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Course Notes

Présenté par : GUERROUDJ Abdelhalim

MCA, Université de Laghouat

Email : a.guerroudj@lagh-univ.dz

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PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
Ministry of Higher Education and Scientific Research
Amar Telidji University of Laghouat
Faculty of Civil Engineering and Architecture
Department of Civil Engineering

COURSE NOTES

CARTOGRAPHY

Maps, Scales, Thematic Cartography and Semiology

Audience	Semester	Speciality	Field
3rd Year Licence	**S5**	**Geomatics & Topography**	**Cartography**

Written by Dr. GUERROUDJ Abdelhalim
Faculty of Civil Engineering and Architecture
Department of Civil Engineering| 2025/2026

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GENERAL INTRODUCTION

Target audience	Semester	Speciality	Field
3rd Year — Licence	S5 — Fifth semester	Geomatics & Topography	Cartography

Cartography is the science and art of representing the Earth's surface, or a portion thereof, on a flat medium. As one of the oldest disciplines in human civilisation, cartography has evolved from simple hand-drawn sketches to sophisticated digital geospatial systems. For students in Geomatics and Topography, mastering cartographic principles is a fundamental prerequisite for all subsequent spatial analysis and field operations.

This course introduces students to the theoretical and practical foundations of cartography. It is structured into four chapters that progressively build understanding: from the basic nature and classification of maps, through the critical concept of scale and measurement, to the specialised domain of thematic mapping, and finally to the visual and semiological principles that govern effective map communication.

Maps are not simply reduced images of the Earth — they are selective, generalised, and symbolised representations designed to serve specific purposes. Understanding how maps are constructed, classified, and read is essential for any professional working in geomatics, topography, urban planning, environmental management, or land registration.

Learning Outcomes

Upon completing this course, students will be able to: (1) identify and classify different types of maps according to scale and purpose; (2) perform accurate distance and area measurements on topographic maps; (3) apply scale conversion techniques; (4) interpret and produce thematic maps using appropriate symbols; and (5) apply semiological principles to design clear and effective cartographic representations.

Prerequisites

- Mathematics (geometry, trigonometry)
- Topography (field surveying concepts)
- Basic statistics
- Technical drawing

Course Structure

- Chapter 1: General overview of maps
- Chapter 2: Scale and measurement
- Chapter 3: Thematic cartography
- Chapter 4: Map semiology
- Chapter 5: Exploitation of Satellite Imagery

CHAPTER 1

General Overview of Maps

1.1 Types of Maps

A map is a graphic representation of all or part of the Earth's surface on a flat plane, using a system of symbols, colours, and scale. Maps are produced for a wide variety of purposes, and their classification reflects both the type of information they convey and the scale at which they are produced.

The main types of maps can be broadly grouped into two major categories: general-purpose maps and special-purpose maps.

1.1.1 General-Purpose Maps

General-purpose maps aim to represent the physical and human features of a territory in a balanced and comprehensive manner, without emphasising any single theme.

Term	Definition / Description
Topographic Maps	Show the physical features of the terrain including relief (contour lines), hydrography, vegetation, built areas, and communication routes. They are the most commonly used maps in geomatics and topography.
Planimetric Maps	Show the horizontal positions of features (roads, rivers, buildings) without representing relief. Used for urban planning and land register purposes.
Chorographic Maps	Cover large territories (regions, countries) at medium scales, providing a general overview of geographic features without fine detail.
Geographic Maps	Small-scale maps representing entire countries, continents, or the world. Used in atlases and for educational purposes.

1.1.2 Special-Purpose Maps

Special-purpose maps — also called thematic maps — are designed to represent a specific phenomenon or dataset. They are produced from base maps and enriched with additional thematic data. Examples include:

- Geological maps — representing rock types, faults, and mineral deposits.
- Soil maps — representing the distribution of soil types and agricultural potential.
- Land use maps — showing how land is occupied (urban, agricultural, forest, etc.).
- Population density maps — representing demographic distributions.
- Hydrological maps — representing watersheds, river networks, and flood zones.
- Administrative maps — showing political and administrative boundaries.
- Navigation charts — aeronautical and maritime maps for navigation purposes.

> **Key Distinction**
>
> The fundamental distinction between general-purpose maps and thematic maps lies in their intent: general maps aim to be universally useful references, while thematic maps are designed to communicate a specific spatial message or phenomenon to a targeted audience.

1.1.3 Classification by Scale

Maps are also classified according to their scale — the ratio between a distance on the map and the corresponding distance on the ground:

Term	Definition / Description
Large-Scale Maps	Scale ≥ 1/25,000. Show small areas with high detail (urban plans, cadastral maps, engineering plans).
Medium-Scale Maps	Scale between 1/25,000 and 1/200,000. Used for regional planning, topographic mapping, and military applications.
Small-Scale Maps	Scale ≤ 1/200,000. Cover large areas with limited detail (national and world maps, atlases).

1.2 Definition of a Topographic Map

A topographic map is a detailed, accurate, and quantitative representation of the natural and man-made features of a portion of the Earth's surface. It is distinguished from other types of maps by its systematic representation of terrain relief through contour lines, enabling users to visualise the three-dimensional nature of the landscape from a two-dimensional document.

> **Official Definition (IGN France)**
>
> A topographic map is a metric, planimetric and altimetric representation of the visible elements of the terrain at a given scale, using a standardised system of symbols, contour lines, and cartographic conventions.

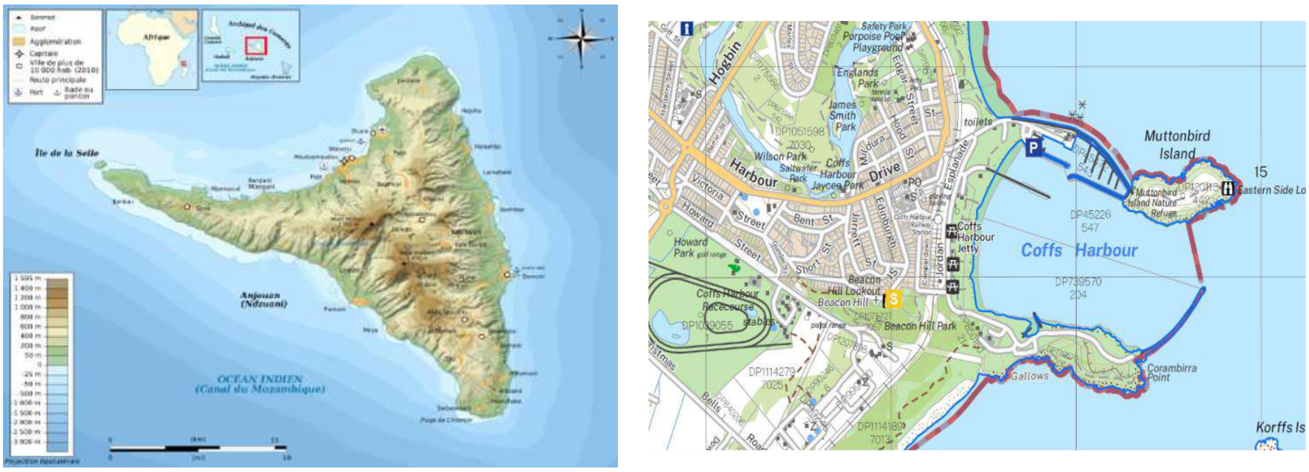


Figure 1.1. Example of a topographic map

1.2.1 Key Characteristics

A topographic map is characterised by the following essential properties:

Metric accuracy: positions and distances are geometrically correct within the tolerance of the map scale.

Relief representation: terrain elevation is represented through contour lines (isoheights) drawn at regular vertical intervals.

Standardised symbols: a consistent system of conventional signs and colours is used to represent specific features.

Reference system: the map is geo-referenced within a defined coordinate system (UTM, Lambert, geographic coordinates).

Defined scale: the scale is clearly indicated and determines the level of detail and generalisation applied.

Figure 1.2. Examples of scale

1.2.2 Components of a Topographic Map

Every standard topographic map sheet includes the following components:

Term	Definition / Description
Map body	The main graphic area containing all cartographic content (relief, hydrography, vegetation, built areas, communications).
Title and sheet reference	Name of the mapped area, sheet number, and series identification.
Scale bar and ratio	Graphic scale bar and numerical scale ratio (e.g. 1:50,000).
Legend	Key explaining all symbols, colours, and line types used on the map.
Grid and coordinates	Coordinate grid (UTM or geographic) with tick marks and labels.
Meridian arrow	Indicates true north, magnetic north, and grid north.
Marginal information	Production date, revision date, contour interval, projection system, and source information.

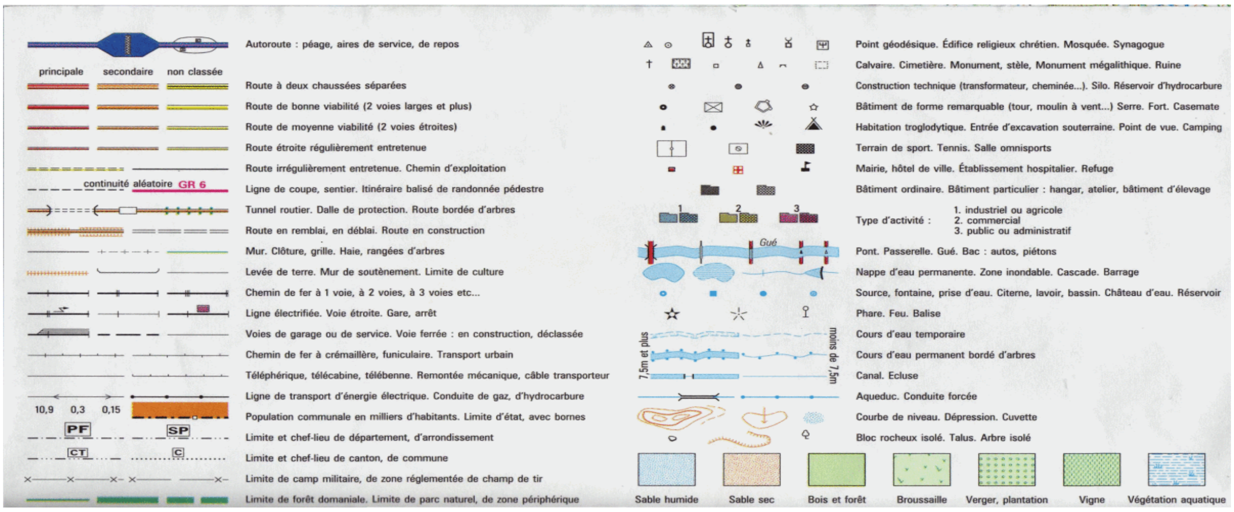


Figure 1.3. Example of a topographic map legend

1.3 Classification of Topographic Maps

In Algeria, as in most countries, topographic maps are produced within a national mapping programme and are classified primarily by scale. Each scale serves a specific operational and administrative purpose.

1.3.1 The Algerian National Topographic Series

Term	Definition / Description
1:200,000	Overview map covering large regions. Used for general planning and orientation at national level. Sheet size covers approximately 1° × 1° of geographic coordinates.
1:100,000	Regional map providing a good balance of coverage and detail. Used for military and civil planning, resource management.
1:50,000	The standard topographic reference map in Algeria. Widely used for engineering projects, agricultural planning, and cadastral operations. Contour interval: 10 m to 20 m.
1:25,000	Detailed map used for detailed engineering surveys, urban planning, and land register support. Contour interval: 5 m to 10 m.

1:10,000	Large-scale urban map used for municipal planning, infrastructure design, and detailed cadastral work.
1:5,000 and larger	Engineering and cadastral maps used for construction projects, land register plans, and urban design.

1.3.2 Classification by Content

Beyond scale, topographic maps are also classified according to the nature of the information they contain:

Physical maps: emphasise natural features — relief, hydrography, vegetation.

Political maps: show administrative and political boundaries.

Economic maps: represent economic activities, resources, and infrastructure.

Military maps: produced to military specifications, include tactical information and coordinate grids.

1.3.3 Classification by Projection

Topographic maps are also classified according to the map projection used to transfer the curved Earth surface onto a flat plane:

Term	Definition / Description
Conical projections	Used for mid-latitude countries. Example: Lambert Conformal Conic (used in France and North Africa for some series).
Cylindrical projections	Used for equatorial regions and for world maps. Example: Mercator projection.
Universal Transverse Mercator (UTM)	The most widely used projection for national topographic series worldwide, including Algeria. The world is divided into 60 zones of 6° longitude each.
Azimuthal projections	Used for polar regions and for maps centred on a specific point.

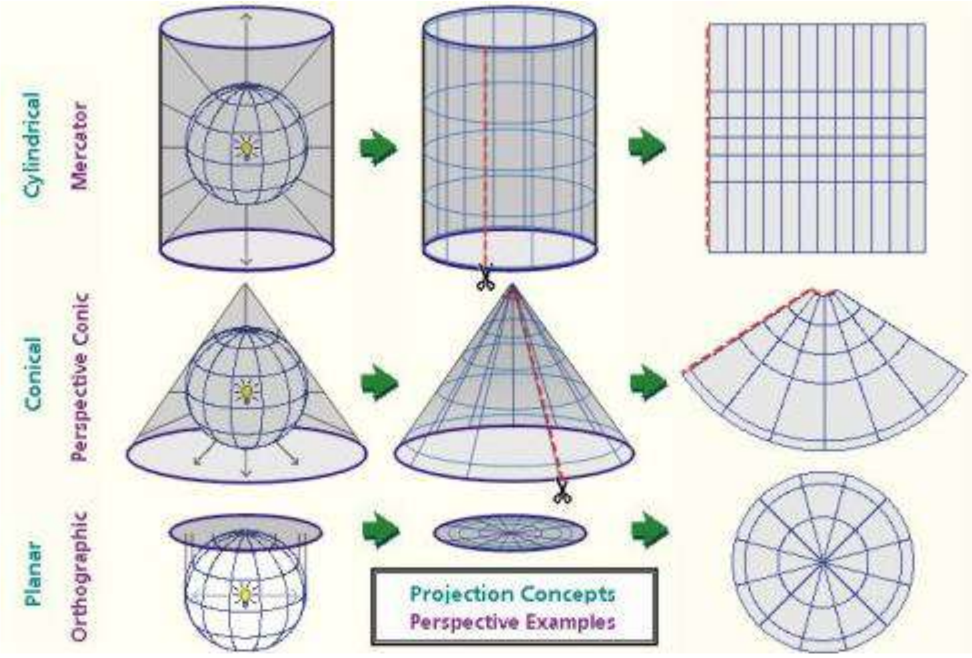


Figure 1.4. Projection Concepts

1.4 Uses of Topographic Maps

Topographic maps are among the most versatile and widely used documents in applied geography, engineering, and environmental sciences. Their uses span virtually all domains of land management and spatial analysis.

1.4.1 Civil and Military Applications

Civil Uses

- Land register and cadastral operations
- Urban and regional planning
- Road and infrastructure design
- Hydrological and watershed studies
- Agricultural land management
- Environmental monitoring
- Geological surveys

Military Uses

- Tactical and operational planning
- Navigation and orientation
- Artillery and fire planning
- Terrain analysis and trafficability
- Logistics and supply route planning
- Border demarcation

1.4.2 Reading and Interpreting a Topographic Map

The ability to read a topographic map is a fundamental professional skill. It involves:

Locating positions: using the coordinate grid to determine the geographic coordinates of any point.

Measuring distances: using the graphic or numerical scale to convert map distances to ground distances.

Determining elevations: reading elevation values from contour lines and interpolating between them.

Calculating slopes: determining the gradient between two points from their elevation difference and horizontal distance.

Interpreting relief: recognising landforms (valleys, ridges, peaks, plateaus) from contour line patterns.

Identifying features: using the legend to identify roads, rivers, forests, buildings, and other map elements.

Conclusion— Chapter 1

Maps are classified by scale (large, medium, small), by purpose (general vs thematic), and by content. The topographic map is the fundamental reference document in geomatics, characterised by accurate metric representation, contour lines for relief, and standardised symbols. In Algeria, the 1:50,000 series is the standard topographic reference. Topographic maps serve a wide range of civil, military, and environmental applications.

CHAPTER 2

Scale of Topographic Maps

2.1 Types of Map Scales

Scale is the fundamental parameter of any map. It expresses the mathematical relationship between a distance measured on the map and the corresponding real distance on the ground. Understanding and correctly applying scale is essential for all cartographic measurements.

2.1.1 Numerical (Fractional) Scale

The numerical scale, also called the representative fraction (RF), expresses scale as a dimensionless ratio or fraction. It indicates that one unit of measurement on the map corresponds to a given number of the same units on the ground.

1 : N or 1/N

where N is the scale denominator (the larger N, the smaller the scale)

Examples:

1:50,000 — 1 cm on the map = 50,000 cm = 500 m on the ground

1:25,000 — 1 cm on the map = 25,000 cm = 250 m on the ground

1:5,000 — 1 cm on the map = 5,000 cm = 50 m on the ground

Important Rule

A larger denominator means a smaller scale (covers more area, less detail). A smaller denominator means a larger scale (covers less area, more detail). 1:5,000 is a LARGER scale than 1:50,000.

2.1.2 Verbal (Statement) Scale

The verbal scale expresses the scale in words, stating the relationship between a map unit and a ground unit explicitly:

- "One centimetre represents five hundred metres"
- "One centimetre to two kilometres"

This form is commonly used in written documents and on maps intended for general public use. It must specify the unit used on both the map and the ground.

2.1.3 Graphic (Bar) Scale

The graphic scale, or scale bar, is a line drawn on the map that is divided into segments, each labelled with the corresponding ground distance. It is the most practical scale representation because it remains accurate when the map is photographically enlarged or reduced — unlike the numerical scale, which becomes invalid if the map dimensions change.

A typical scale bar is divided into two parts: a primary scale (right of the zero mark, divided into full ground units) and an extension scale (left of the zero mark, divided into fractions for finer reading).

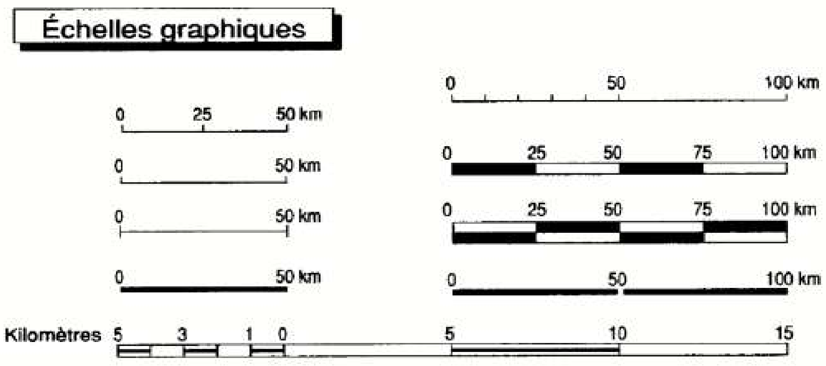


Figure 2.2. Graphical scales

> **Advantage of the Graphic Scale**
>
> The graphic scale is the only scale type that remains valid after photocopying, scanning, or printing at a different size. It should always be included on maps that may be reproduced.

2.1.4 Comparison of Scale Types

Term	Definition / Description
Numerical scale	1:50,000
Verbal scale	"1 cm = 500 m"
Graphic scale	Bar diagram

2.2 Methods for Measuring Distances

Distance measurement on topographic maps is a fundamental operation in field preparation, route planning, and engineering design. Several methods are available depending on the type of distance (straight line or along a path) and the precision required.

2.2.1 Straight-Line Distance Measurement

For straight-line (as-the-crow-flies) distances, the procedure is straightforward:

Step 1: Identify the two points A and B on the map.

Step 2: Measure the distance d between A and B using a ruler (in centimetres or millimetres).

Step 3: Apply the scale formula to convert to ground distance.

$$\mathbf{D = d \times N}$$

D = ground distance (m or km) | *d = map distance (cm)* | *N = scale denominator*

Example: On a 1:50,000 map, the measured distance between two points is 4.6 cm. Ground distance = 4.6 × 50,000 = 230,000 cm = 2,300 m = 2.3 km.

2.2.2 Distance Along a Curved Path (Road, River, Boundary)

For irregular lines such as roads, rivers, or contour lines, three methods are commonly used:

Method 1: Straight-Segment Approximation

Divide the curved line into a series of short straight segments. Measure each segment with a ruler, sum the lengths, and apply the scale. This method is simple but introduces error for highly curved lines.

Method 2: Thread Method

Place a flexible thread or string along the curved line on the map, following it precisely. Then straighten the thread against a ruler to read its length. Apply the scale formula. This is a quick and practical method for approximate measurements.

Method 3: Curvimeter (Map Wheel / Opisometer)

A curvimeter is an instrument equipped with a small wheel that rolls along the map line. An internal mechanism converts the total rolling distance into a map distance reading. The curvimeter is then applied to the scale bar to read the ground distance directly. This is the most accurate method for long, irregular lines.

$$D = L_{curvimeter} \times N$$

L_curvimeter = reading from the instrument (cm) | N = scale denominator

2.2.3 Horizontal vs Slope Distance

An important distinction must be made between horizontal distance (planimetric) and slope distance (measured along the terrain surface):

- **Horizontal distance:** the distance measured on the map, which always represents the horizontal projection of the ground distance.
- **Slope distance:** the actual distance along the terrain surface, which is always longer than the horizontal distance on sloping terrain.

$$d_{slope} = d_{horiz} / \cos(\alpha)$$

α = slope angle (degrees) | d_horiz = horizontal distance

Practical Note

For most topographic applications (route planning, cadastral measurements, watershed delineation), horizontal distances are used. Slope distances are needed in detailed engineering design, volume calculations, and gradient analysis.

2.3 Methods for Measuring Areas

Area measurement on topographic maps is required for land use assessment, watershed analysis, cadastral operations, and planning studies. Several methods are available, ranging from simple geometric approaches to precise instrumental techniques.

2.3.1 Geometric Method (Regular Shapes)

For areas with regular geometric shapes (rectangles, triangles, circles), standard geometric formulas are applied to the measured dimensions on the map. The resulting map area is then converted to ground area using the square of the scale denominator:

$$S_{ground} = S_{map} \times N^2$$

S_{map} = area measured on the map (cm^2) | N = scale denominator

Example: On a 1:50,000 map, a rectangular plot measures 3 cm × 2 cm = 6 cm^2 on the map. Ground area = 6 × $(50{,}000)^2$ = 6 × 2,500,000,000 cm^2 = 15,000,000,000 cm^2 = 150 ha.

2.3.2 Grid Square Method

A transparent grid of unit squares (e.g. 1 cm × 1 cm) is overlaid on the area to be measured. The total area is estimated by counting:

- Complete squares entirely within the boundary — counted as 1 unit each.
- Partial squares intersecting the boundary — counted as ½ unit each.

The total count is multiplied by the area of one grid square converted to ground area.

$$S = (n_{full} + n_{partial}/2) \times (scale\_factor)^2$$

n_{full} = complete squares | $n_{partial}$ = partial boundary squares

2.3.3 Geometric Decomposition Method

Complex irregular areas can be decomposed into a series of simple geometric shapes (triangles, trapezoids). The area of each component is calculated using its formula, and the total area is the sum of all components. This method is accurate for moderately irregular shapes.

$$S_{total} = \Sigma S_i$$

S_i = area of each individual geometric component

2.3.4 Planimeter Method

The planimeter is a mechanical instrument used to measure the area of any irregular plane figure by tracing its perimeter. The traditional polar planimeter consists of a tracing arm and a measuring wheel; as the operator traces the boundary of the shape, the wheel records the enclosed area.

Polar planimeter: the anchor point (pole) is fixed outside the figure; the tracing arm follows the boundary.

Digital planimeter: electronic version with a digital readout. Results directly in map area units.

GIS software: modern digital area measurement using geographic information systems provides the most accurate results.

Accuracy Comparison

The accuracy of area measurement methods, from least to most precise: Thread/Grid < Geometric decomposition < Planimeter < Digital GIS measurement. For official cadastral and legal purposes, digital GIS measurements are now standard in Algeria.

2.3.5 Coordinate Method (Shoelace Formula)

When the boundary of an area is defined by a series of surveyed points with known coordinates (x, y), the area can be calculated algebraically using the Shoelace formula (Gauss formula):

$$S = \frac{1}{2} \left|\Sigma(x_i \times y_{i+1} - x_{i+1} \times y_i)\right|$$

Coordinates (x_i, y_i) of successive boundary vertices, closing at the starting point

This method is exact (no geometric approximation) and is the basis of all digital area calculations in GIS and CAD software.

2.4 Map Reduction and Enlargement

In practice, it is often necessary to change the scale of a map — either to reduce it (to fit a larger area on a sheet) or to enlarge it (to show more detail for a specific area). This operation must be performed carefully to maintain geometric accuracy.

2.4.1 Scale Change Formulas

$$K = N_1 / N_2$$

K = scale change factor | N_1 = original scale denominator | N_2 = new scale denominator

If $K > 1$: the map is being enlarged (new map has larger scale).

If $K < 1$: the map is being reduced (new map has smaller scale).

$$d\_new = d\_old \times K$$

d_old = distance on original map | d_new = distance on new map

$$S\_new = S\_old \times K^2$$

For area conversion between scales

2.4.2 Methods of Scale Change

Method 1: Pantograph

A mechanical pantograph is a linkage-based instrument that allows manual reduction or enlargement of drawings by a fixed ratio. The operator traces the original map; the pantograph simultaneously draws the scaled version. Now largely replaced by digital methods.

Method 2: Grid (Squares) Method

A grid is drawn over the original map, and a proportionally scaled grid is drawn on a new sheet. The content of each grid square on the original is reproduced by hand in the corresponding square on the new sheet. This is a simple but time-consuming method suited to field use.

Method 3: Photographic and Photocopier Method

The map is photographically reduced or enlarged using a process camera, enlarger, or modern photocopier with percentage scaling. The scale bar on the map must be used to verify the actual output scale after reproduction.

Method 4: Digital Method (GIS / CAD)

In digital cartography, scale change is instantaneous — the digital dataset can be rendered at any scale, and printed at any desired output scale. This is the standard method used in all modern cartographic production environments.

> **Important Warning**
>
> When a map is photocopied or printed at a different percentage, the numerical scale printed on the map becomes INVALID. Only the graphic scale bar remains correct (since it scales with the image). Always verify the actual scale using the graphic scale bar after any reproduction.

2.5 Comparing Two Maps of Different Scales of the Same Region

In many professional situations, it is necessary to work simultaneously with two maps of the same area but at different scales — for example, a 1:50,000 topographic map and a 1:10,000 urban plan. Understanding the differences between them is essential for correct interpretation.

2.5.1 Differences in Level of Detail

Term	Definition / Description
Feature	1:50,000 Map
Road representation	Single line for all roads
Building representation	Block footprints only, generalised
Contour interval	10 m or 20 m
Forest boundary	Generalised outline
Rivers and streams	Only permanent watercourses shown

2.5.2 Converting Measurements Between Scales

When working with two maps of the same area, distances and areas measured on one map must be converted for use with the other:

$$\mathbf{d_2 = d_1 \times (N_1 / N_2)}$$

d_1 = distance on map at scale 1:N_1 | d_2 = equivalent distance on map at scale 1:N_2

Example: A road measured as 8.5 cm on a 1:50,000 map. Equivalent on a 1:10,000 map: d_2 = 8.5 × (50,000/10,000) = 8.5 × 5 = 42.5 cm.

Conclusion— Chapter 2

Map scale is expressed as a numerical ratio (1:N), a verbal statement, or a graphic bar. Distance measurement methods include straight-line ruler measurement, thread tracing, and the curvimeter. Area methods include grid counting, geometric decomposition, and the planimeter. Scale change uses the factor $K = N_1/N_2$, with distances scaling by K and areas by K^2. Comparing maps of different scales requires understanding the differences in generalisation, contour interval, and level of detail.

CHAPTER 3

Thematic Maps

3.1 Types of Thematic Maps

A thematic map is a map designed to display the spatial distribution of one or more specific phenomena or datasets. Unlike topographic maps, which aim to represent the terrain comprehensively, thematic maps focus on communicating a particular geographic message or pattern. They are produced by overlaying thematic data onto a simplified base map.

Thematic maps are widely used in geography, urban planning, environmental sciences, social sciences, public health, economics, and land management. Their design requires both cartographic skill and subject-matter expertise.

3.1.1 Qualitative Thematic Maps

Qualitative maps represent the spatial distribution of categories or types, without implying any quantitative difference between them. Colour, pattern, or symbol differences are used to distinguish categories.

Term	Definition / Description
Land Use Map	Shows the distribution of land use categories (urban, agricultural, forest, water, bare land). Uses distinct colours for each category. Fundamental tool for planning and environmental management.
Geological Map	Represents the distribution of rock types, geological formations, structural features (faults, folds), and mineral deposits. Uses standardised colours and symbols defined by international conventions.
Soil Map	Shows the spatial distribution of soil types classified according to physical, chemical, and pedological characteristics. Used in agriculture and land evaluation.

Vegetation Map	Represents the distribution of plant communities and vegetation types. Used in ecology, forestry, and environmental planning.
Administrative Map	Shows political and administrative boundaries at various levels (commune, wilaya, country). The simplest form of thematic map.

3.1.2 Quantitative Thematic Maps

Quantitative thematic maps represent the spatial distribution of measured quantities or statistical data. They require a method of visual encoding that correctly communicates numerical differences.

Choropleth Maps

Choropleth maps represent statistical data aggregated by administrative or geographic units (communes, wilayas, countries) using colour gradients or shading intensities. The darker (or more saturated) the colour, the higher the value.

Applications: population density, GDP per capita, literacy rate, rainfall by region.

Rule: data must be normalised (e.g. per km², per 1,000 inhabitants) before mapping — absolute values in choropleth maps are misleading.

> **Design Warning**
>
> Choropleth maps are often misused when absolute values (total population, total rainfall) are mapped instead of relative values (density, percentage). Always normalise data before creating a choropleth map to avoid misrepresentation.

Graduated Symbol Maps

Graduated symbol maps use symbols (typically circles or squares) whose size is proportional to the data value at each location. They are appropriate for absolute values (total population, total production volume) at point or area locations.

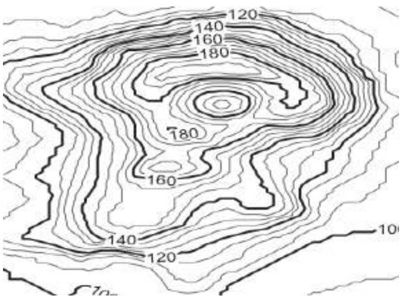
Advantages: visually intuitive; easy to compare values across locations.

Limitation: symbol overlap becomes a problem when many points are mapped in a small area.

Isoline (Contour) Maps

Isoline maps connect points of equal value with continuous lines, creating a smooth representation of a continuously varying surface. The most familiar example is the contour map showing terrain elevation, but the method applies to any spatially continuous variable.

Term	Definition / Description
Isobar	Lines of equal atmospheric pressure (meteorological maps).
Isotherm	Lines of equal temperature.
Isohyet	Lines of equal rainfall.
Isohypse (contour line)	Lines of equal terrain elevation (topographic maps).
Isobath	Lines of equal water depth (bathymetric maps).
Isoseist	Lines of equal seismic intensity.



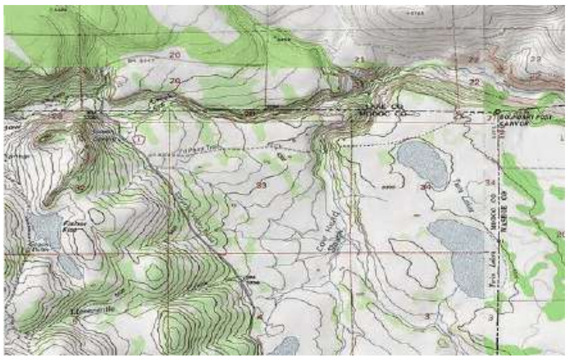


Figure 3.1 Example of a Isoline Contour

Dot Density Maps

Dot density maps use uniformly sized dots, each representing a fixed quantity of a phenomenon, distributed across the map according to the spatial concentration of the data. The density of dots indicates the relative intensity of the mapped variable.

Example: a dot map of population where each dot = 1,000 inhabitants, distributed within each commune.

Limitation: dot placement is partly manual/estimated and does not indicate exact locations.

Flow Maps

Flow maps show the movement of people, goods, resources, or information between locations. Arrows or bands of proportional width represent the direction and volume of flows.

Applications: migration flows, trade patterns, traffic volumes, river discharge networks.

3.1.3 Composite Thematic Maps

Composite maps combine two or more thematic variables on a single map. They are powerful analytical tools but require careful design to remain readable. Examples include bivariate choropleth maps (combining two data variables using a two-dimensional colour scheme) and maps combining isoline and choropleth layers.

3.2 Symbols Used in Thematic Maps

Symbols are the fundamental building blocks of all maps. In thematic cartography, symbols must not only locate features in space but also communicate qualitative or quantitative differences in the mapped data. The design of map symbols is governed by the principles of map semiology (treated in detail in Chapter 4).

3.2.1 Classification of Cartographic Symbols

Map symbols are classified according to two criteria: their geometric dimension (point, line, or area) and whether they represent qualitative or quantitative information.

Term	Definition / Description
Point symbols	Used to represent features that occupy a negligible area at the map scale (cities on a small-scale map, sampling stations, individual buildings). Can be geometric (circles, squares, triangles), pictographic (pictogram icons), or alphanumeric.
Line symbols	Used to represent linear features (roads, railways, rivers, pipelines, boundaries). Varied by colour, thickness, pattern (solid, dashed, dotted), and direction arrows.
Area symbols	Used to represent features that extend over a significant area at the map scale (land use zones, administrative regions, geological formations). Varied by fill colour, pattern, and texture.

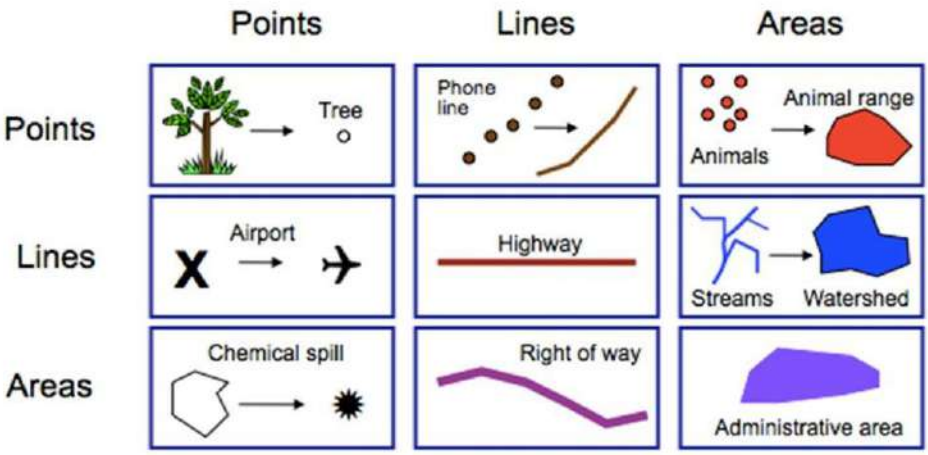


Figure 3.2 Cartographic Symbols

3.2.2 Point Symbol Types

Geometric symbols

- Circle: general-purpose, widely used for quantities (graduated circles)
- Square/Rectangle: useful for comparing two variables (divided squares)
- Triangle: often used for directional data or special facilities
- Star/Diamond: used for prominent landmarks or capitals

Pictographic symbols

- Airport icon: represents airports
- Church/Mosque symbol: religious buildings
- Hospital cross: medical facilities
- Tree symbol: forested areas or parks
- Industry symbol: industrial zones

3.2.3 Conventional Signs on Topographic Maps

Topographic maps use a standardised set of conventional signs defined by national mapping agencies. In Algeria, the conventional signs used by the Institut National de Cartographie et de Télédétection (INCT) follow international standards. Key categories include:

Term	Definition / Description
Relief	Contour lines (brown), spot heights, bench marks (BM), cliff symbols, slope indicators.
Hydrography	Permanent rivers (solid blue), seasonal watercourses (dashed blue), lakes (blue fill), wells, springs, canals.
Vegetation	Forest (green stipple or pattern), orchard, vineyard, scrubland, palm grove.
Built areas	Populated areas (pink or grey fill), individual buildings (black rectangles), ruins (open squares).
Communications	Motorways (double red lines), main roads (red), secondary roads (orange/yellow), tracks (dashed), railways (black with ties), paths.
Administrative	National boundary (red dash-dot), wilaya boundary (red dashed), commune boundary (black dashed).
Geodetic control	Triangulation points (triangle symbol), benchmarks, GPS control points.

3.2.4 Colour Conventions in Thematic Cartography

Colour is the most powerful visual variable in thematic maps. Established conventions guide its use:

Term	Definition / Description
Blue tones	Water-related data (rainfall, rivers, sea depth, flood risk).
Green tones	Vegetation, agriculture, environmental quality, positive values.
Brown/Orange	Relief (topographic contours), soil, arid environments.
Red tones	High values, danger, temperature, urban areas, important infrastructure.

Yellow tones	Semi-arid areas, secondary roads, moderate values.
Grey/Black	Urban fabric, infrastructure, boundaries, neutral data.
Diverging colour schemes	Used for data with a meaningful midpoint (e.g. above/below average rainfall): cold colours for below, warm for above.

Conclusion— Chapter 3

Thematic maps focus on communicating a specific spatial phenomenon. They include qualitative maps (land use, geology, soil) and quantitative maps (choropleth, graduated symbols, isolines, dot density, flow). Map symbols are classified as point, line, or area, and may be geometric or pictographic. Colour conventions and standardised signs ensure consistent interpretation. Choropleth maps must use normalised data (density or rates, not absolute values).

CHAPTER 4

Map Semiology

4.1 Introduction to Map Semiology

Semiology is the science of signs and symbols and their meaning within communication systems. Applied to cartography, map semiology — also known as graphical semiology or cartographic semiology — is the systematic study of the visual variables available to map designers and the rules governing their effective use to communicate geographic information.

The foundations of modern map semiology were established by the French cartographer Jacques Bertin in his landmark work "Sémiologie Graphique" (1967). Bertin identified a limited set of visual variables that can be varied in graphic representations, and defined their perceptual properties — which types of geographic information each variable is suited to represent.

For the cartographer, semiology provides a scientific basis for design decisions. Rather than choosing symbols arbitrarily or based purely on aesthetic preference, the semiological approach requires selecting visual variables that are perceptually appropriate for the type of data being mapped — whether it is qualitative (categories), ordered (ranks), or quantitative (measured values).

Jacques Bertin — Father of Graphical Semiology

Jacques Bertin (1918–2010) was a French cartographer and theorist at the École des Hautes Études en Sciences Sociales (EHESS) in Paris. His 1967 work "Sémiologie Graphique" (translated into English as "Semiology of Graphics") established the theoretical framework for understanding how visual variables communicate information. It remains the foundational reference for cartographic design.

4.2 Visual Variables

Bertin identified the following visual variables as the primary means by which graphic marks can be varied to encode geographic information. Each variable has specific perceptual properties that make it suitable for certain types of data.

4.2.1 The Seven Visual Variables (Bertin, 1967)

In his seminal work *Sémiologie Graphique* (1967), Jacques Bertin identified seven elementary visual variables that a cartographer can manipulate to encode geographic information on a map. These variables represent the complete set of graphic dimensions along which marks — points, lines, and areas — can be systematically varied to convey meaning. Each variable possesses distinct perceptual properties: some are perceived as ordered (suggesting a progression from low to high), others as associative (suggesting difference without hierarchy), and some as quantitative (allowing the reader to estimate magnitudes). Choosing the correct visual variable for a given data type is the most fundamental decision in thematic map design, as a mismatch between variable and data type leads to maps that are either unreadable or actively misleading. The seven variables are described individually below.

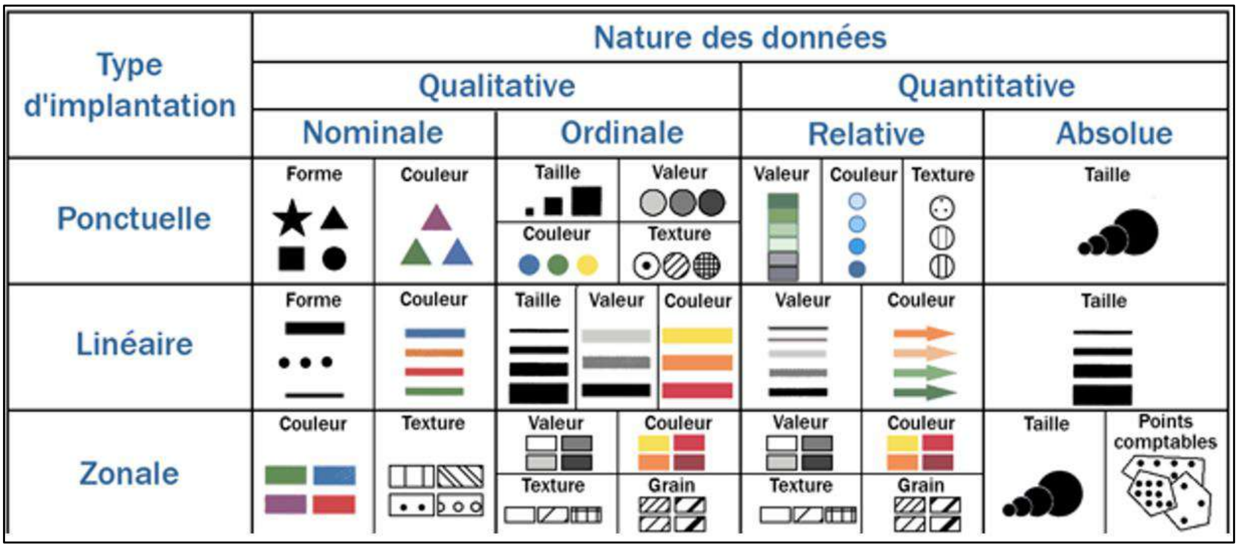


Figure 4.1 Visual Variables and Their Applicability According to Implantation Type and Data Nature (after Bertin, 1967)

1. Position (X, Y)

Position is the most fundamental variable — the location of a mark on the two-dimensional plane. On a map, position is primarily determined by geographic coordinates (the location of the feature on Earth). Position automatically encodes both qualitative (different locations = different places) and quantitative (distance between locations) information.

• Suitable for: all data types (associative, ordered, quantitative).

• Note: in thematic cartography, position is often 'used up' by geographic location, so other variables must carry the thematic information.

2. Size

Size refers to the overall dimensions of a symbol — larger symbols represent higher values. Size is the primary variable used in graduated symbol maps (proportional circles, squares, etc.).

Quantitative: strongly — size differences are immediately perceived as quantity differences.

Ordered: yes — a large circle is clearly perceived as representing more than a small one.

Associative (qualitative): poor — different sizes imply a value hierarchy, not equal categories.

Application: population of cities (graduated circles), flow volumes (proportional arrows).

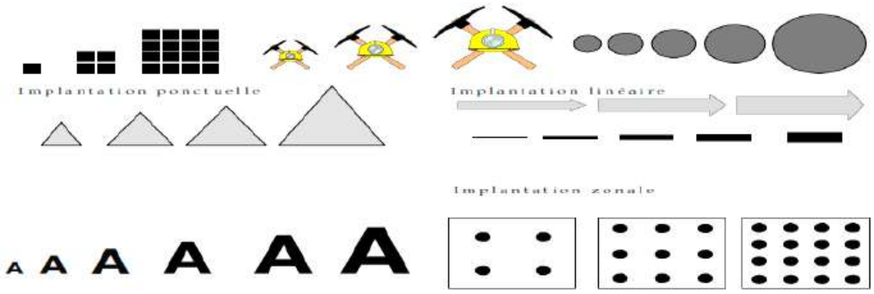


Figure 4.2 Examples of Visual Variables Type Size Applied to Point, Line, and Zonal Implantation

3. Value (Lightness)

Value refers to the lightness or darkness of a colour — the grey level from white to black, or from light to dark within a single hue. Dark = high, light = low.

Quantitative: moderate — value differences can suggest quantity but not precise values.

Ordered: excellent — dark-to-light progression is immediately perceived as high-to-low.

Application: choropleth maps (light = low density, dark = high density), terrain shading.

Figure 4.3 Variation of Hue (or Saturation) and thus of Value from White to Black

4. Texture (Grain)

Texture refers to the fineness or coarseness of a pattern fill — the density of pattern elements (lines, dots, hatching) within an area symbol. More texture = more dense.

Ordered: fine to coarse can suggest a progression.

Associative: different textures can distinguish qualitative categories.

Application: distinguishing land use categories, geological formations, vegetation types.

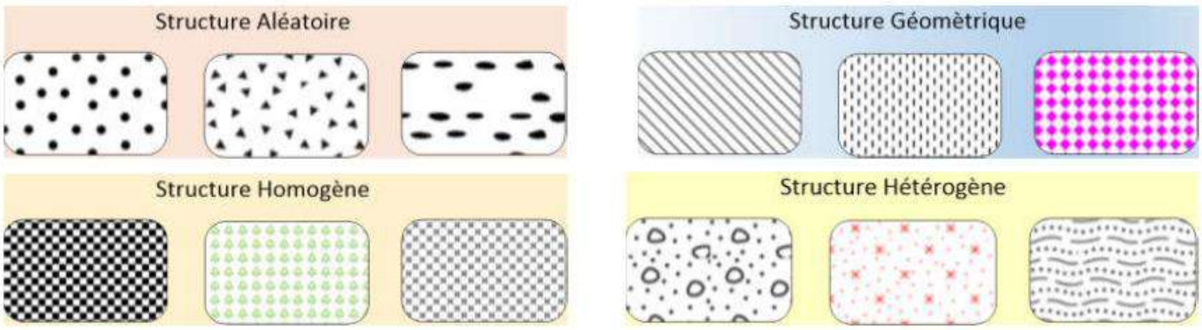


Figure 4.4 The Four Texture Structures — Random, Geometric, Homogeneous, and Heterogeneous

5. Colour (Hue)

Colour (hue) refers to the specific wavelength of light — red, blue, green, yellow, etc. — independent of lightness or saturation. Colour is the most powerful qualitative variable.

Associative (qualitative): excellent — different hues immediately suggest different categories with no implied order.

Ordered/Quantitative: poor when used alone — different hues do not naturally suggest a progression.

Application: land use maps (each category gets a distinct colour), geological maps.

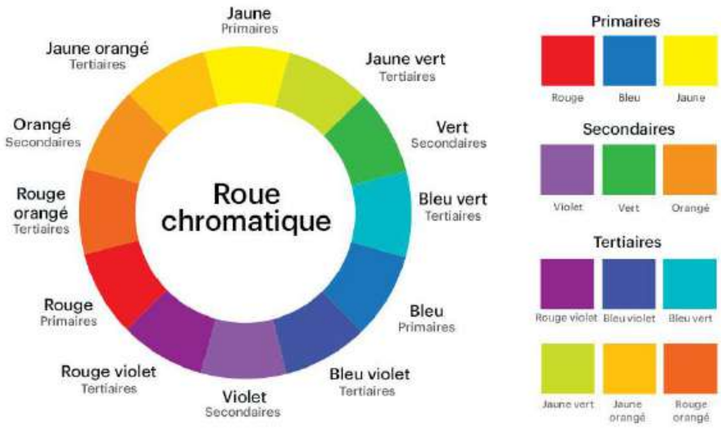


Figure 4.5 The Colour Wheel — Primary, Secondary, and Tertiary Colours

Colour vs Value

This is a common source of design errors: colour (hue) communicates QUALITATIVE differences (categories), while value (lightness) communicates ORDERED or QUANTITATIVE differences. Using different bright colours (red, blue, green) for a choropleth map violates this rule — a progression from light to dark of a single hue should be used instead.

6. Orientation

Orientation refers to the direction or angle of a linear or repeated element within a symbol (e.g. hatching lines at 0°, 45°, 90°). Orientation is primarily a qualitative variable.

Associative (qualitative): yes — different orientations clearly distinguish categories.

Ordered/Quantitative: very poor — no natural ordering between orientations.

Application: distinguishing categories of area fills (forest vs farmland), geological strike directions.

7. Shape

Shape refers to the overall form of a symbol — circle, square, triangle, cross, pictogram, etc. Shape is the primary variable for distinguishing categories of point features.

Associative (qualitative): excellent — different shapes immediately suggest different categories.

Ordered/Quantitative: very poor — shapes have no inherent numerical order.

Application: city types, infrastructure types, sampling station categories, administrative levels.

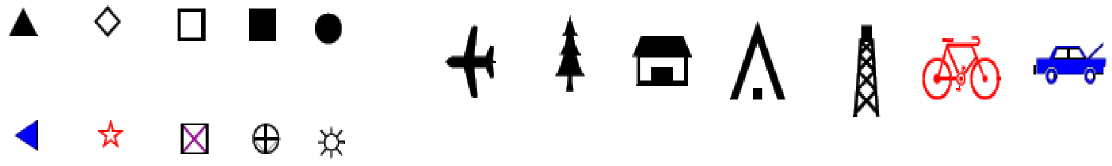


Figure 4.6 Types of Map Symbols — Geometric Shapes and Pictographic (Symbolic) Forms

4.2.2 Summary Table of Visual Variables

Term	Definition / Description
Position	All levels
Size	Quantitative, Ordered
Value	Ordered, Quantitative
Texture	Ordered, Qualitative
Colour (hue)	Qualitative only
Orientation	Qualitative
Shape	Qualitative

4.3 Graphic Rules and Design Principles

Beyond the visual variables, effective map design is guided by a set of graphic rules and perceptual principles derived from cognitive psychology and cartographic practice.

4.3.1 The Three Levels of Map Reading

Bertin identified three levels at which a reader interacts with a graphic:

Term	Definition / Description
Elementary level	Reading the value of an individual element: 'What is the population density of this commune?' Requires precise symbol design and a clear legend.
Intermediate level	Reading patterns or groups: 'Which communes have the highest density?' Requires a clear visual hierarchy and well-chosen class boundaries.
Overall level	Reading the general structure of the map: 'Is population concentrated in coastal areas?' Requires good generalisation and clear visual organisation.

4.3.2 Principles of Perceptual Effectiveness

Figure-ground contrast: the mapped phenomenon (figure) must stand out clearly from the base map (ground). Use stronger colours and thicker lines for thematic content; subdued grey tones for base map features.

Visual hierarchy: important information must be visually dominant. The thematic layer is the most important; administrative boundaries are secondary; graticule grid is tertiary.

Legibility: all text must be readable at the intended reproduction size. Minimum font size: 6–7 pt for print; 8–10 pt for screen.

Simplicity: avoid unnecessary graphic complexity. Each visual element must serve a communicative purpose.

Consistency: use the same symbol for the same feature throughout the map. Do not use the same symbol for different features.

Balance: the visual weight of the map should be distributed evenly. Avoid overcrowding in some areas while leaving others empty.

4.3.3 Data Classification for Choropleth Maps

When producing choropleth maps, the continuous data range must be divided into a limited number of classes (typically 4–7). The choice of classification method significantly affects the visual message of the map.

Term	Definition / Description
Equal interval	Divides the data range into equal-width classes. Simple but may produce empty classes if data is not uniformly distributed.
Quantile (equal count)	Each class contains an equal number of observations. Ensures good visual differentiation but may group very different values in the same class.
Natural breaks (Jenks)	Classes are defined at natural gaps or inflections in the data distribution. Best represents the actual data structure. Most commonly recommended method.

Standard deviation	Classes defined relative to the mean and standard deviation. Useful for normally distributed data; highlights deviations from the average.
Manual classification	Classes defined by the cartographer based on domain knowledge or threshold values (e.g. poverty line, flood threshold). Most appropriate when breaks have real-world significance.

4.3.4 Colour Scheme Selection

The choice of colour scheme should match the nature of the data:

Sequential scheme (light to dark, single hue): for ordered or quantitative data with no meaningful midpoint. Example: population density from low (light blue) to high (dark blue).

Diverging scheme (two hues meeting at a neutral midpoint): for data with a meaningful centre value. Example: temperature anomaly — blue for below average, red for above average.

Qualitative scheme (distinct hues, similar lightness): for categorical data with no inherent order. Example: land use — green for forest, yellow for farmland, grey for urban.

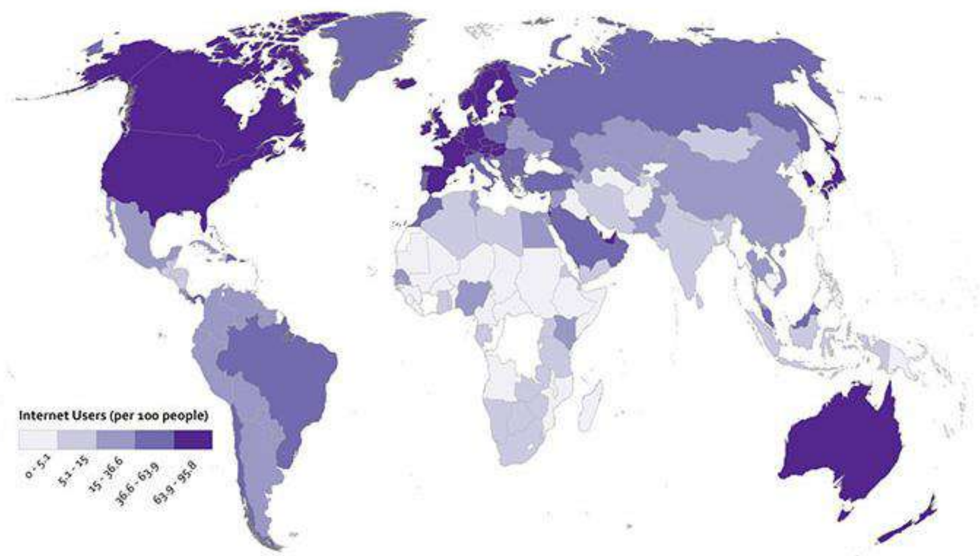


Figure 4.7 World Map of Internet Penetration (Internet Users per 100 People) (MAPFAST).

Recommended Resource

ColorBrewer (colorbrewer2.org), developed by Cynthia Brewer (Penn State University), provides scientifically designed colour schemes for all three data types. It also indicates which schemes are colour-blind safe and printer-friendly. It is the standard reference for cartographic colour selection.

4.4 Practical Applications of Semiology

The semiological principles described above are applied in all cartographic production contexts — from hand-drawn sketch maps to professional GIS output. The following examples illustrate how visual variables should be selected and combined in practice.

4.4.1 Application 1: Mapping Population Density (Choropleth)

Data type: quantitative, continuous, aggregated by administrative unit (commune).

Variable chosen: value (lightness) — single hue (blue or orange), sequential scheme, 5 classes.

Classification: Jenks natural breaks or quantile.

Base map: light grey commune boundaries, minimal road network.

Legend: 5 colour swatches with class boundaries in inhabitants/km².

Common error to avoid: mapping total population (absolute values) — always map density (population/km²).

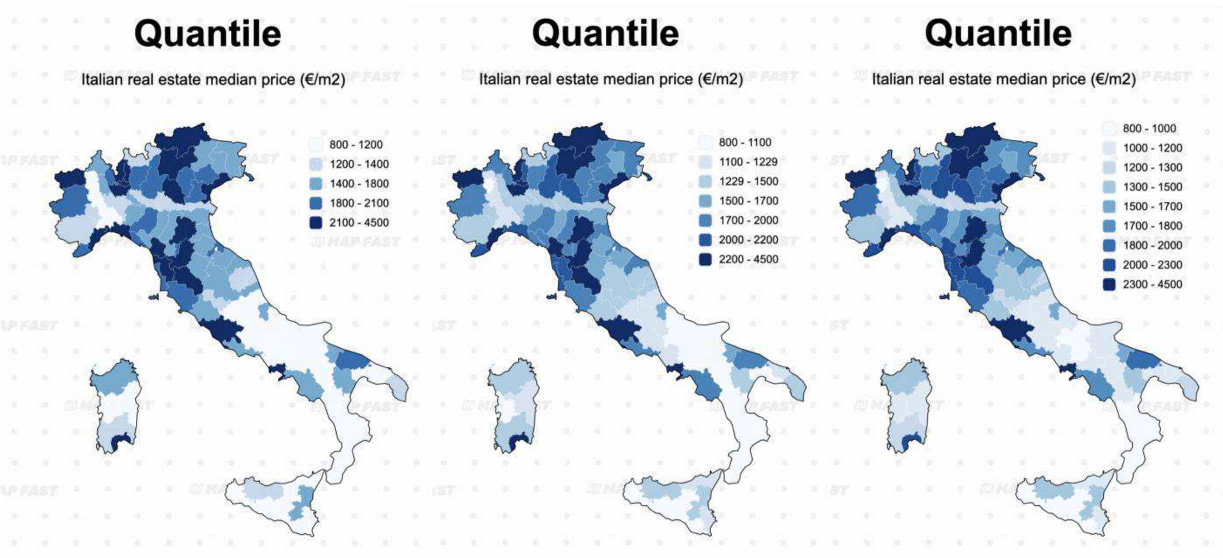


Figure 4.8 Quantile classification example with 5, 7 and 9 groups. Data: Italian real estate prices (€/m2) (MAPFAST).

4.4.2 Application 2: Mapping Land Use (Qualitative)

Data type: qualitative (nominal categories).

Variable chosen: colour (hue) — distinct hues for each category, similar lightness levels.

Standard colours: urban = grey/pink, forest = dark green, farmland = light green/yellow, water = blue, bare land = beige.

Texture: optional, to assist colour-blind readers.

Common error to avoid: using a dark-to-light progression for land use categories — this implies a non-existent hierarchy.

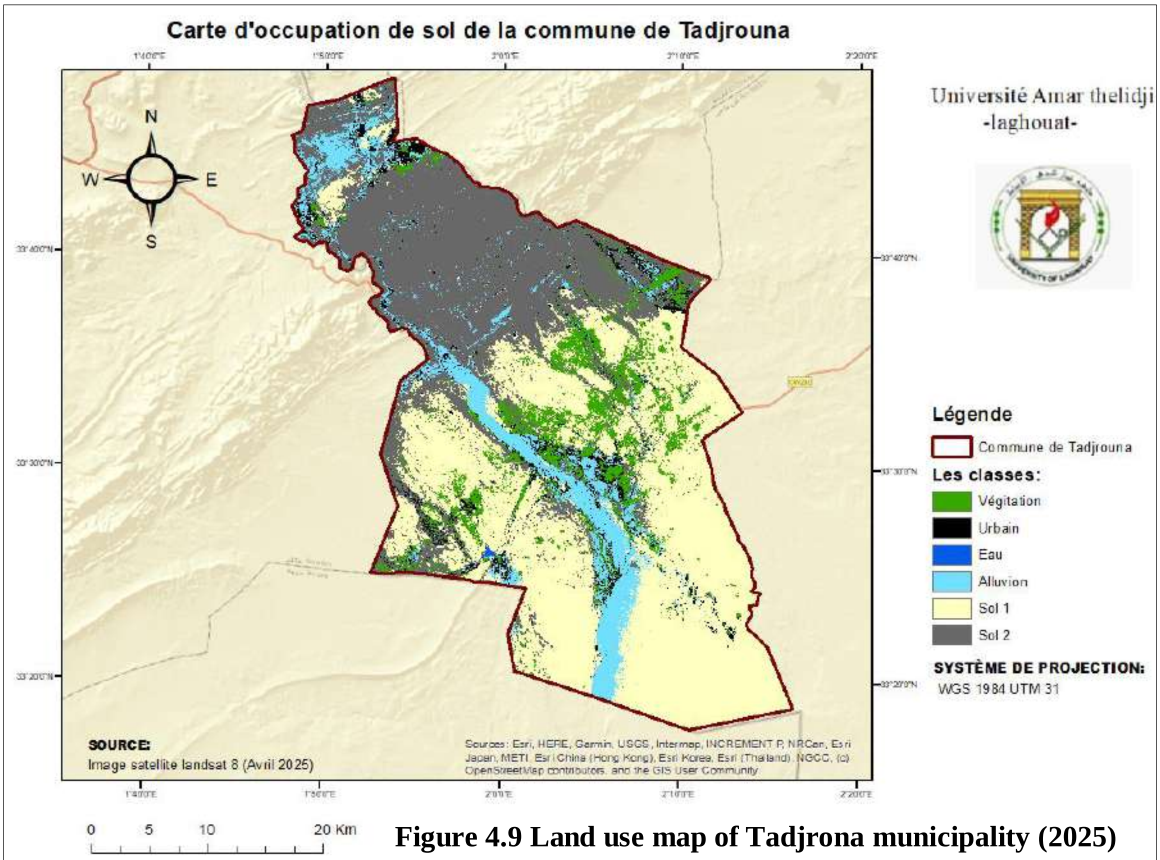


Figure 4.9 Land use map of Tadjrona municipality (2025)

4.4.3 Application 3: Mapping City Populations (Graduated Symbols)

Data type: quantitative (total population at point locations).

Variable chosen: size — proportional circles, where area is proportional to population (not radius — area is the perceptually correct variable for quantities).

Scale: define the reference circle size (e.g. 1 cm² = 100,000 inhabitants) and show in legend.

Overlap: for densely mapped areas, use transparency or shift symbols slightly.

Common error to avoid: scaling circle radius (not area) proportionally to population — this exaggerates differences.

$$r = \sqrt{S / \pi}$$

r = circle radius | S = symbol area proportional to data value

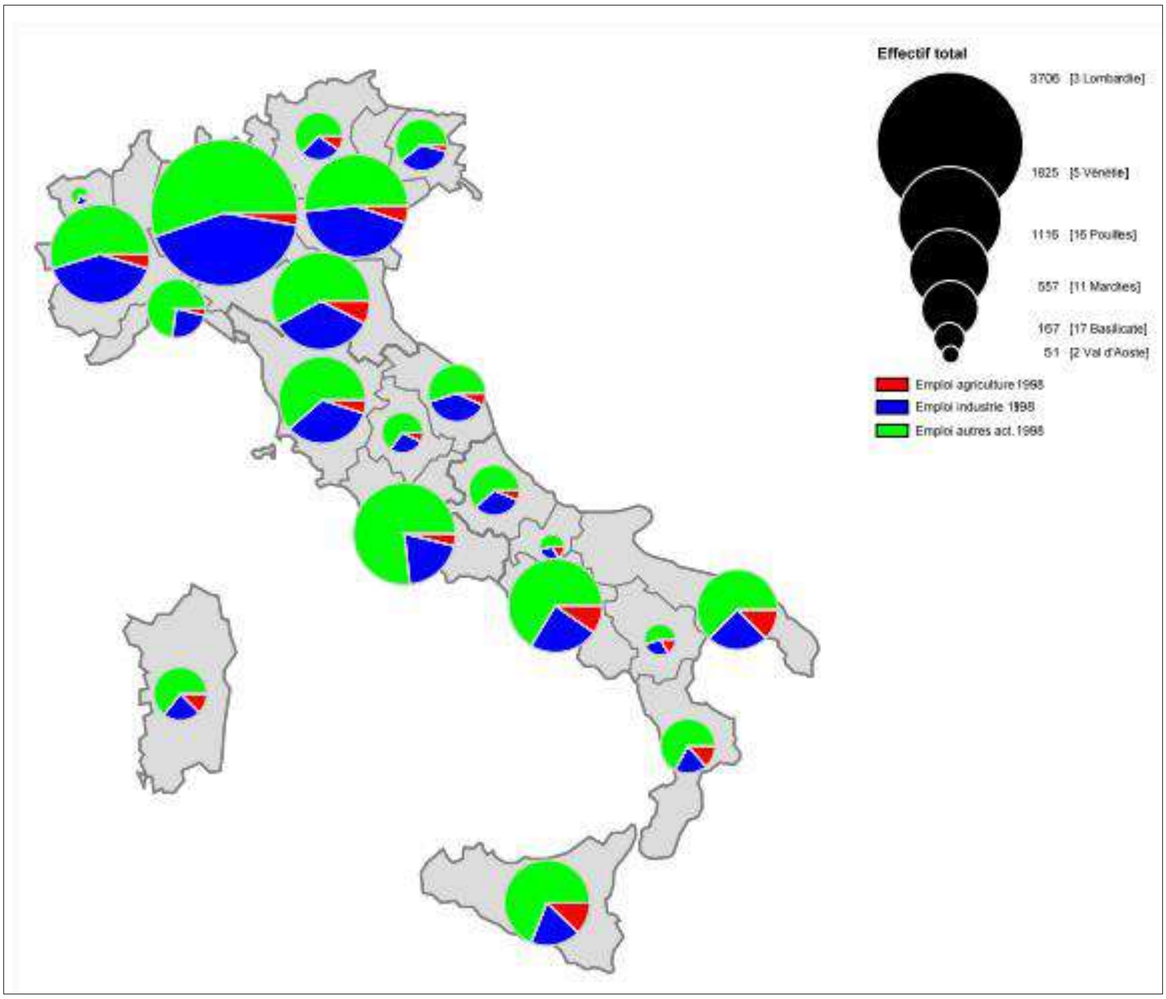


Figure 4.10 Italy (regions) Agricultural, industrial and service sector employment (1998)

4.4.4 Application 4: Flow Map Design

Data type: quantitative, directional (migration flows, trade volumes).

Variable chosen: size (line width) — width proportional to flow volume. Direction indicated by arrows.

Colour: single colour or colour-coded by flow type/origin.

Overlap: heavy traffic corridors may require schematic simplification.

Common error to avoid: drawing too many overlapping flows that obscure the spatial pattern — aggregate minor flows or use a simplified network.

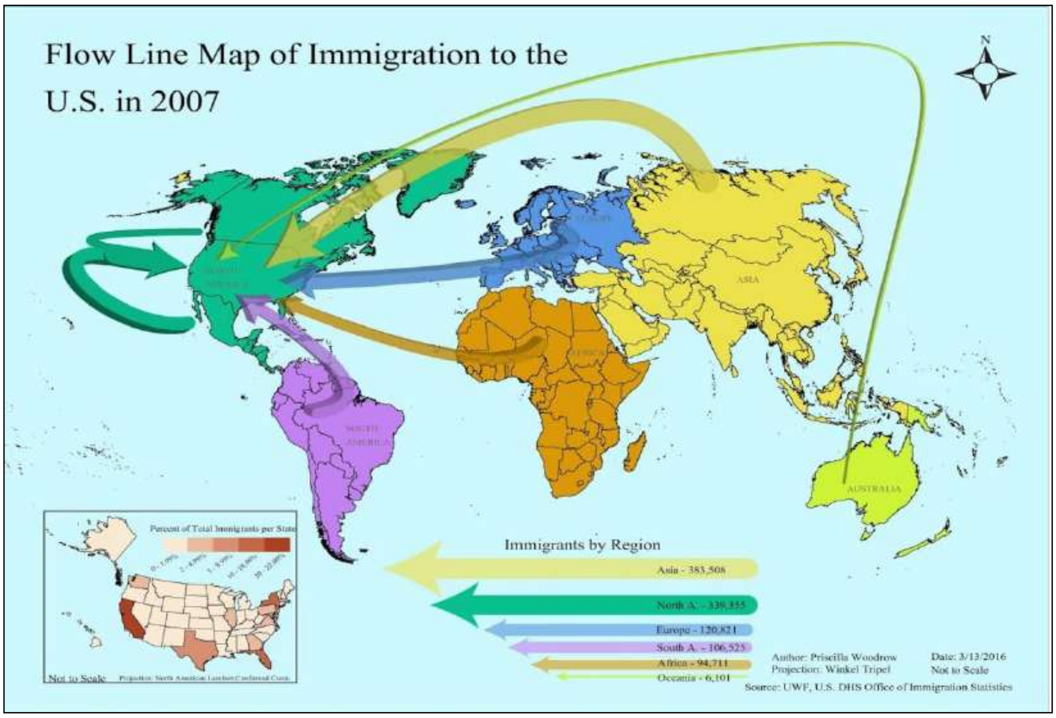


Figure 4.11 Flow Line Map of Immigration to the U.S. in 2007

Conclusion— Chapter 4

Map semiology, founded by Jacques Bertin (1967), identifies seven visual variables: position, size, value, texture, colour, orientation, and shape. Each variable has specific perceptual properties: size and value for quantitative/ordered data; colour (hue) and shape for qualitative/categorical data. Effective map design follows principles of figure-ground contrast, visual hierarchy, legibility, and consistency. Choropleth maps require appropriate data classification (Jenks, quantile, equal interval) and colour schemes matched to the data type (sequential, diverging, or qualitative).

CHAPTER 5

Exploitation of Satellite Imagery for Cartography

5.1 Introduction

Since the launch of the first Earth observation satellites, numerous studies have been dedicated to the extraction and exploitation of the information content of acquired images. This has been particularly relevant with the emergence of sensors providing metric and sub-metric resolution imagery. In this chapter, we address the concepts related to the use of satellite imagery for cartography, in accordance with the needs of various users and decision-makers.

5.2 Users of Geographic Information and Their Needs

5.2.1 Users of Geographic Information (GI) and Their Level of Expertise

Three categories of users can be distinguished according to their level of expertise (or competence) in handling geographic information (GI), in the fields of spatial planning and urban development:

Expert users: highly skilled in the integration and processing of geographic data.

Informed users: moderate knowledge of geographic data manipulation within their specific domain.

General public: no precise knowledge of geographic data or the tools to exploit it.

Expert users are characterised by their high capacity for integrating and processing geographic data. They handle and manage large volumes of geographic data in urban databases adapted to daily territorial management (technical management of networks, urban furniture, etc.). These expert users — GI technicians — operate at an 'operational' level.

Informed users have an average knowledge of geographic data manipulation and exploitation. They are only interested in it within their own area of competence. They have a basic knowledge of GIS tools. Their competences are related to urban planning, pre-operational urbanism, impact studies, observatories, and prospective studies. These informed users — planners — operate at a 'tactical' level.

General public users have no precise knowledge of geographic data and are unfamiliar with the tools to exploit it. This category encompasses both decision-makers, who make decisions at a 'strategic' level in an urban context (through the presentation of final documents, such as maps), and the general population who must be informed of territorial planning policies [1].

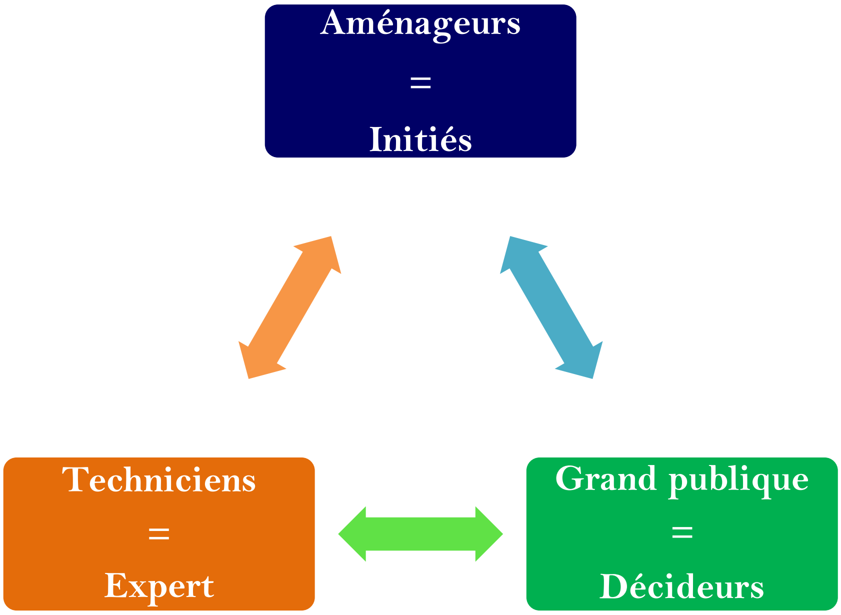


Figure 5.1 Geographic information users classified according to their level of expertise

Regardless of the planning, management, and decision-making process, all stakeholders and users need precise information about the administered territory — both to respond to residents' needs and to anticipate future developments or ensure the maintenance of infrastructure. Interactions occur through urban practices between the various stakeholders and users [1].

5.2.2 Information Needs and Application Types

Each category corresponds to a level of responsibility, associated with a need for basic data that is distinguished by the volume of data required, the level of generalisation, the required precision, and the form in which this information must be delivered. Each level interacts with the level above [1].

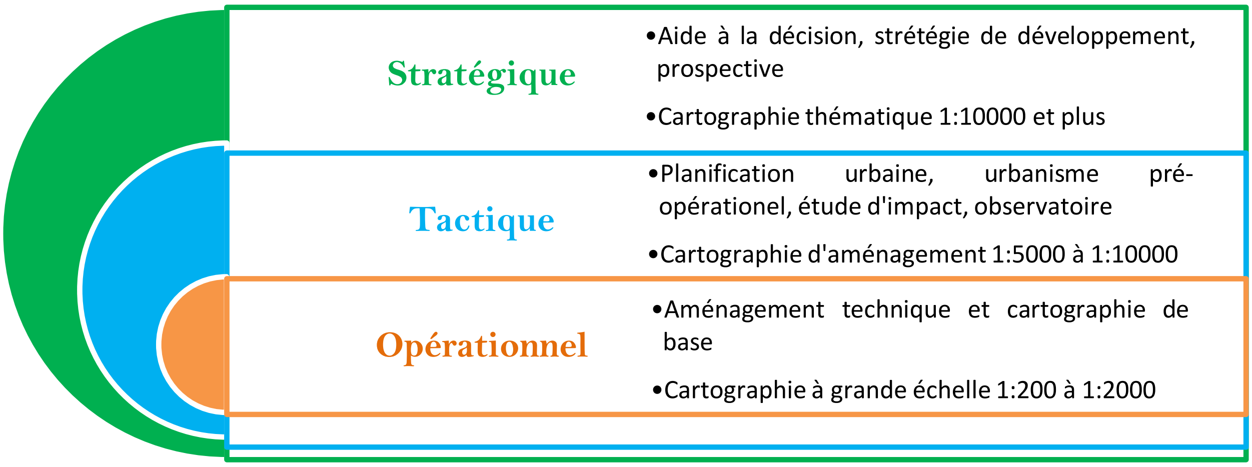


Figure 5.2 Stakeholders and their associated needs in geographic information. [1]

The first group — 'territorial managers' — comprises public law organisations (administrations and local authorities) or private entities (network operators, for example). Their activities have a strong geographic component (GIS experts). They form the core of the GI market. Their applications require large-scale base data (from 1:200 to 1:10,000, from topographic surveys, cadastral plans, etc.) and high geometric precision. Technical planning applications require data at 1:200 to 1:500, while base cartography requires data at around 1:1,000 to 1:2,000.

The second group — 'territorial analysts' — comprises organisations whose common aim is to understand, analyse, and forecast the functioning of a territory or its components. It includes Urban Planning Agencies and Planning Consultancies. Applications include urban planning, pre-operational urbanism, impact studies, and road engineering studies. Data used are multi-source and multi-scale, originating partly from the operational level. Unlike group 1, high precision is not required, but spatial analysis processing is often needed. Data scales range from 1:5,000 to 1:10,000 and come from cartographic documents, aerial photographs, and orthophotos.

The third group — decision-makers and elected officials — require 'geographic syntheses' (e.g. mapping social policy effects, market penetration by district) in terms of thematic editing (communication support) and distribution analysis for decision-making. Data used are generally at small to medium scales from 1:10,000 to 1:1,000,000. Processing consists of map dressing and thematic overlays, planning scenarios (3D simulations, etc.).

The fourth category — transversal to the other three — corresponds to persons responsible for the administration and daily management of data integrated in a GIS. Their activity concerns archiving, formatting, and storing geographic and non-geographic data manipulated by all other levels. The primary objective is to facilitate data access across different departments. These data administrators require standardised data to facilitate GIS integration [1].

5.3 Use of Satellite Imagery

5.3.1 The Information Content of the Image

The generation or updating of topographic maps using satellite or aerial imagery requires consideration of the relationship between spatial resolution and map scale, taking into account not only geometric precision but also the level of reading and generalisation of the output map.

In general, it is not the geometric precision of the image that poses a problem — the real limiting factor is the informational content of the image. What objects can be seen in the image? The distinction between detection and interpretability must therefore be considered.

Example

A white line may be detected on an image. But is this white line a road, a path, or simply a boundary between agricultural plots? This illustrates the problem of interpretation.

For reference, NATO developed the concept of image interpretability analysis, in which object interpretation is organised into four hierarchical levels:

Detection: discovery of an object without recognition. Example: 'There is a white linear object in this part of the image.'

Recognition: ability to assign an identity to an object within a group. Example: 'This white linear object is a road.'

Identification: ability to identify the object as a specific type. Example: 'This road has two carriageways.'

Technical analysis: ability to precisely describe the attributes of the object. Example: 'The two carriageways are separated by a wall.' [2]

Objective	Detection	Recognition	Identification	Analysis
Terrain features	800 m	90 m	3 m	0.75 m
Urban areas	60 m	15 m	3 m	0.75 m
Roads	6 m	4.5 m	1.5 m	0.38 m
Railways	15 m	4.5 m	1.5 m	0.38 m
Bridges	6 m	4.5 m	1.5 m	0.3 m

Table 5.1. Ground pixel size for image interpretation [3]

Applications	Scale	Resolution	Geometric Accuracy	Source Images
Operational level — Technical planning	1:200 to 1:500	20 cm	15–50 cm	Orthophoto / Airborne images
Operational level — Base cartography	1:1,000 to 1:2,000	20–50 cm	15–50 cm	Orthophoto / Airborne images
Tactical level — Territorial planning	1:5,000 to 1:10,000	50 cm – 5 m	±1 m	Orthophoto, IKONOS-2, QuickBird-2, OrbView-3, SPOT5
Strategic level — Prospective	1:10,000 to 1:100,000	>5 m / 10–30 m	±10–100 m	IRS, SPOT, Landsat, QuickBird-2, OrbView-3

Table 5.2. Applications and images used [1]

5.3.2 Applications and Images Exploited

Few studies analyse exclusively the demand of users for image data (aerial or satellite). At the European scale, a report commissioned by the Centre of Earth Observation (CEO) on 'the identification of tasks and user needs in European cities' analyses the use of satellite images by various organisations. The study specifies the type of image products currently used according to the categories of users and applications defined in Table 5.2.

Analogue and digital aerial photographs (orthophotographs) are currently the most widely used image products for applications at 1:200 to 1:10,000. High-resolution satellite images of the LANDSAT and SPOT type are used only in urban prospective applications at scales of 1:25,000 and smaller [1].

- 'Image data' are used in urban applications (orthophotographs only) at scales from 1:200 to 1:10,000.
- Satellite images are used only by a minority of users at scales of 1:25,000 and smaller (land use change analysis).

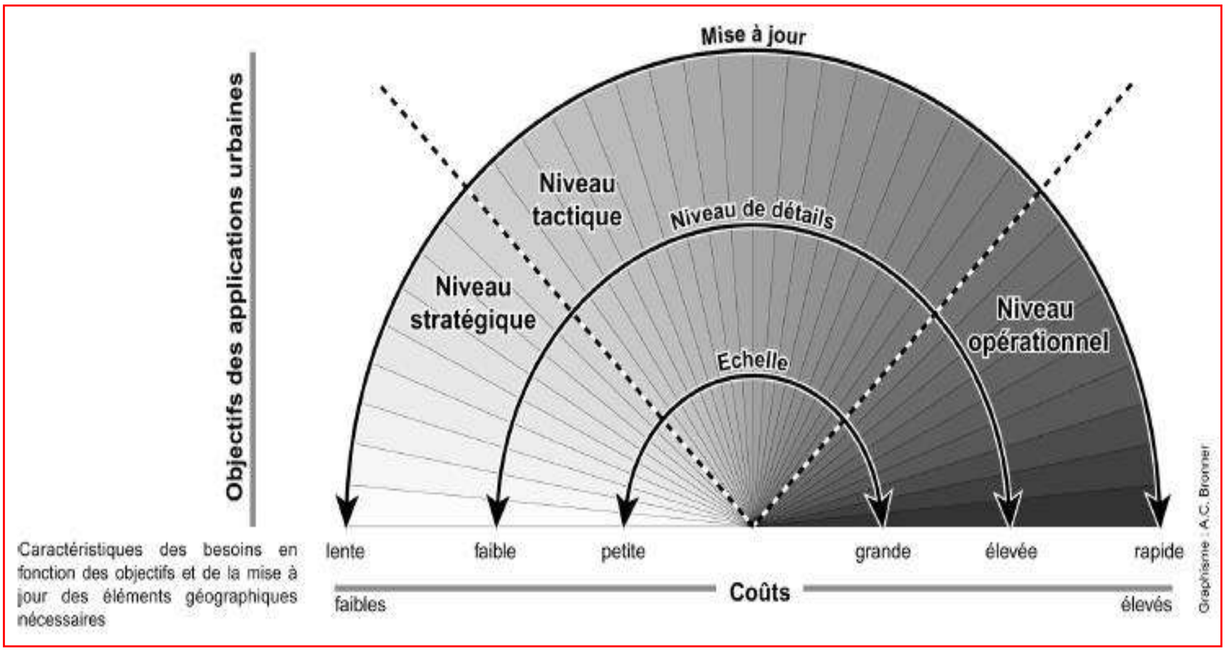


Figure 5.3 Relationship between objectives, needs, and costs during data acquisition and updating

Relationship between objectives, needs, and costs during data acquisition and updating: Operational level (large scale, high detail, frequent updates — high cost); Tactical level (medium scale, moderate precision — moderate cost); Strategic level (small scale, low precision, slow updates — low cost). [1]

5.4 From Land Use Maps to Cadastral Plans

Application	Percentage (%)
Land use mapping	50%
Identification of green spaces	22%
Identification of impervious surfaces	11%
Change detection	11%
Complementary territorial view	6%

Table 5.3. Applications of satellite imagery [1]

The primary use of satellite imagery — by far predominant — is land use mapping, followed by the detection of green spaces. These two applications represent three quarters of all applications [1]. A small number of users employ imagery for the identification of impervious surfaces, change analysis, or as a complementary territorial view at a different scale from other information layers.

5.4.1 High-Maturity Operational Applications

Operational applications in which satellite images are used as the primary source of information are few in number. They are carried out mainly from LANDSAT and SPOT images by fusing panchromatic and multispectral channels.

Level	Applications
Operational	Land use/occupation mapping (1:25,000 to 1:100,000) and statistical production; land use change mapping; flood plain mapping; flooded and marshy zone mapping; fire-risk forest zone mapping; urban morphological unit boundary mapping; control of agricultural plots under the CAP; production of Digital Terrain Models (DTMs). Cartographie et évolution des limites de « l'unité urbaine », correspondant à l'enveloppe de l'espace urbain, encore appelé Zone Morphologique Urbaine (Weber, 1995) ; Contrôle des parcelles déclarées par les agriculteurs dans le cadre de la PAC (Politique Agricole Commune) : depuis 2001, les agriculteurs sont obligés de délimiter sur des photographies aériennes et des images satellites HR (SPOT),

	voire THR (Ixs) leurs parcelles (Van de Steene, 2002) ; Production de modèles numériques de terrain (MNT) ;
Tactical	Calculation of runoff coefficients; biomass index calculation to characterise urban structure; optimal location search for new commercial or industrial zones; road impact studies including land use consumption, vegetation rarity, noise exposure, and flood risk assessment. Searching for an optimal location for a new commercial or industrial activity zone, In impact studies within the framework of a new motorway project, the assessment of the consumption by the footprints of the different categories of land use and vegetation cover, the rarity and relative diversity of the vegetation cover affected compared to the surrounding area, the congestion and fragmentation of space, the exposure of nearby urbanized areas to noise levels, exposure to risks (floods for example);
Strategic	Thematic cartography as communication support for new planning projects. 3D simulations.

Table 5.4. High-maturity operational applications of satellite imagery [1]

At the operational level, the most common processing operations concern thematic mapping and statistical production. At the tactical level, index calculations are most frequently performed. At the strategic level, the contribution of natural colour allows the development of this type of application, since the satellite image then becomes as readable as an aerial photograph to the general public — whereas previously it was the preserve of remote sensing specialists (with its false colours) [1].

5.4.2 Low-Maturity Non-Operational Applications

These applications — belonging exclusively to the research domain or in demonstration phase — are of low maturity. The images used are SAR, IRS, and increasingly IKONOS and QUICKBIRD (from 2000 onwards).

Level	Research / Demonstration Applications
Operational	Cadastral updating (new construction, changes); plant species identification; automatic tree counting; updating of existing databases (BD Topo); production of 3D databases (Digital Elevation Models); road network identification; mapping of disaster zones and assessment of material damage. 3D database production: Digital Elevation Model (DEM), Identification of communication networks (main and secondary road network; rail network); Mapping of disaster areas and assessment of material damage following an earthquake, an explosion in an urban area, etc.
Tactical	Urban morphology analysis (urban fabric types); updating of planning documents; search for potential sites for communication networks; emergency management; production/updating of risk prevention plans; assessment of urban area vulnerability. Researching potential sites for communication networks, Emergency response management (finding the shortest route and emergency response site), Creating or updating risk prevention plans, Assessing the vulnerability of urban areas
Strategic	Risk prevention (decision support); population estimation based on built-up morphology criteria; urban growth and sprawl modelling; DTM/DEM navigation. Population estimation based on building morphology criteria Modeling of urban growth and sprawl Navigation within a DEM, DEM

Table 5.5. Low-maturity non-operational applications of satellite imagery [1]

These applications correspond to those for which improvements in spatial, spectral, and temporal resolution — through the proliferation of VHR satellite images — should generate new application domains and multiply users in the fields of spatial planning and urban management [1].

5.5 The Advent of Very High Resolution (VHR)

From a technical standpoint, the main difference between High Resolution (HR) and Very High Resolution (VHR) lies in the following: at decametric resolution, the landscape in an image can be considered as a 'texture' draped over a low spatial-frequency relief (smoothed, flattened). At metric (and decimetric) resolution, high spatial-frequency altitude variations become visible. Hidden faces (buildings, trees), cast shadows, and the three-dimensional aspect of objects become perceptible. This 3D information appears at resolutions below 3–4 m (the average size of urban objects).

HR allows progression to the stage of recognition or identification of all objects, whereas VHR enables technical analysis of all objects/observations [1].

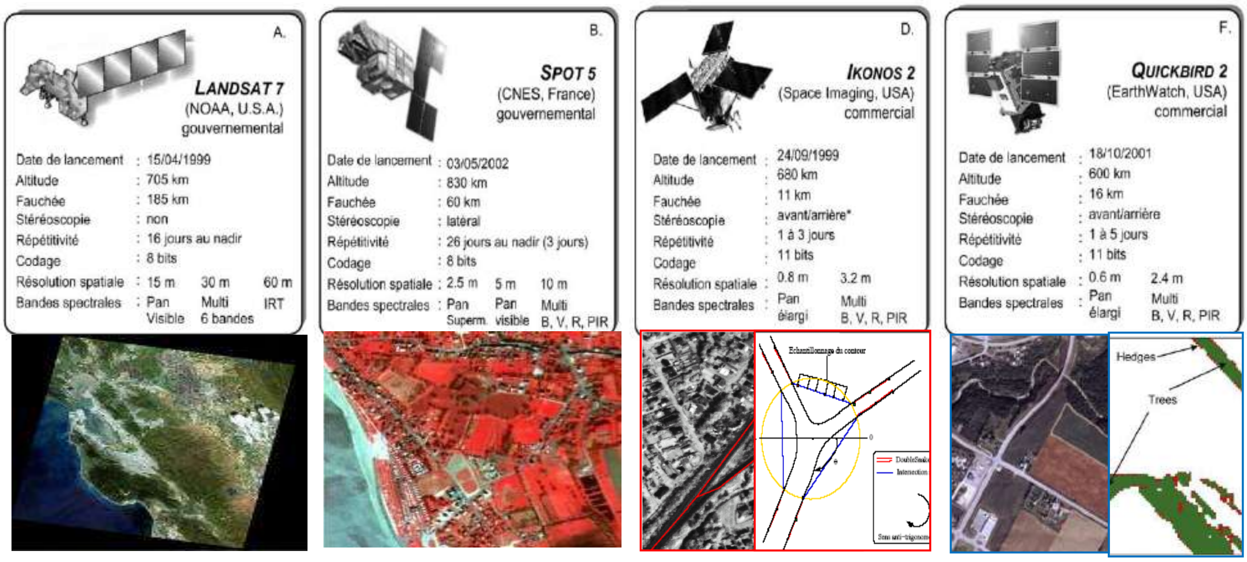


Figure 5.4 Main sensors providing images at various resolutions: from coarse-resolution sensors

Main sensors providing images at various resolutions: from coarse-resolution sensors (MODIS, LANDSAT, SPOT) through high-resolution (SPOT5, IRS) to very high resolution sensors (IKONOS, QuickBird, OrbView) at metric and sub-metric levels. [1]

5.6 Matching Sensor Type to Cartographic Scale

5.6.1 Detection Thresholds

In general, several pixels are required to detect an object. A minimum of 4 pixels is needed, except for objects that contrast strongly with their immediate environment — such as a pond in the middle of grassland [4].

5.6.2 Identification Thresholds

Identifying an object requires 3 times more pixels than its detection — i.e. a minimum of 12 pixels. A figure of 28 pixels is recommended for complex agricultural landscapes [4].

5.6.3 Cartographic Thresholds

In cartography, an important factor to consider is the size of the object to be mapped. The minimum cartographic threshold for an object is generally 2 × 2 mm. The corresponding area depends on the map scale. For example, at 1:25,000, an object of 2 × 2 mm has an area of 0.25 ha.

The following table indicates various possible combinations as a function of the sensor. For example, with IKONOS multispectral (spatial resolution 3.2 m), maps at 1:10,000 can be produced with objects of 0.04 ha, good identification capacity (28 pixels), and good cartographic representation (2 × 2 mm) [4].

Formula

Maximum pixel size (m) = √(area in m² / number of pixels) | Example: for 0.25 ha and 12 pixels → √(2,500/12) = 14.43 m

Map Scale	1:5,000		1:10,000		1:25,000	
Cartographic threshold (mm)	2×2	3×3	2×2	3×3	2×2	3×3
Object area (m²/ha)	100/0.01	225/0.023	400/0.04	900/0.09	2500/0.25	5625/0.56
Identification threshold (pixels)	12 / 28	12 / 28	12 / 28	12 / 28	12 / 28	12 / 28
Max pixel size (m)	2.89 / 1.89	4.33 / 2.84	5.77 / 3.78	8.66 / 5.67	14.43 / 9.45	21.65 / 14.17
QB panchromatic — 0.64 m	✓	✓	✓	✓	✓	✓
IKONOS panchromatic — 0.8 m	✓	✓	✓	✓	✓	✓

EROS panchromatic — 1.8 m	✓	✓	✓	✓	✓	✓
QB multispectral — 2.44 m	✓	✓	✓	✓	✓	✓
SPOT5 panchromatic — 2.5 m	✓	✓	✓	✓	✓	✓
IKONOS multispectral — 3.2 m	—	—	✓	✓	✓	✓
SPOT5 multispectral — 10 m	—	—	—	—	✓	✓

Table 5.6. Cartographic and identification thresholds at 1:5,000, 1:10,000, and 1:25,000 [4]

5.7 Accuracy and Correction of Satellite Images

5.7.1 Geometric Accuracy

Geometric accuracy estimates the variation in discrepancies between nominal positions (positions in the nominal terrain) and the positions contained in the dataset. It is decomposed into two types: the accuracy of point and linear positions, and shape accuracy [5].

5.7.2 Semantic Accuracy

Semantic accuracy represents the conformity of the values of dataset elements with the values of their counterparts in the nominal terrain. It concerns the classification of objects, the coding of attributes, and the relationships between objects.

For satellite images to be usable in cartography and GIS projects, pre-processing operations are required — operations applied to images upstream of all processing, in order to correct or improve them geometrically and thematically. Two types of pre-processing exist: radiometric corrections and geometric corrections [5].

5.7.3 Radiometric Corrections

Radiometric corrections are applied to images to reassign to each pixel a radiometric value as close as possible to that measured in the field. The recorded variations may be due to ageing of sensors, their deregulation, or instrument design defects. SPOT images have a slight banding problem, and LANDSAT MSS and TM images exhibit an important striping phenomenon (particularly at the start of the series).

It is often the distributing organisations of satellite images that carry out radiometric pre-processing (equalisation of detector sensitivity, etc.), but this can also be performed using appropriate procedures. Fourier analysis, for example, can reduce the banding in LANDSAT images [5].

5.7.4 Geometric Corrections

In 1972, the effects of geometric distortions were quite negligible for several reasons: images such as Landsat-MSS were taken at nadir with coarse resolution (~80–100 m); processed products were analogue on paper; evaluation was visual; and multi-source data fusion did not exist.

Today, geometric distortions are no longer negligible because: images are taken off-nadir with sub-metric resolution; processed products are entirely digital; evaluation is computer-based; and multi-source image fusion (different platforms, sensors) and multi-format data (raster/vector) are a general trend in geomatics.

Sources of distortion fall into two major categories: the observer/acquisition system (platform, sensor, measurement instruments) and the observed (atmosphere and Earth).

Category	Sub-category	Description of Error Sources
Observer / Acquisition system	Platform	Movement variation; altitude variation (below frequencies)
	Sensor (VIR, SAR, HR)	Sensor mechanical variation (scan rate, scan speed); panoramic effect with wide field of view
	Measurement instruments	Time variations

Observed	Atmosphere	Refraction and turbulence
	Earth	Curvature, rotation, topographic effect
	Map	Transition from geoid to ellipsoid and from ellipsoid to map

Table 5.7. Sources of geometric errors in satellite images [5]

5.7.5 Geometric Modelling of Satellite Systems

Geometric models represent the relationship between object space and image space — they are theoretical models describing how the image of a given object is constructed by the system. Two major categories of models exist for very high resolution imaging systems [2]:

Explicit models: models based on the physical parameters of the acquisition system.

Implicit models: models that represent the acquisition system through a mathematical transformation between the two spaces.

Due to the unavailability of precise information about detectors (calibration parameters), most models are implicit or non-parametric, which can optimally describe the true (physical) geometry of the system [2].

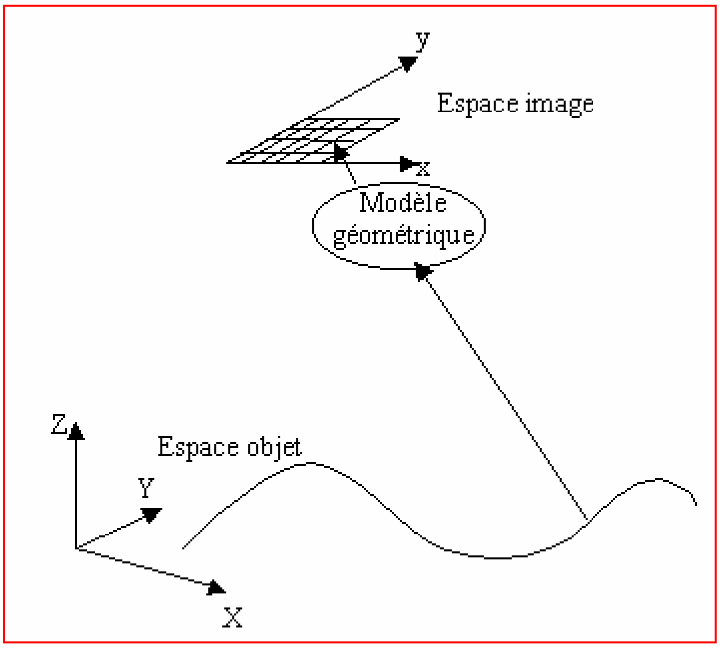


Figure 5.5 The geometric model

The geometric model: relationship between object space (ground coordinates X, Y, Z) and image space (pixel coordinates x, y), mediated by the acquisition system's geometric parameters. [2]

Non-Parametric (Empirical) Models

These models are independent of the sensor and platform, do not account for the physical process of image capture, and are flexible and easy to use. The main types include:

Planar affine transformation: a 6-parameter plane transformation (translations, rotation, different scale factors in u and v, plus axis non-orthogonality).

$$x = A_1X + A_2Y + A_3$$
$$y = A_4X + A_5Y + A_6$$

Planar projective transformation: an 8-parameter transformation representing a projection between two planes.

$$x = \frac{L_1X + L_2Y + L_3}{L_7X + L_8Y + 1}$$

$$y = \frac{L_4X + L_5Y + L_6}{L_7X + L_8Y + 1}$$

DLT (Direct Linear Transformation): created by Abdelaziz and Karara (1971) for terrestrial photogrammetry. Based on the collinearity condition. Requires a minimum of 6 ground control points.

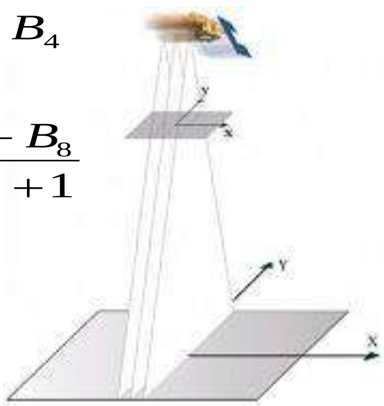
$$x = \frac{L_1X + L_2Y + L_3Z + L_4}{L_9X + L_{10}Y + L_{11}Z + 1}$$

$$y = \frac{L_5X + L_6Y + L_7Z + L_8}{L_9X + L_{10}Y + L_{11}Z + 1}$$

Parallel Perspective model: acquisition by a push-broom instrument represented by a perspective in the Y direction and affine in the X direction.

$$x = B_1 X + B_2 Y + B_3 Z + B_4$$

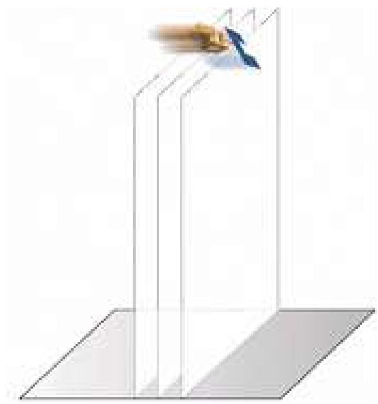
$$y = \frac{B_5 X + B_6 Y + B_7 Z + B_8}{B_9 X + B_{10} Y + B_{11} Z + 1}$$



Affine model: describes an affine transformation from 3D object space to 2D image space. Defined by 8 parameters: translations (2), rotations (3), non-uniform scale (2), and skew distortion (1).

$$x = A_1 X + A_2 Y + A_3 Z + A_4$$

$$y = A_5 X + A_6 Y + A_7 Z + A_8$$



2D/3D polynomial functions: empirical models based on polynomial functions. 3D polynomial functions extend 2D polynomials by adding a Z term for terrain elevation. Applicable to small areas with homogeneous control point distribution.

3D Rational Function Model (RFM): used by commercial satellite providers (e.g. Space Imaging) in place of confidential sensor models. Facilitates exploitation by non-specialist users.

2D fonctionnements polynômes	$P_{2D}(XY) = \sum_{i=0}^{m} \sum_{j=0}^{n} a_{ij} X^i Y^j$
3D polynomial functions	$P_{3D}(XYZ) = \sum_{i=0}^{m} \sum_{j=0}^{n} \sum^{p} a_{ijk} X^i Y^j Z^k$

X, Y, Z are the terrain coordinates or cartographic coordinates; i, j, k are integer increments; and m, n, p are integer values, generally ranging between 0 and 3, with m + n (+ p) being the degree of the polynomials, generally three [5].

3D polynomial functions are an extension of 2D transformation polynomials through the addition of the Z term, which represents the third dimension of the terrain.

In general, the polynomial order is less than three, and is used with certain precautions in order to maintain good accuracy:

- Applicable to small images (areas).
- Homogeneous distribution of control points.
- The correction is local (at the control point).
- Highly sensitive to errors in the input data.

These polynomials correct all systematic distortions except those caused by terrain relief; the altitude-related term in 3D polynomials must be reduced to a first-degree term for high-resolution images, regardless of the polynomial order used [2].

3D Rational Function Model (RFM)

3D rational functions (RFM) have recently regained interest among civilian users of remote sensing and photogrammetry, due to the launch of new civilian high-resolution satellites. The main reason for this interest is that certain image providers, such as Space Imaging, do not disclose information about the satellite and sensor. These functions are used to replace the sensor model — which remains confidential — and on the other hand to facilitate the exploitation of these images by non-specialist users.

In general, this type of function is written in the following form:

3D RFM	$$R_{3D}(XYZ) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n}\sum_{k=0}^{p} a_{ijk}X^{i}Y^{j}Z^{k}}{\sum_{i=0}^{m}\sum_{j=0}^{n}\sum_{k=0}^{p} b_{ijk}X^{i}Y^{j}Z^{k}}$$

X, Y, Z are the terrain coordinates or cartographic coordinates; i, j, k are integer increments; and m, n, p are integer values, generally ranging between 0 and 3, with m + n (+ p) being the degree of the polynomials, generally three.

Parametric (Explicit) Approaches

CCRS 3D Model (Canadian Centre of Remote Sensing)

Although each imaging system has its own specificities, the same general principle is used to develop 3D parametric models to correct all distortions present for this type of imager. These models integrate the geometry of the following elements:

- The platform (position, velocity, and attitude),
- The sensor (viewing angles, panoramic effect),
- The Earth (ellipsoid, relief),
- And the cartographic projection.

Geometric correction can be performed step by step — with each distortion corrected separately — or all at once. In practice, the best approach is to consider the acquisition geometry in its entirety (platform + sensor + Earth + map), given that certain distortions are correlated.

Theoretically, it is more judicious to calculate the combined parameters and separate them afterwards. For example, image orientation is a combination of the track azimuth (the inclination of the orbital plane relative to the pole), the yaw effect, and meridian convergence. The scale factor along the track is a combination of the velocity effect, pitch, the CCD signal recording time (exposure time), and the Earth rotation component along the track. The correction for the lateral viewing effect is a combination of roll, the viewing angle, and Earth curvature.

In general, the starting point for these models remains the collinearity condition, which is always valid for each image line. Since the parameters of neighbouring lines are correlated, it is possible to link the perspective centres and rotation angles using additional data.

IGP Model (Institute of Geodesy and Photogrammetry, Zurich)

A rigorous model was proposed by Daniela Poli, developed at IGP Zurich, for the geo-referencing of images acquired by linear (push-broom) sensors for satellite and airborne systems. The collinearity equations describe the perspective geometry for each image line; the position of the detector and its attitude are represented by a second-degree polynomial function of time. This trajectory is divided into segments according to the distribution of control points, with a zero constraint at the junction points of adjacent segments and continuity of the first and second derivatives of the trajectory function. The solution is based on observations of position, velocity, and attitude provided by on-board platform instruments.

This model also includes a self-calibration procedure for internal parameters, which are necessary for the correction of systematic errors due to:

- Displacement of the principal point,
- Variation in focal length,
- Radial and tangential distortion parameters,
- Scale variation in Y,
- Rotation of the detector array in the focal plane.

The functions modelling the external and internal orientations are integrated into the collinearity equation.

Parametric (Explicit) Models

Despite the specific characteristics of each imaging system, the same principle is generally used to develop 3D parametric models to correct all distortions present. These models integrate the geometry of: the platform (position, velocity, attitude), the sensor (viewing angles, panoramic effect), the Earth (ellipsoid, relief), and the cartographic projection.

CCRS 3D model (Canadian Centre of Remote Sensing): integrates the full geometry of the imaging system. Geometric correction can be performed step-by-step or simultaneously for all distortions. Theoretically, it is more judicious to calculate combined parameters and separate them afterwards.

IGP model (Institute of Geodesy and Photogrammetry, Zurich): developed by Daniela Poli for the geo-referencing of images taken by push-broom linear sensors (satellite and airborne). The external orientation and trajectory are modelled by second-degree polynomial functions of time, divided into segments with continuity constraints. The model also includes a self-calibration procedure for internal parameters (principal point displacement, focal length variation, radial and tangential distortion, scale variation in Y, and rotation of the detector array). The result is a non-linear function linearised by a first-order Taylor decomposition and solved by least squares.

Conclusion — Chapter 5

Satellite imagery serves cartographic needs at three user levels: operational (large scale, high precision), tactical (medium scale, spatial analysis), and strategic (small scale, decision support). The informational content of an image is characterised by four interpretability levels: detection, recognition, identification, and technical analysis. VHR imagery (below 3–4 m resolution) enables 3D object analysis. Geometric corrections are essential for cartographic use, involving either non-parametric models (polynomial, DLT, RFM) or parametric models (CCRS, IGP) that account for platform, sensor, Earth, and projection distortions.

GENERAL CONCLUSION

Cartography — From Theory to Satellite Applications

This course has provided a comprehensive introduction to the science and practice of cartography — from its foundational theoretical principles to the cutting-edge applications of satellite imagery in modern map production. The five chapters have progressively built a coherent body of knowledge, moving from the general to the specific, from concept to application.

Key Takeaways by Chapter

Chapter 1	Maps are classified by scale, purpose, and content. The topographic map — characterised by metric accuracy, contour lines, and standardised symbols — is the fundamental reference document in geomatics. In Algeria, the 1:50,000 series constitutes the national standard.
Chapter 2	Scale is the fundamental parameter of any map. Mastery of distance and area measurement techniques — from the simple ruler to the planimeter and digital GIS tools — and of scale change operations is essential for all field and office applications in topography.
Chapter 3	Thematic maps focus on communicating a specific spatial phenomenon. Their design requires rigorous application of symbol conventions (point, line, area) and data-appropriate visual encoding — avoiding, in particular, the common error of mapping absolute values in choropleth maps.
Chapter 4	Map semiology, founded by Jacques Bertin (1967), provides the scientific framework for cartographic design. The seven visual variables — position, size, value, texture, colour, orientation, and shape — each have distinct perceptual properties suited to specific data types. Effective map communication requires matching the variable to the data.
Chapter 5	Satellite imagery has transformed cartographic production at all levels of spatial planning. The progression from HR to VHR sensors has dramatically expanded the range of operational applications — from land use mapping at

	1:25,000 to cadastral updating at 1:10,000 and below. Geometric and radiometric corrections, coupled with appropriate parametric or non-parametric geometric models, are prerequisites for cartographic-quality satellite image exploitation.

The Evolving Role of Cartography

Cartography is not a static discipline. Over the past five decades, it has undergone a profound transformation driven by three technological revolutions: the advent of digital computing and GIS in the 1970s–1980s, the launch of commercial high-resolution satellite sensors in the 1990s–2000s, and the emergence of web-based and participatory mapping platforms in the 2010s. Each revolution has expanded the scope of cartographic production, the range of applications, and the diversity of users.

For students in Geomatics and Topography, the concepts taught in this course — map classification, scale, thematic symbolisation, visual variables, and satellite image geometry — form the theoretical foundation upon which all advanced geospatial skills are built. Whether working in cadastral operations, urban planning, environmental management, or remote sensing, the ability to produce and interpret maps accurately and communicatively is an indispensable professional competence.

Perspectives

Looking ahead, several trends will continue to shape the discipline:

Very High Resolution (VHR) and sub-metric imagery: sensors such as Pléiades, WorldView, and GeoEye now provide spatial resolutions below 50 cm, enabling cartographic production at 1:5,000 and below from satellite data alone.

UAV (drone) photogrammetry: unmanned aerial vehicles equipped with calibrated cameras now offer centimetric-resolution imagery for small-area, large-scale mapping — bridging the gap between field surveying and satellite remote sensing.

Machine learning and AI: deep learning algorithms are increasingly used for automated feature extraction, land use classification, and change detection from satellite imagery — dramatically reducing processing time and human intervention.

OpenStreetMap and crowdsourced cartography: volunteer geographic information (VGI) is reshaping how base maps are produced and maintained, particularly in areas underserved by national mapping agencies.

3D and 4D cartography: the integration of LiDAR, SAR interferometry, and photogrammetric point clouds is enabling the production of highly accurate 3D city models and temporal change analysis.

Final Note for Students

Cartography sits at the intersection of science, technology, and visual communication. A good cartographer must master not only the technical tools but also the principles of graphic design and the needs of map users. The discipline rewards both precision and creativity. The concepts presented in this course are the starting point — their true value is realised in practice, through the production of maps that are accurate, readable, and genuinely useful to those who rely on them.

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