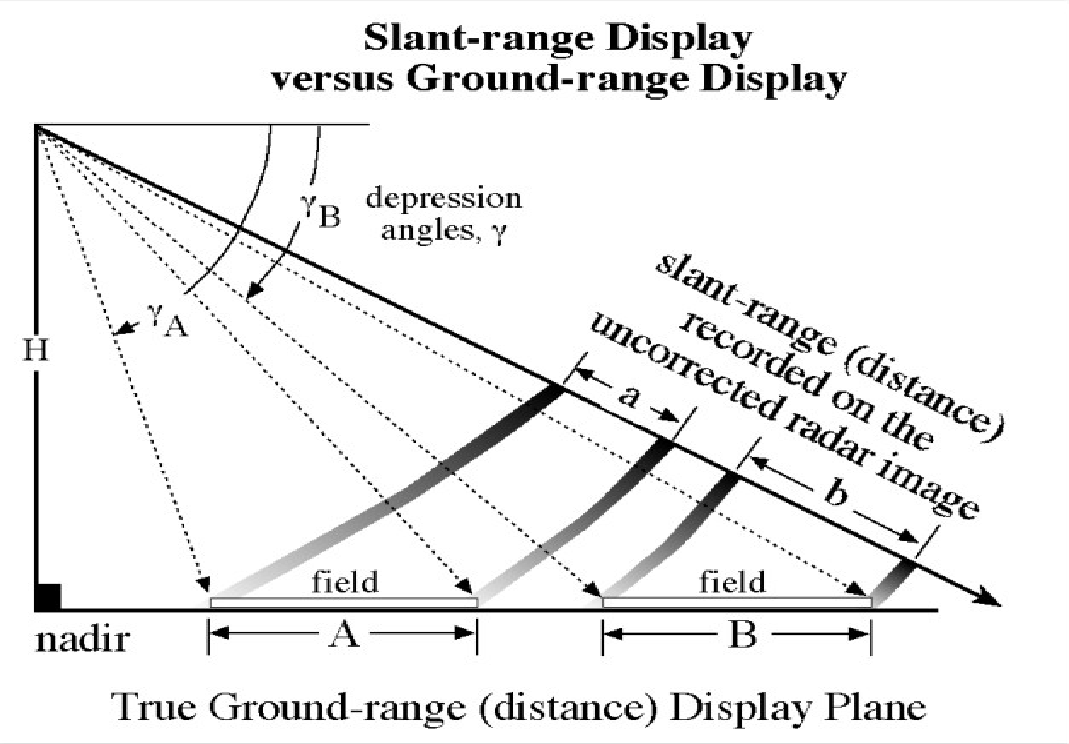
Radar swath: the ground distance from **near** to **far** range.

Incidence Angle (θ): the angle between the line of sight of radar in slant range and the vertical to the terrain

The incidence angle changes across the range. At near range, the angle is **small (steeper).** The angle is **larger (shallower)** at the far range.



Radar Geometry



- In slant range (SARs natural viewing geometry), distances are compressed relative to their true ground range distance
- Degree of compression is a function of the distance from the antenna to the target, in slant range

Range Resolution (Real Aperture Radar)

Slant **Range resolution** (δ_{range})depends on the bandwidth (B_e) and is defined as

$$\delta_{range} = \frac{C}{2 \times B_e}$$

Where
C : speed of light (3x10^8 m/s)
B_e : bandwidth (Hz)

Bandwidth is inversely related to pulse duration (τ)

Pulse duration = the time the radar's transmitter is energized during each cycle

Large bandwidth = short pulse duration = short pulse length = **finer resolution**

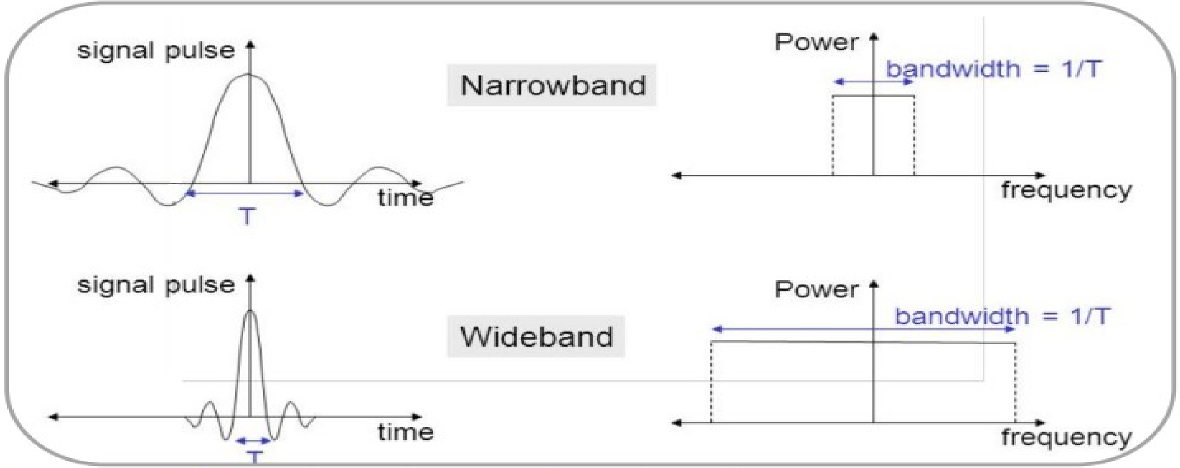
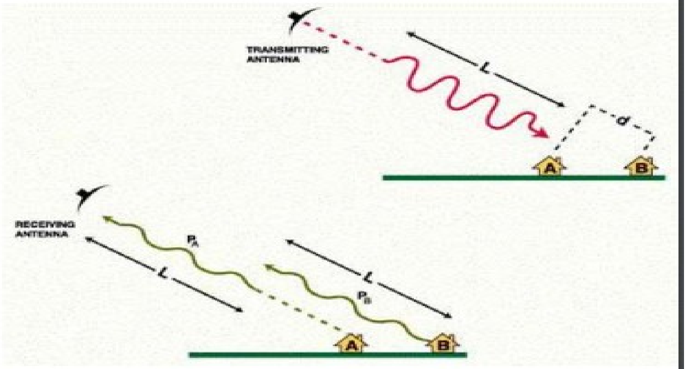


Image source: slideplayer.com/slide/6622331/23/images/27/Pulse+Width+vs.+Bandwidth.jpg

Range Resolution (Real Aperture Radar)

- Radars send out short pulses of energy and then wait to "hear" the echo from its target, between these transmitted pulses
- For the radar to be able to distinguish two targets, the echoes for each target must be received at different times.
- In the case of buildings A and B, for the radar to "hear" the echoes from A and B separately, the distance between buildings (in slant range) must be larger than half the length of the pulse (L/2)
- Range resolution is equal to L/2 (half the pulse length).



Since the radar pulse must travel two ways, the two buildings result in distinct echoes if $d > L/2$

- The range resolution can be improved by increasing the bandwidth (reducing the length or duration of the pulse) of the radar. Shorter wavelengths will enable higher bandwidth.
- Pulse compression is a signal processing technique commonly used to improve range resolution

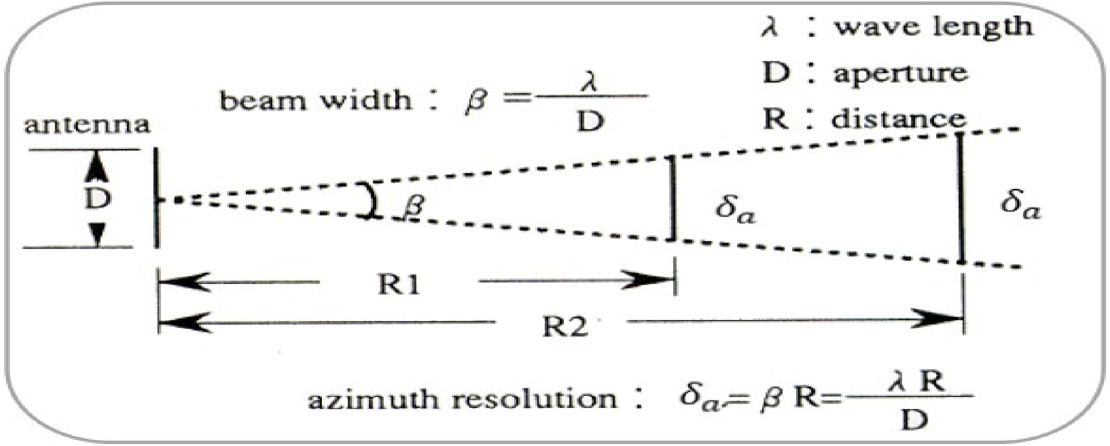
Image source: www.earth.esa.int

Azimuth Resolution (Real Aperture Radar)

Azimuth resolution $\delta_{azimuth}$ depends on the length of the antenna and increases with range.

$$\delta_{azimuth} = \beta \times R$$

$$= \frac{\lambda}{D} \times R$$



Resolution **degrades** with:
β = beam width
R = distance (slant range) from antenna to midpoint of swath
λ = wavelength

Resolution **improves** with:
D = antenna length

Image source: sar.kangwon.ac.kr

Azimuth Resolution

$$\delta_{azimuth} = \beta \times R = \frac{\lambda}{D} \times R$$

What if RADARSAT-1 was a
Real Aperture Radar
$\lambda = 5.6$ cm
R = 792 km
D = 15 m

$$\delta_{azimuth} = \frac{(792 \times 10^3\ \text{m})\ (0.0566\ \text{m})}{15\ \text{m}} = 3\ \text{km!!!}$$

RADARSAT-1 at David Florida Lab (Ottawa)

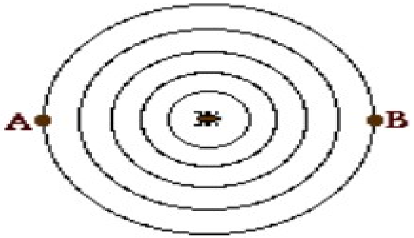
- the longer the antenna, the narrower the aperture (results in a finer azimuth resolution)
- azimuth resolution can be improved only by a longer antenna or shorter wavelength

Unfortunately

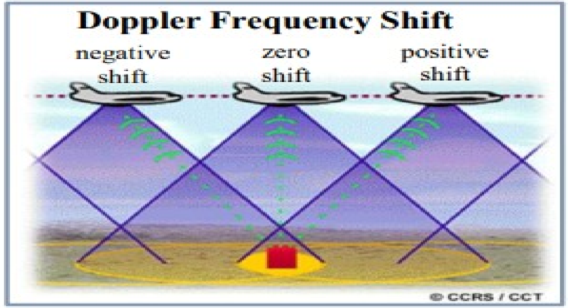
- very short wavelengths leads to greater atmospheric attenuation, reducing the all-weather capability of imaging radars
- placing very large antennas in space is problematic.

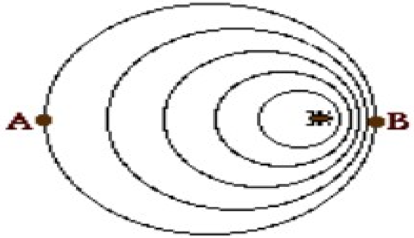
Synthetic Aperture Radar (SAR)

- in 1951 Carl Wiley realized that the Doppler shift of the echo signal could be used to synthesize a much longer aperture to improve the resolution of a side-looking radar.
- Doppler effect: produced by a moving source of waves (i.e. an orbiting radar antenna) where there is an upward shift in frequency for observers towards whom the source is approaching and a downward shift in frequency for observers from whom the source is receding. The effect does not result because of an actual change in the frequency of the source.
- as SAR passes over the target, the first echoes will have a positive Doppler shift; zero at target; negative Doppler shift as the target exits the last echoes.



A stationary bug producing disturbances in water.



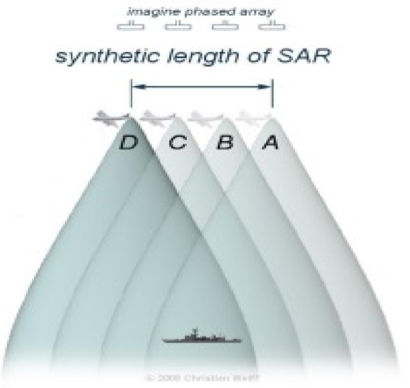


A bug moving to the right and producing disturbances.

Image source: www.physicsclassroom.com/class/waves/Lesson-3/The-Doppler-Effect

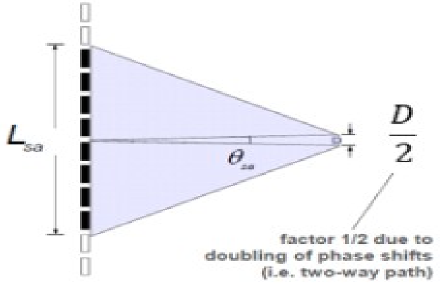
Synthetic Aperture Radar (SAR)

- SAR processor stores all the radar returned signals for the time period T from position A to D (have different Doppler shifts)
- this is used to reconstruct the signal which would have been obtained by an antenna of length $v \cdot T$, where v is the platform speed
- making T large makes the "synthetic aperture" large and hence a higher resolution can be achieved
- in effect, by processing these shorter looks at the target together, the physical (short) antenna "sees" any point on the ground for a longer period of time, which is equivalent to a longer virtual antenna and thus higher azimuth resolution
- the achievable azimuth resolution of a SAR is approximately equal to one-half the length of the actual (real) antenna



Azimuth resolution ($\delta_{azimuth}$) is half the length of the radar antenna (D).

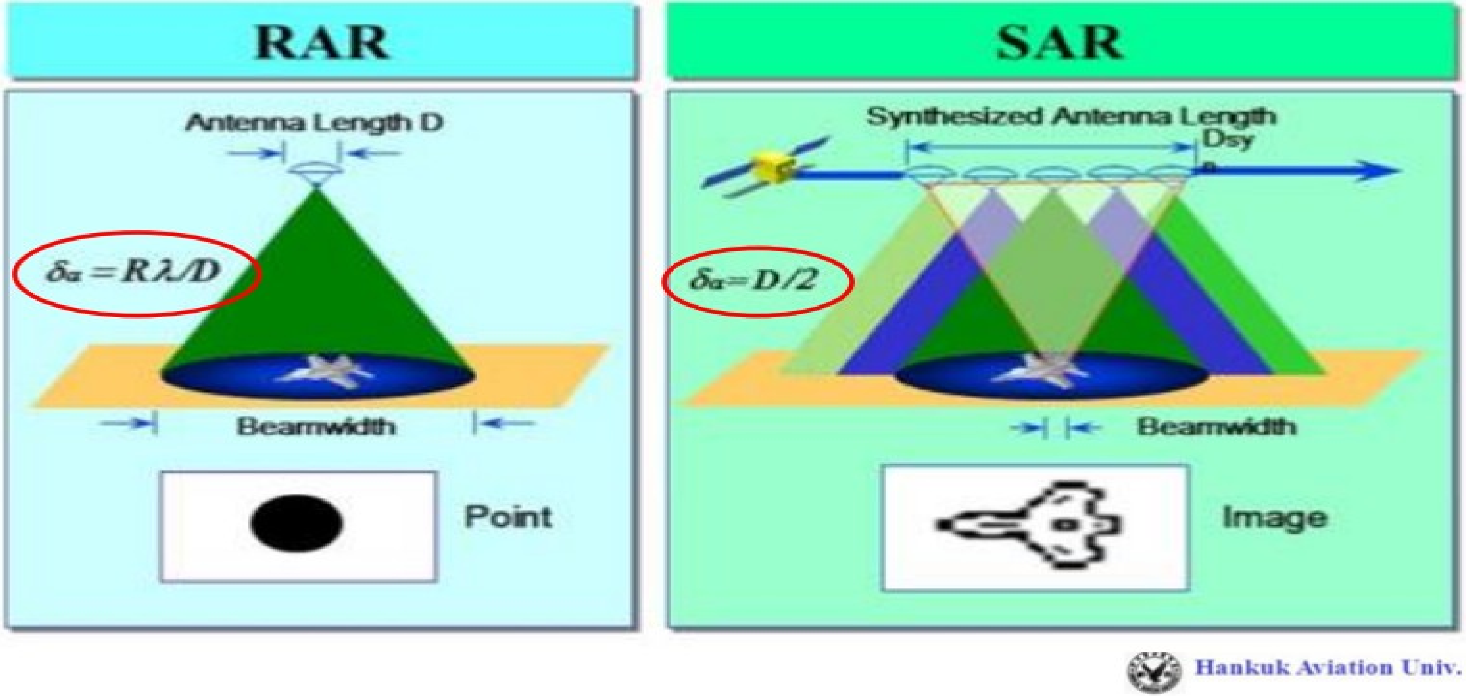
$$\delta_{azimuth} = \frac{D}{2}$$



Information source: Moreira et al., 2013

RAR and SAR

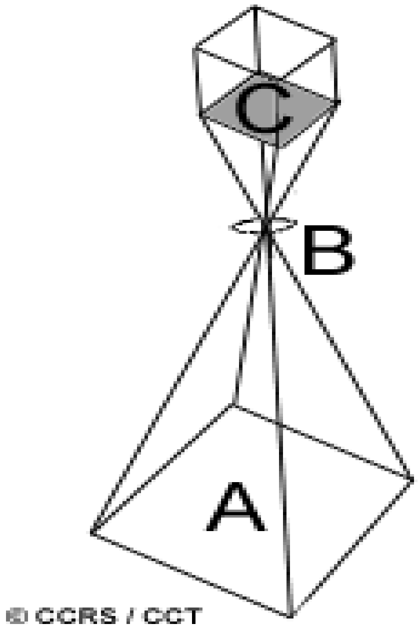
The size of the antenna (D) is the same, but with much different results!



Photographic and Digital Imaging

Cameras and Aerial Photography

- Cameras and their use for aerial photography are the simplest and oldest of sensors used for remote sensing of the Earth's surface
- Cameras are **framing systems** which acquire a near-instantaneous "snapshot" of an **area (A)**, of the surface.
- Camera systems are passive optical sensors that use a **lens (B)** to form an image at the focal plane (C), the plane at which an image is sharply defined.



Cameras and Aerial Photography

- **Photographic films** are sensitive to light from 0.3 μm to 0.9 μm in wavelength covering the ultraviolet (UV), visible, and near-infrared (NIR)
- **Panchromatic films** are sensitive to the UV and the visible portions of the spectrum, which produces black and white images and is the most common type of film used for aerial photography.
- Cameras can be used on a variety of **platforms** including ground-based stages, helicopters, aircraft, and spacecraft.
- Very detailed photographs taken from aircraft are useful for many applications, which can provide fine detail down to spatial resolutions of less than 50 cm.

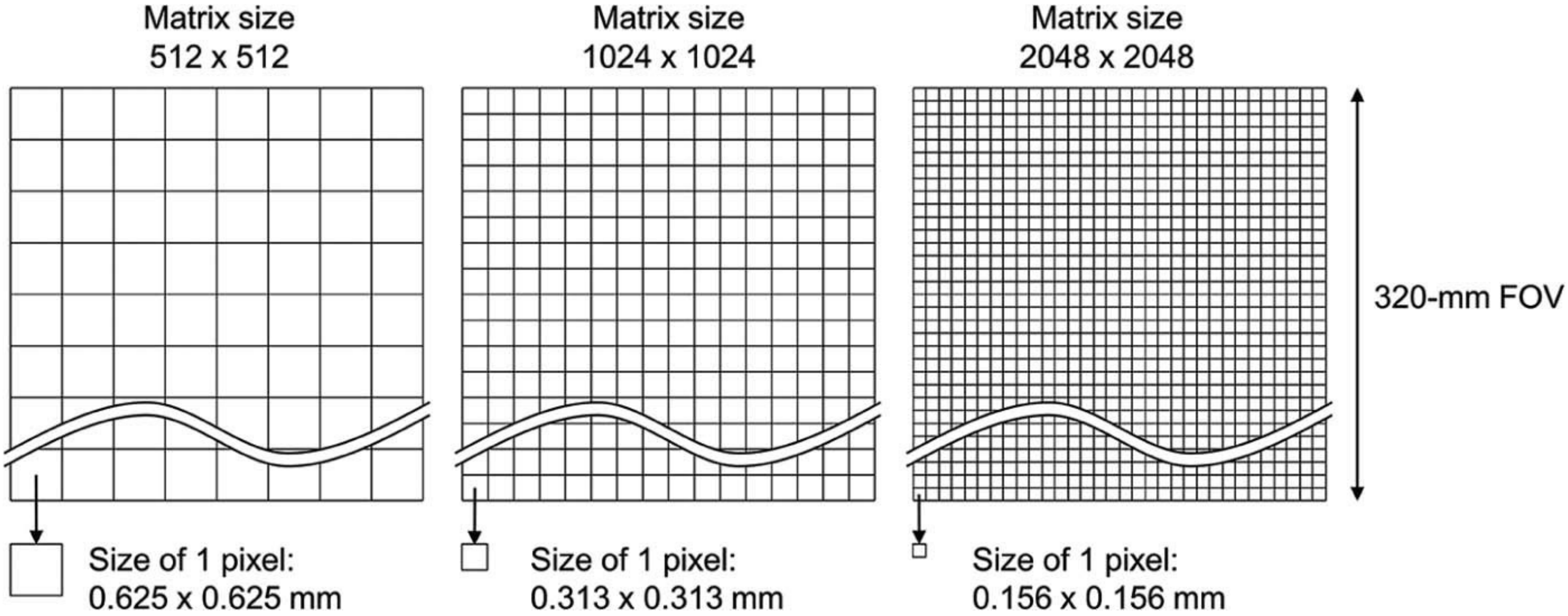
Cameras and Aerial Photography

- **Digital cameras** record electromagnetic radiation electronically,
- Instead of using film, it uses a gridded array of silicon coated CCDs (charge-coupled devices) that **captures images by converting photons to electrons,**
- Energy reaching the surface of the CCDs causes the generation of an electronic charge which is proportional in magnitude to the "brightness" of the ground area.
- A digital number for each spectral band is assigned to each pixel based on the magnitude of the electronic charge.

Cameras and Aerial Photography

- Quicker turn-around for acquisition and retrieval of data and allow greater control of the spectral resolution.
- Capable of collecting data with a spatial resolution of 0.3m, and with a spectral resolution of 0.012 mm to 0.3 mm.
- The size of the pixel arrays varies between systems, but typically ranges between 512 x 512 to 2048 x 2048.

Matrix size and the size of 1 pixel



Source: Hata et al., 2018. https://www.sciencedirect.com/science/article/pii/S1076633217305044

Scanning Techniques

- Ultrasound scanning techniques
  - probe sends high-frequency sound waves (1-5 MHz) into the body
  - sound waves travel into tissue and get reflected by boundaries
  - reflected waves are recorded by the probe
  - time of flight gives spatial information about the boundaries
- Ultrasound Characteristics
  - No radiation, Poor resolution (~1mm) non-uniform, distortion, noisy, low penetration proporties, relatively cheap and easy

Scanning Techniques

- X-rays: film, digital, fluoroscopy, Digital Subtraction Angiography (DSA)
  - create a pre-contrast image, then subtract it from later images after a contrast medium has been introduced
- computed tomography (CT scan)
  - 3D images are generated from a large series of 2D X-ray images taken around a single axis of rotation (produces a volume of data for analysis) physics: same as x-ray
- Magnetic resonance imaging (MRI)- use strong magnetic fields, magnetic field gradients, and radio waves to generate images of the organs in the body

CT versus MRI

The main differences between CT and MRI are:

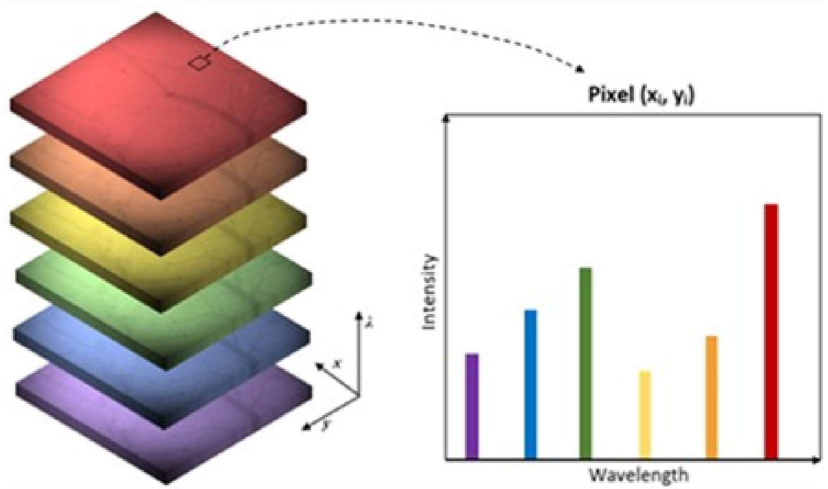
- A CT scan uses X-rays, but an MRI uses magnets and radio waves.
- Unlike an MRI, a CT scan does not show tendons and ligaments.
- MRI is better for examining the spinal cord.
- A CT scan is better suited to cancer, pneumonia, abnormal chest x-rays, bleeding in the brain, especially after an injury.
- A brain tumor is more clearly visible on MRI.
- A CT scan shows organ tear and organ injury more quickly, so it may be more suitable for trauma cases
- Broken bones and vertebrae are more clearly visible on a CT scan.
- CT scans provide a better image of the lungs and organs in the chest cavity between the lungs.

Hyperspectral imaging (HSI)

- is a technique that analyzes a wide spectrum of light instead of just assigning primary colors (red, green, blue) to each pixel.
- allows for the identification of objects and materials by analyzing their unique spectral signatures.
- hyperspectral imaging measures **the continuous spectrum of the light for each pixel of the scene** with fine wavelength resolution, not only in the visible but also in the near-infrared.

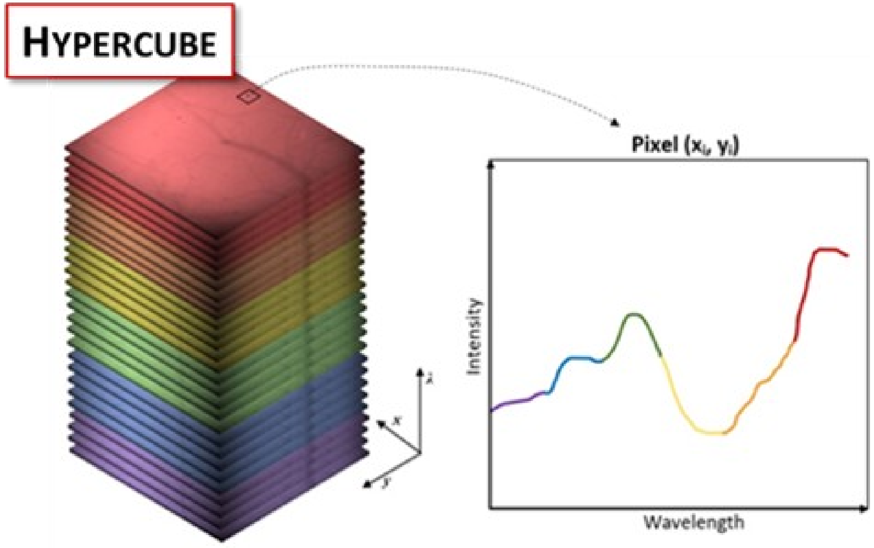
Multispectral imaging

- N separated bands



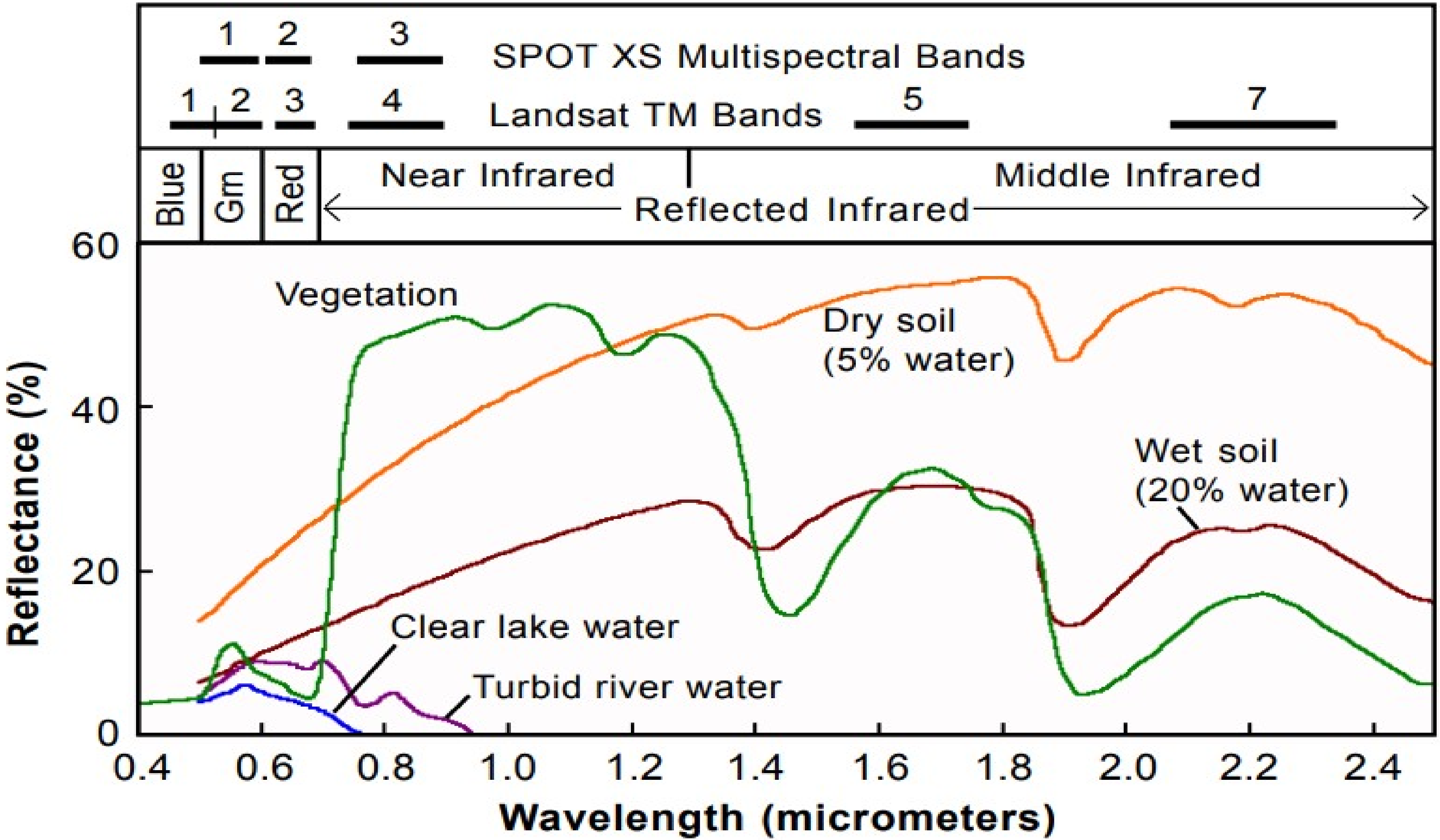
Hyperspectral imaging

- Continuous spectrum

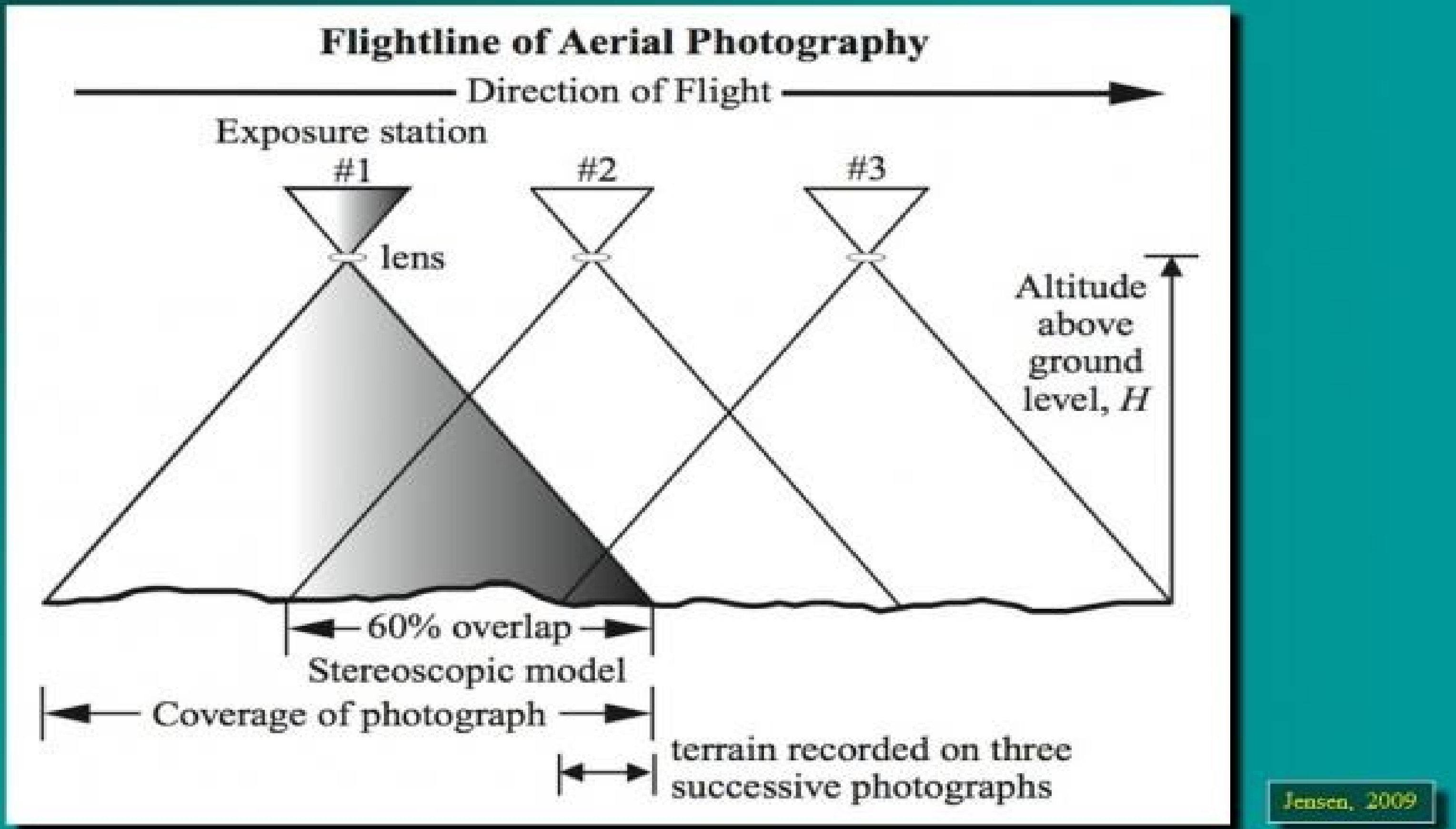


Enables spectral analysis

- Segmentation
- Spectral unmixing
- Evolution of spectra in time



1 2 3
SPOT XS Multispectral Bands
1 2 3 4 5 7
Landsat TM Bands
Blue
Grn
Red
Near Infrared
Middle Infrared
Reflected Infrared
Vegetation
Dry soil
(5% water)
Wet soil
(20% water)
Clear lake water
Turbid river water
Reflectance (%)
60
40
20
0
0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
Wavelength (micrometers)


Flightline of Aerial Photography
Direction of Flight
Exposure station
#1
#2
#3
lens
Altitude above ground level, H
60% overlap
Stereoscopic model
Coverage of photograph
terrain recorded on three successive photographs
Jensen, 2009

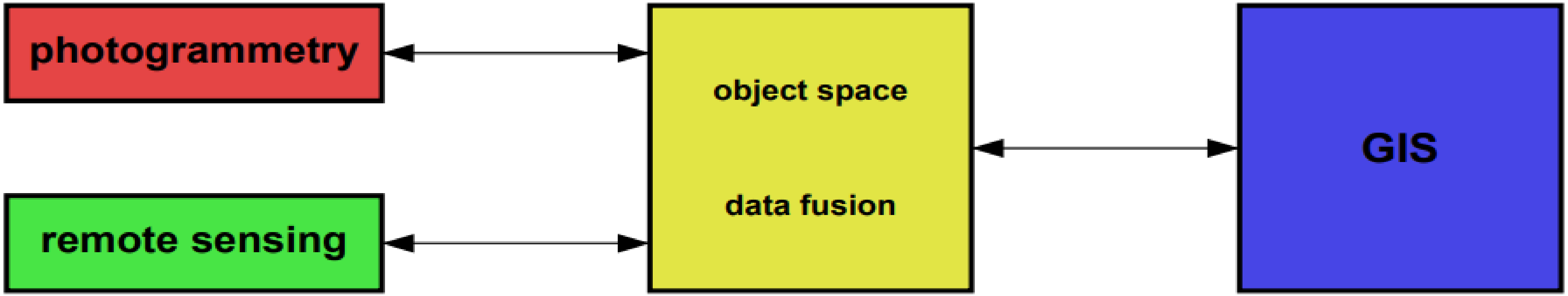
Photogrammetry

Introduction;
Development and Classification;
Photogrammetric Process;
Acquisition of Imagery and its Support Data;
Orientation and Triangulation;
Stereo Model Compilation;
Stereoscopic 3D Viewing;
Stereoscopic Measurement;
DTM/DEM Generation;

- Counter Map Generation;
- Orthorectification;
- 3D Feature Extraction and 3D Scene Modeling;
- Photogrammetry and LiDAR;
- Radargrammetry and Radar Interferometry;
- Limitations

Photogrammetry

Photogrammetry is the science of obtaining reliable information about the properties of surfaces and objects without physical contact with the objects, and of measuring and interpreting this information.



Relationship of photogrammetry, remote sensing and GIS

data acquisition	photogrammetric procedures	photogrammetric products
		photographic products
		enlargements/reductions
	rectifier	rectifications
	orthophoto projector	orthophotos
camera --> photographs	comparator	points
	stereoplotter	DEMs, profiles, surfaces
scanner		
	analytical plotter	maps
		topographic maps
		special maps
sensor --> digital imagery	softcopy workstation	

Types of remotely received information

- **Geometric information** involves the spatial position and the shape of objects. It is the most important information source in photogrammetry.
- **Physical information** refers to properties of electromagnetic radiation, e.g., radiant energy, wavelength, and polarization.
- **Semantic information** is related to the meaning of an image. It is usually obtained by interpreting the recorded data.
- **Temporal information** is related to the change of an object in time, usually obtained by comparing several images which were recorded at different times.

Photogrammetric Products and Procedures

- Photogrammetric products fall into three categories: photographic products, computational results, and maps.
  - Photographic products are derivatives of single photographs or composites of overlapping photographs
  - A*erial triangulation is a very successful application of photogrammetry and delivers 3-D* positions of points, measured on photographs, in a ground control coordinate system,
  - most popular form for representing portions of the earth's surface is the DEM (Digital Elevation Model)
  - Maps are the most prominent product of photogrammetry: Planimetric maps, topographic maps, Thematic maps

Photogrammetric Products and Procedures

- Photogrammetric Input - aerial photograph
- Projection system-
- amount of data (~ 0.5 GB of 9 inches size of photo)
- Implicit information - clearly expressed (data labeled, feature has attribute information…

- Output – map
- Projection system – Orthogonal
- Less amount of data
- Explicit information - not directly expressed (pixel have no attribute …….)

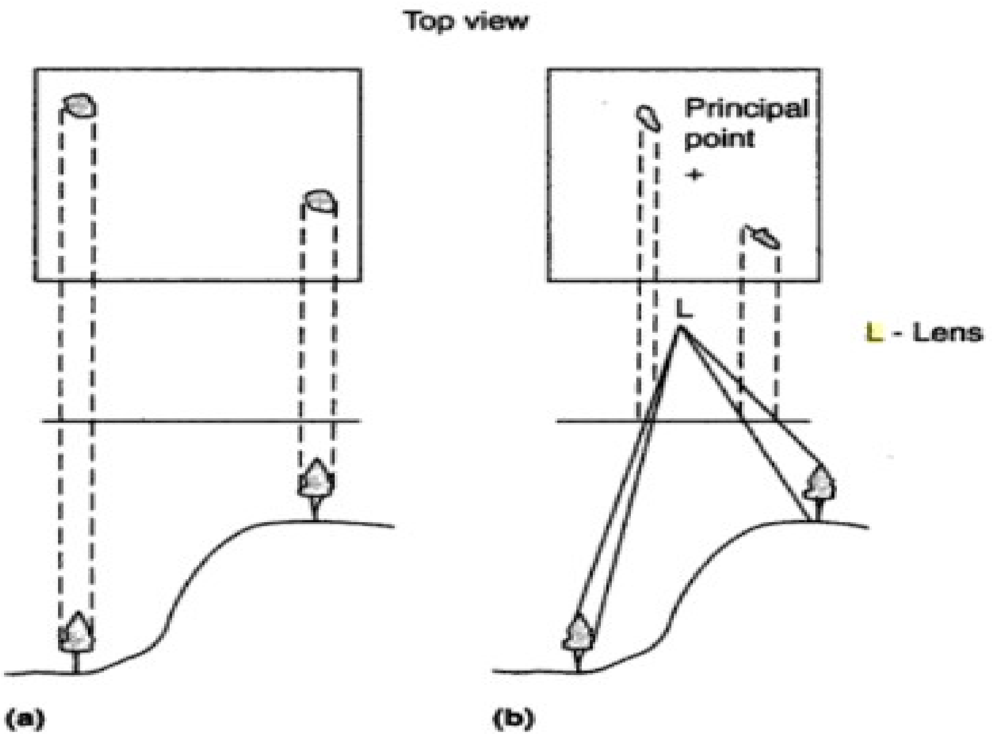
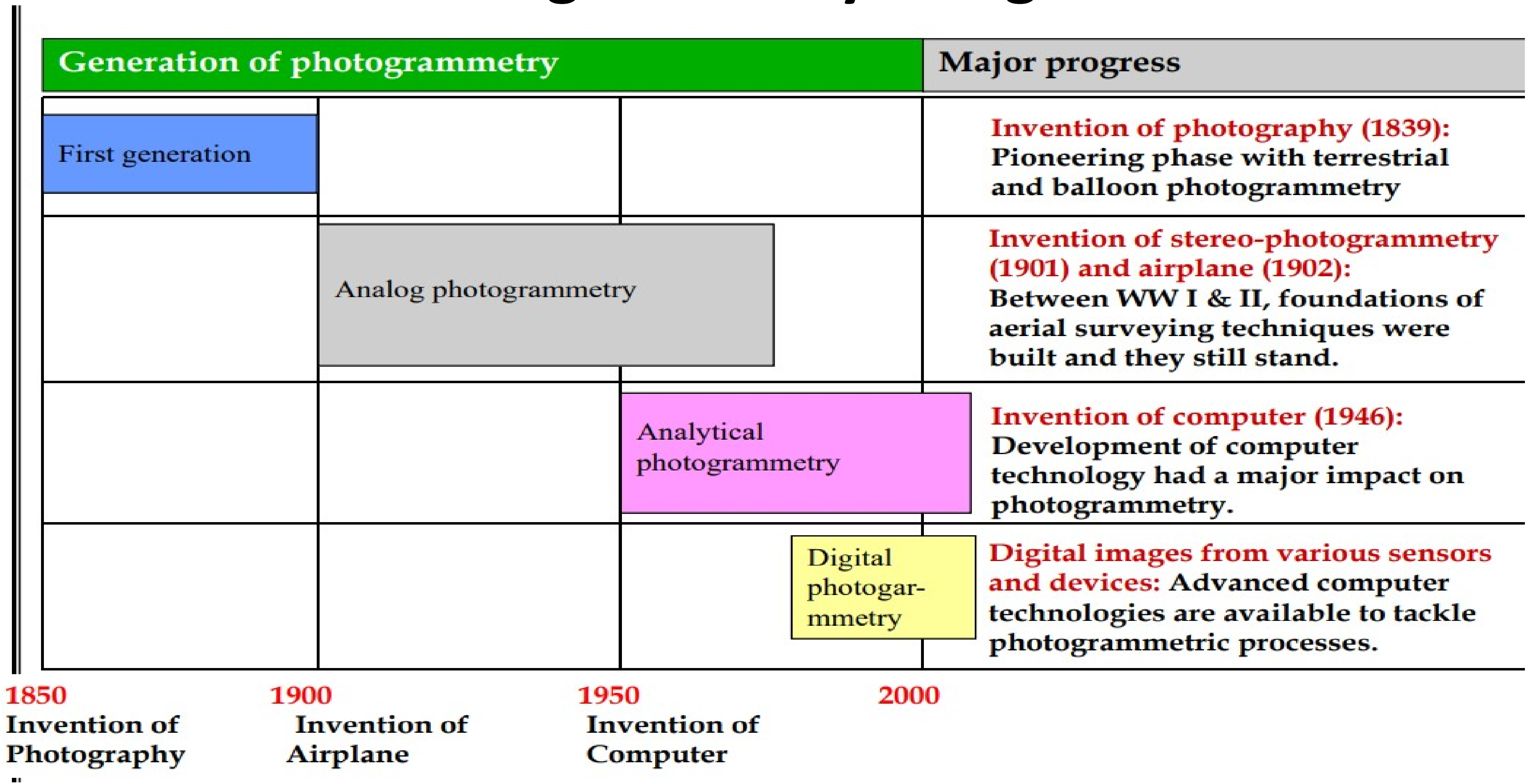
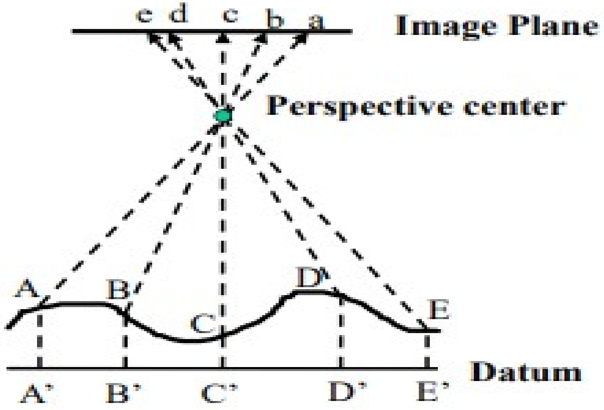


Fig. 6.11 The geometrical differences in a map. (a) (orthographic projection) and a vertical aerial photograph; (b) (central projection). In the map (a), we have a top view of the object in its true relative horizontal position. (Reprinted from '*Remote Sensing and Image Interpretation*', 1^{st} Edn., Lillesand & Kieffer, 1979, with permission of John Wiley & Sons, Inc)

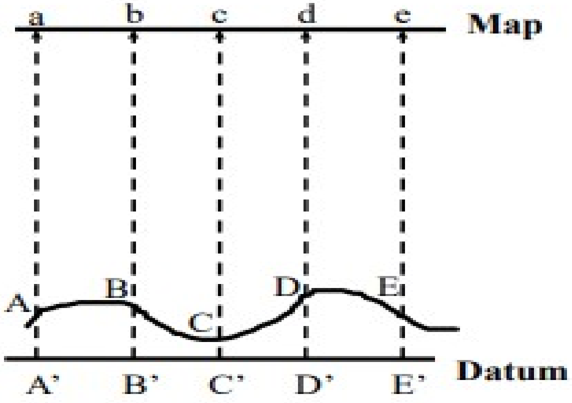
Photogrammetry- Progress



An Image Versus a Map

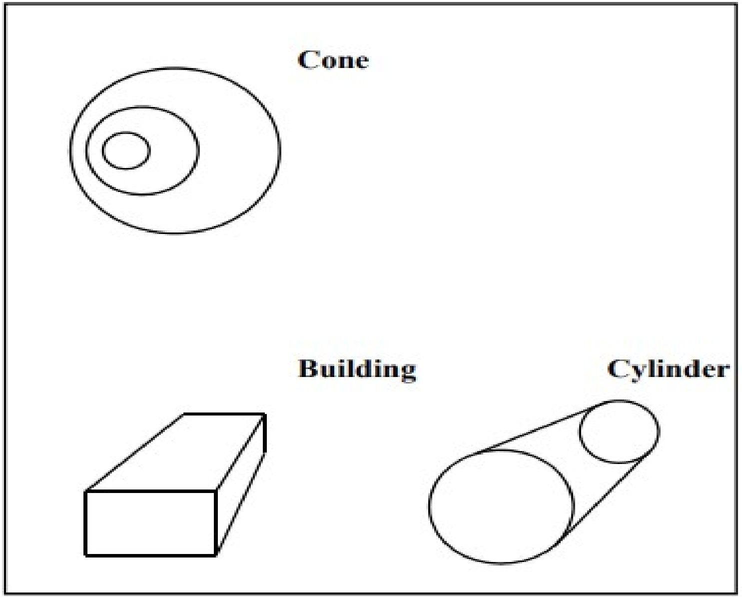


Image

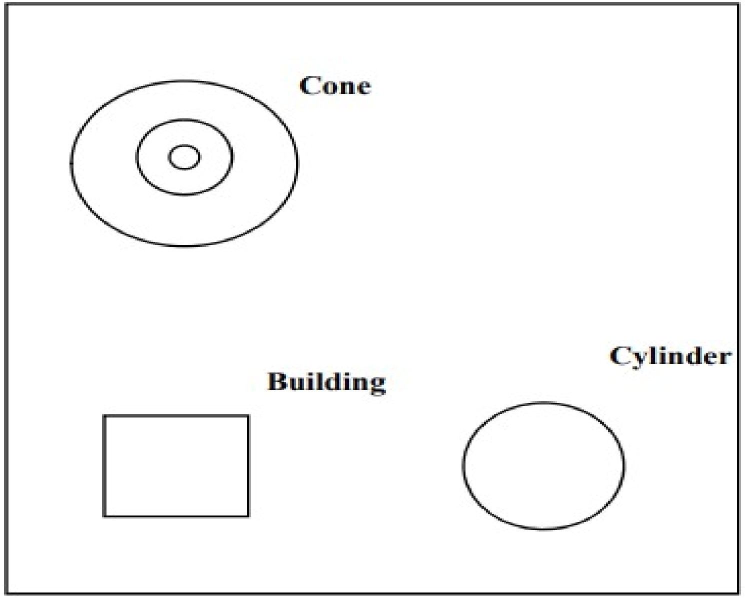


Map

Perspective Versus Orthogonal Projection



(A) Perspective Projection



(B) Orthogonal Projection

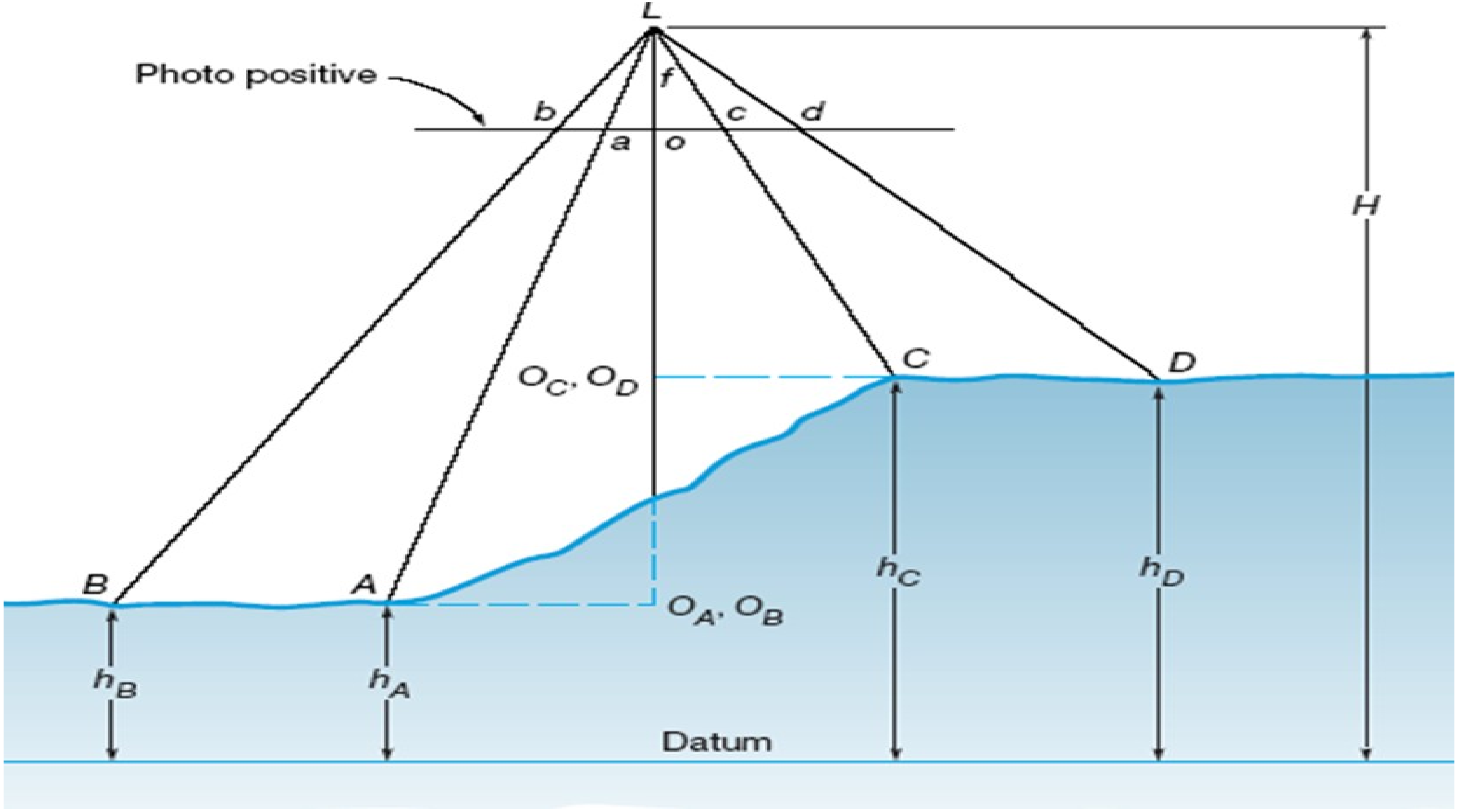
An Image Versus a Map

- Images have the following properties:
  - Perspective projection
  - Non-uniform scale
- Maps, on the other hand, have the following characteristics:
  - Orthogonal (parallel) projection
  - Maps have a uniform scale

Scale of Vertical Photograph

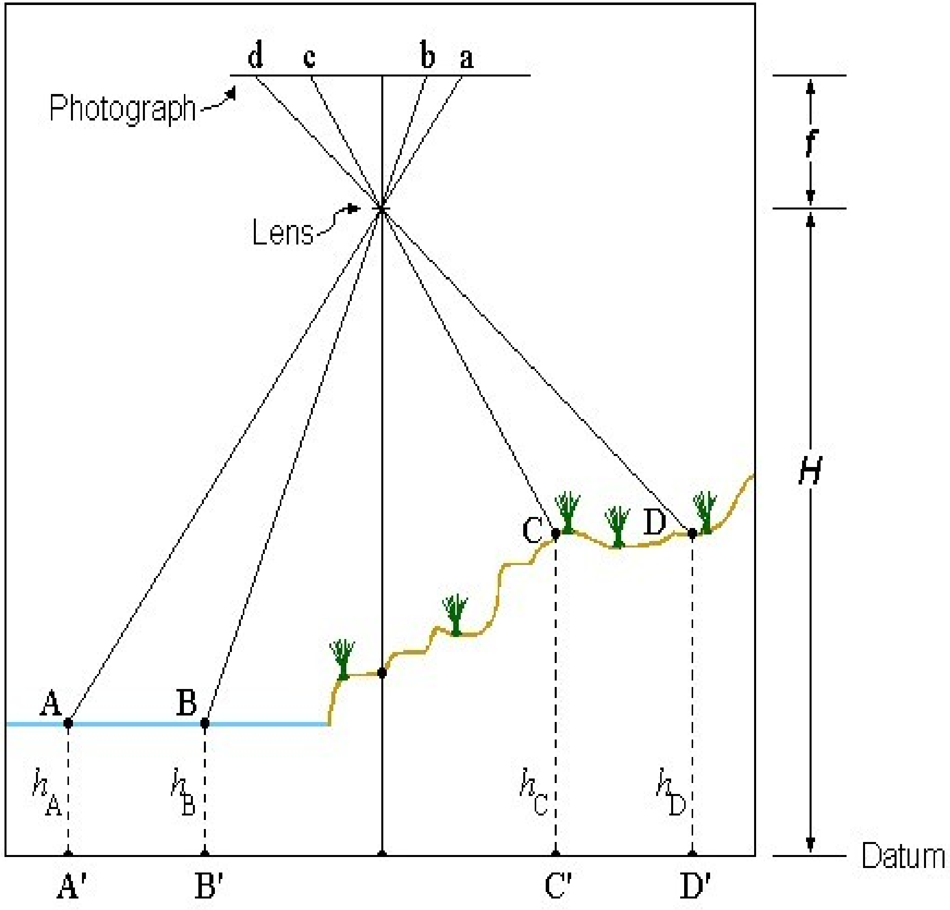
- Ratio of distance in photo to the same distance on ground
- Photographs are not map..
- Orthophoto
- Scale of at any points,
  - **$s = f/(H-h)$**
  - **S_{avg} = f= ($H-h_{avg}$)**
- If the f, H, h are not available, but a map is available,
  - **Photo scale = Photo distance/map distance x (map scale)**

Scale of Vertical Photograph



Relief displacement

- Relief displacement is the shift in an object's image position caused by its elevation above a particular datum.
- For vertical or near vertical photography the shift occurs radially from the nadir point. This effect is demonstrated in the diagram below. Though the distances between A-B and C-D are identical on the datum plane, their corresponding representations on the photo plane are not (i.e. distances between a-b and c-d are not equivalent).



Relief displacement

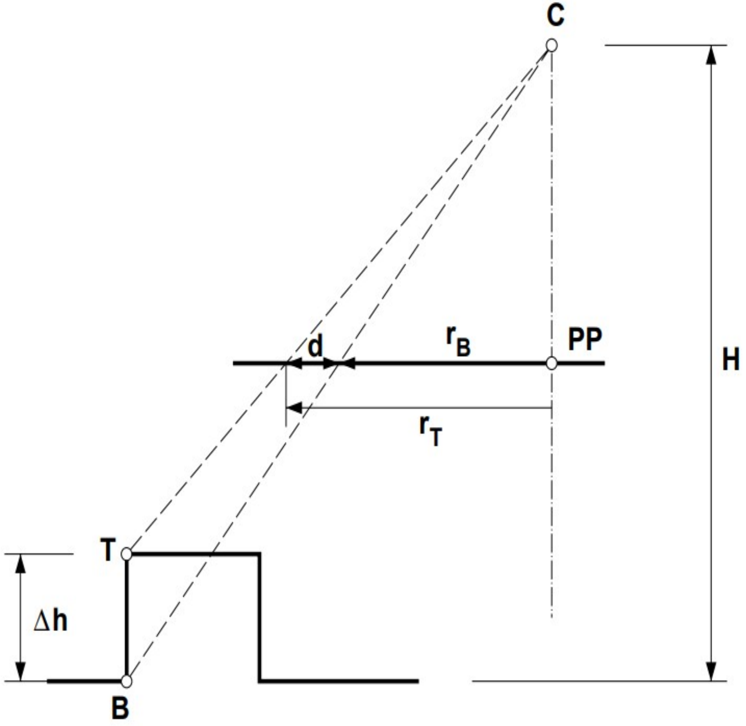
- The distance **d** between the two photo points is called relief displacement because it is caused by the elevation difference **Δh** between T and B
- The magnitude of relief displacement for a true vertical photograph can be determined by the following equation

The magnitude of relief displacement for a true vertical photograph can be determined by the following equation

$$d = \frac{r\,\Delta h}{H} = \frac{r'\,\Delta h}{H - \Delta h} \qquad (4.5)$$

where $r = \sqrt{x_T^2 + y_T^2}$, $r' = \sqrt{x_B^2 + y_B^2}$, and Δh the elevation difference of two points on a vertical. Eq. 4.5 can be used to determine the elevation Δh of a vertical object

$$h = \frac{d\,H}{r} \qquad (4.6)$$



Photogrammetry and LiDAR

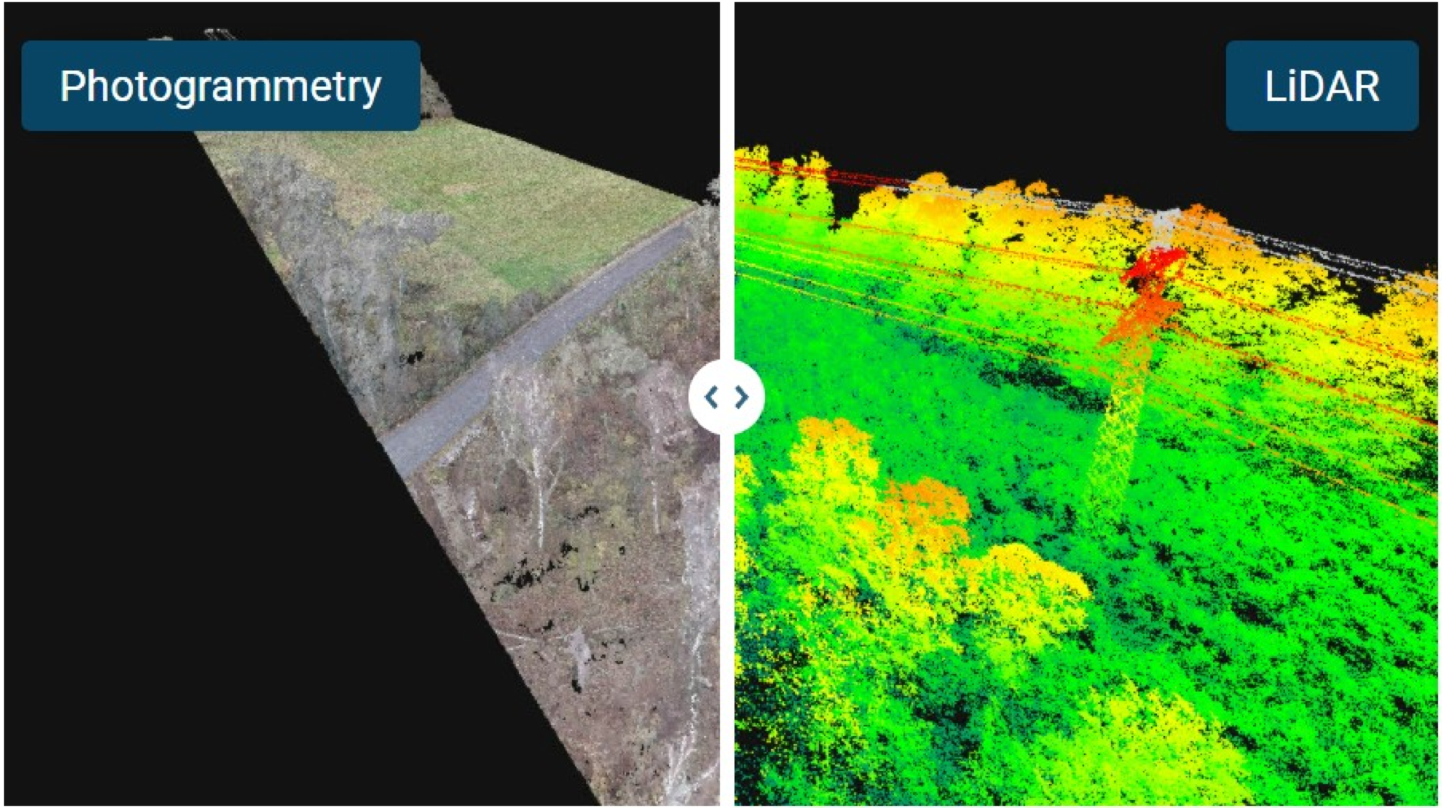
- LiDAR technology competes with, but also complements photogrammetry,
- LiDAR is light detection and ranging, which is also known as 3D laser scanning and was first used in the 1960s,
- It works by illuminating a target object or space with a laser light and recording the time it takes the laser light to return to the sensor to measure distances with high accuracy.
- LiDAR methods produce a geo-referenced and non-colored 3D point cloud, which is highly detailed that photogrammetry may not recognize as easily.

Photogrammetry and LiDAR

- LiDAR produces its own light, so, not affected by weather conditions
- LiDAR can penetrate the spaces between pieces of foliage and pick up small details
- LiDAR is often expensive
- LiDAR only produces a point cloud.

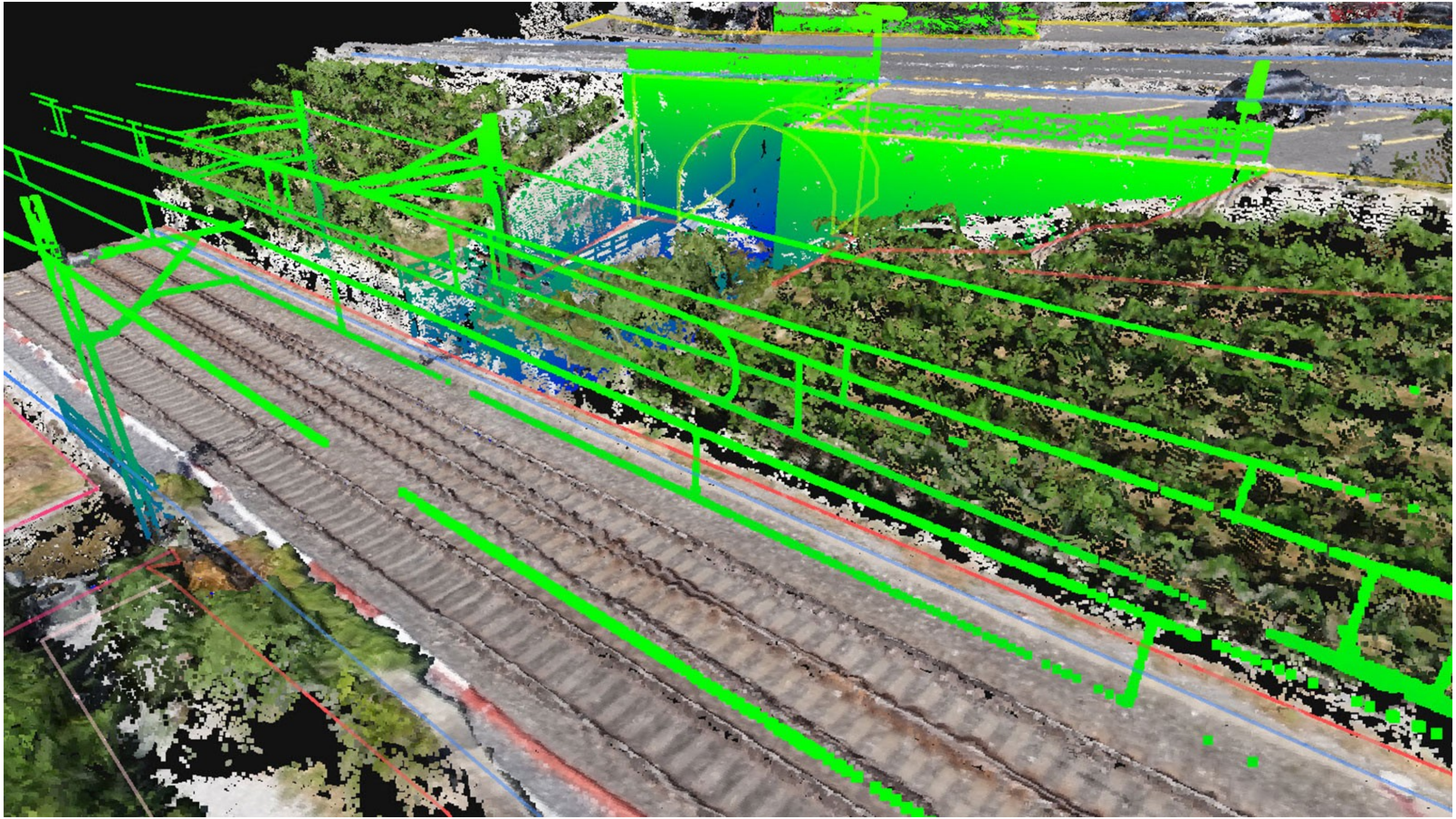
- Photogrammetry using drones or handheld cameras does suffer in poor lighting,
- It depends on photos, reconstructing only what is visible at the surface,
- It can be performed, with varying degrees of accuracy, with a wide range of cameras
- It produces a range of outputs, including colorized point clouds, textured meshes, and orthomosaics.

Photogrammetry and LiDAR



LiDAR managed to detect more points in the dense vegetation area as well as narrow

Combination of Photogrammetry and LiDAR



https://www.pix4d.com/blog/lidar-photogrammetry