UNIVERSITÉ PARIS 1
PANTHÉON SORBONNE

GÉOGRAPHIE-CITÉS
UMR 8504

Geographic Information

DELHI GIS-R School

9-12th April 2019

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Definitions

Geographical Information

Quantitative information, localized in 1, 2, 3 or n dimensions. This information is addressed from itls localization point of view.

Geographical information types :

1. Geographical objects (volcanos, railways, forest, etc.)
2. Event occurences (fires, crimes, etc.)
3. Measure points (altitude, temperature, etc.)
4. « Statistics » (population, unemployment rate, etc.)
5. Interaction measures (flows, catchment area, etc.)

Definitions

The question of nature

The nature of the geographical information is independent from the geographical object, it has to be set by the analyst, according to the research question.

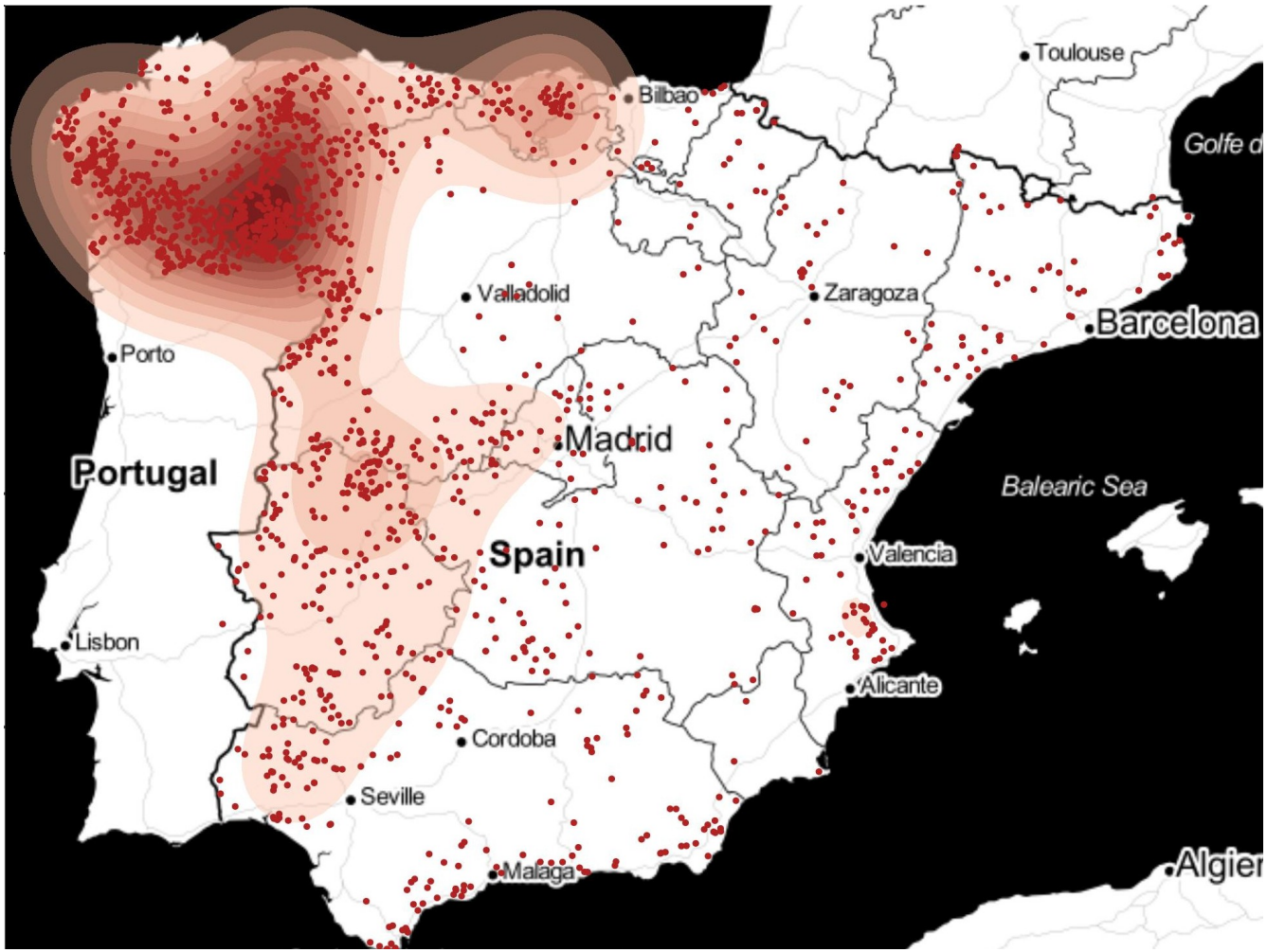
1. Dewellings point patterns (spatial object)
2. Dweelings sales (occurrences)
3. Dwellings prices (measure points)
4. Average price by district (« statistics »)

(1) Geographical Objects

Geographical objects come in three types : **points**, **lines** and **areas**.
Geographical data analysis focus on their **geometry** (e.g. length, morphology) and their **topology** (e.g. neighborhood , distance).

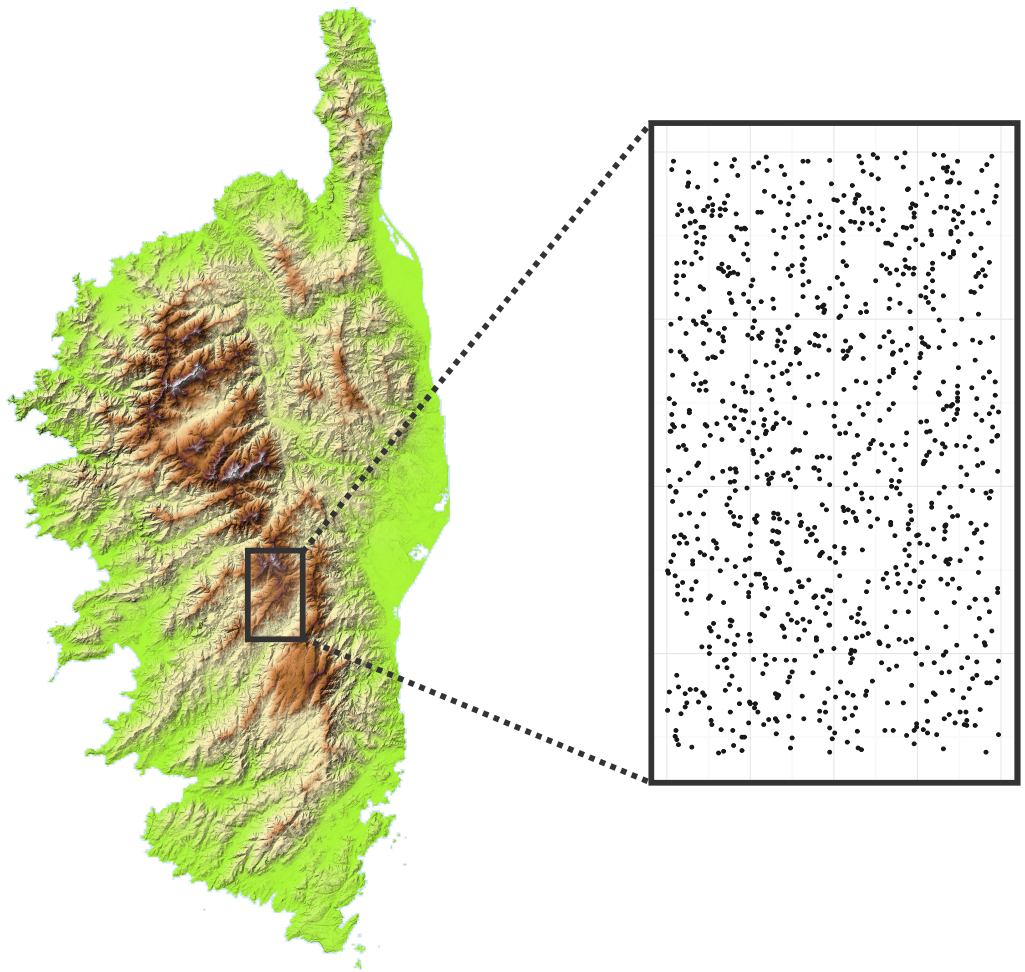
(2) Event occurence

Point data, **sampled or extensive**, whose localization is under study.
When it comes to model, localization is the **response variable**.



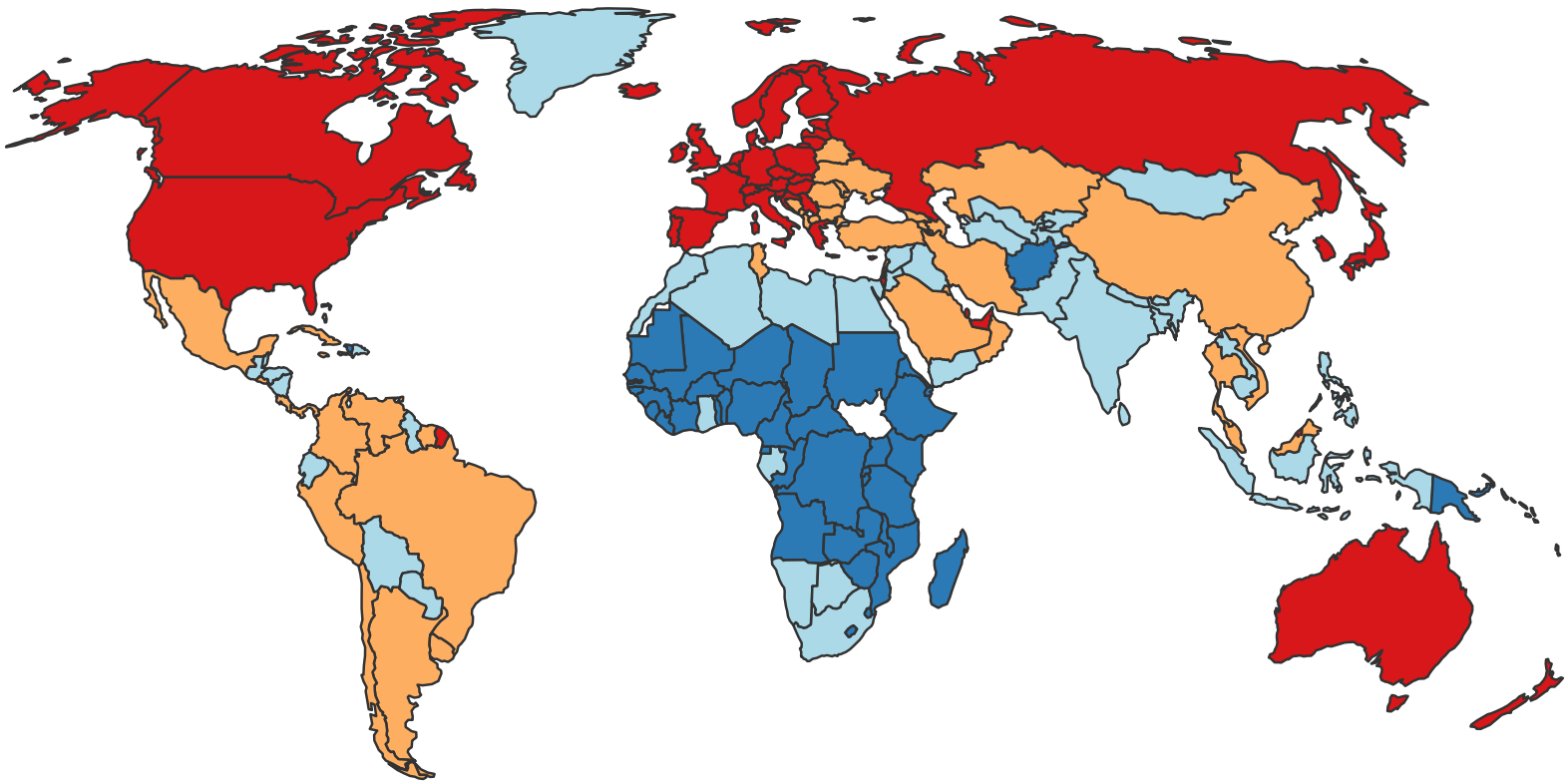
(3) Measure points

Point data, **sampled or extensive**, where a **value** is associated to each localization. Phenomenon under study is **the value variation according to the localization**.



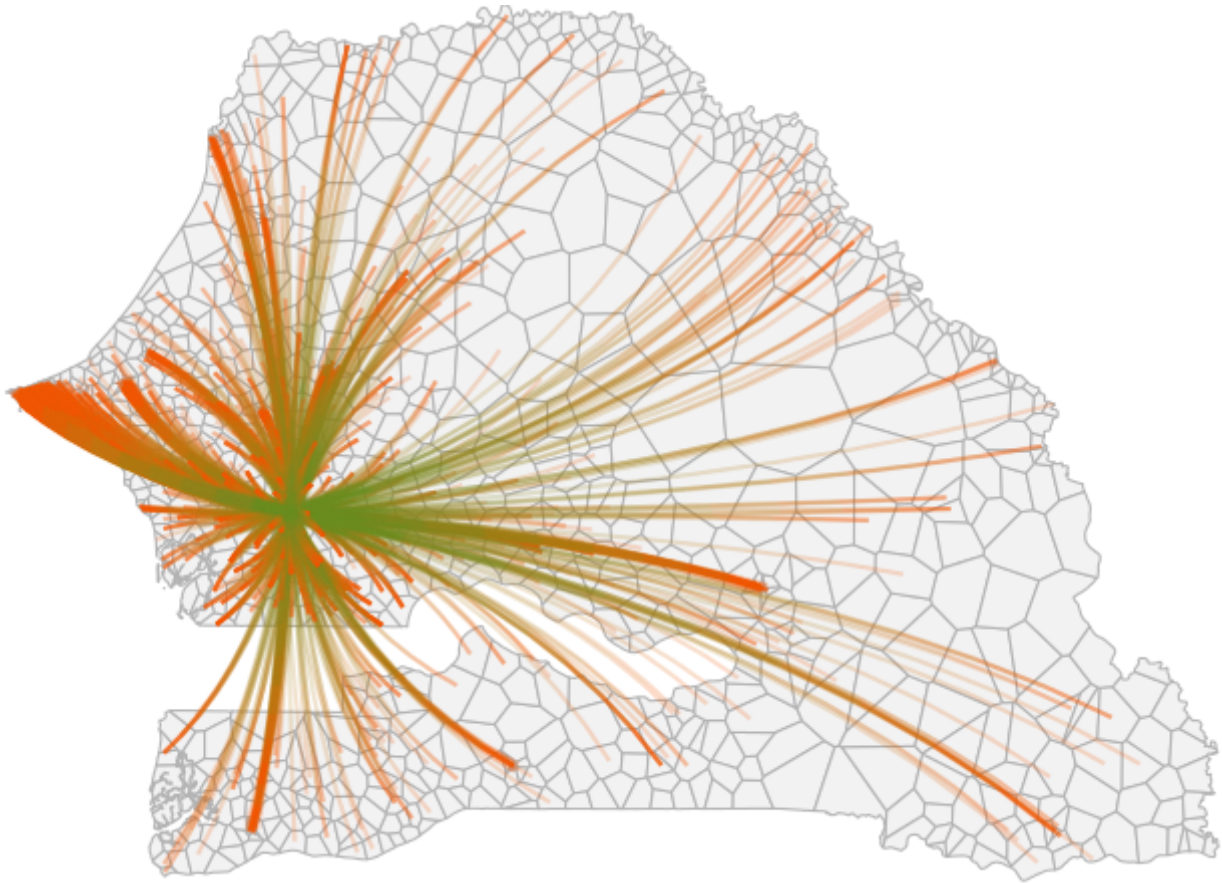
(4) Statistics

«Statistics», from *statista*, «state man» in italian.
Zonal extent variables created from census - **sampled or extensive** - for territorial management.
Such variables are attributes measured or computed **within spatial units**.

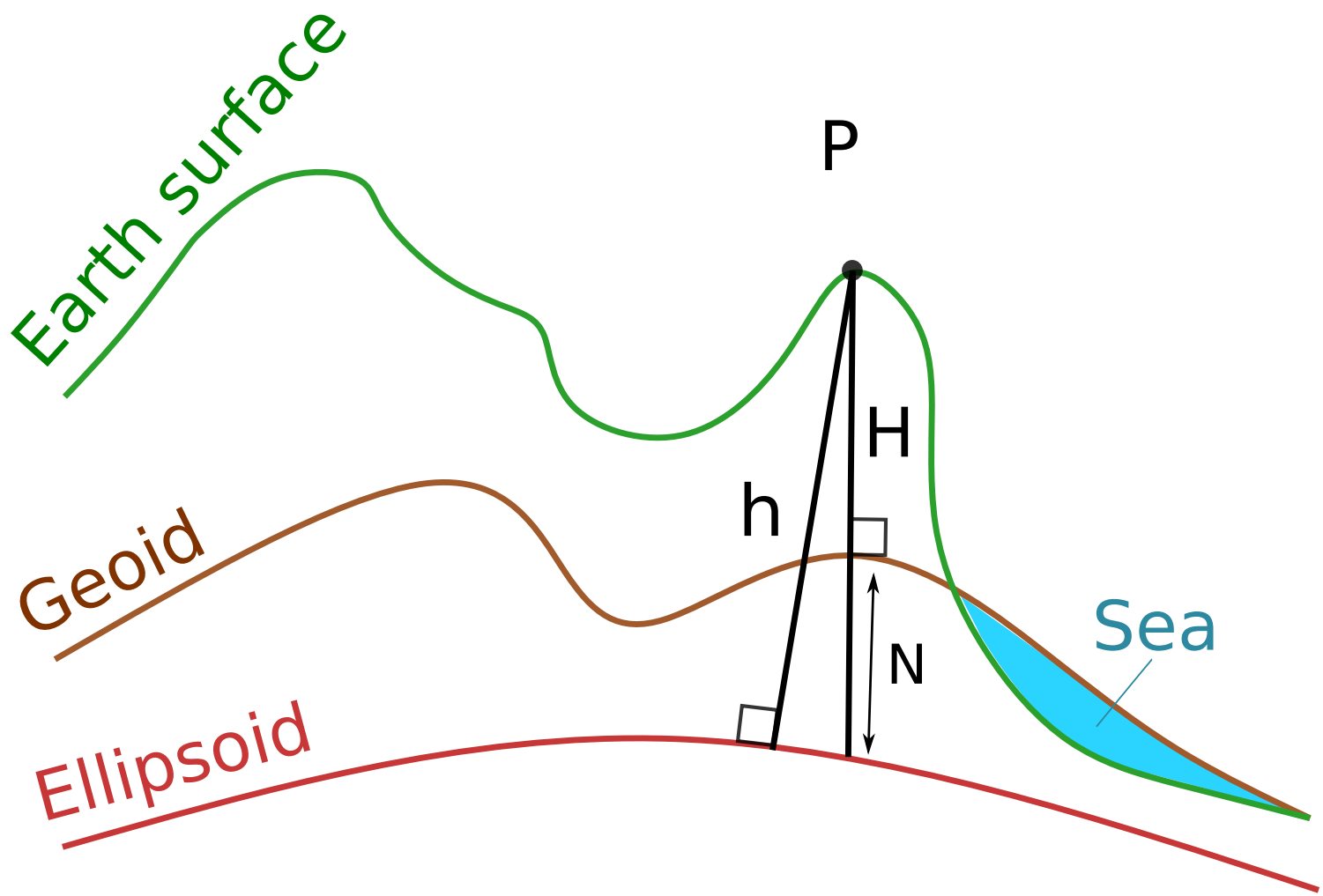


(5) Interactions

Interactions concern **geographical objects**, **occurrences** or **spatial units** and the **links** between them. The object under study is the **structure** and **dynamic** of these links (network analysis).



Coordinates, areas, distances



Source : ENSG, Les projections et référentiels cartographiques

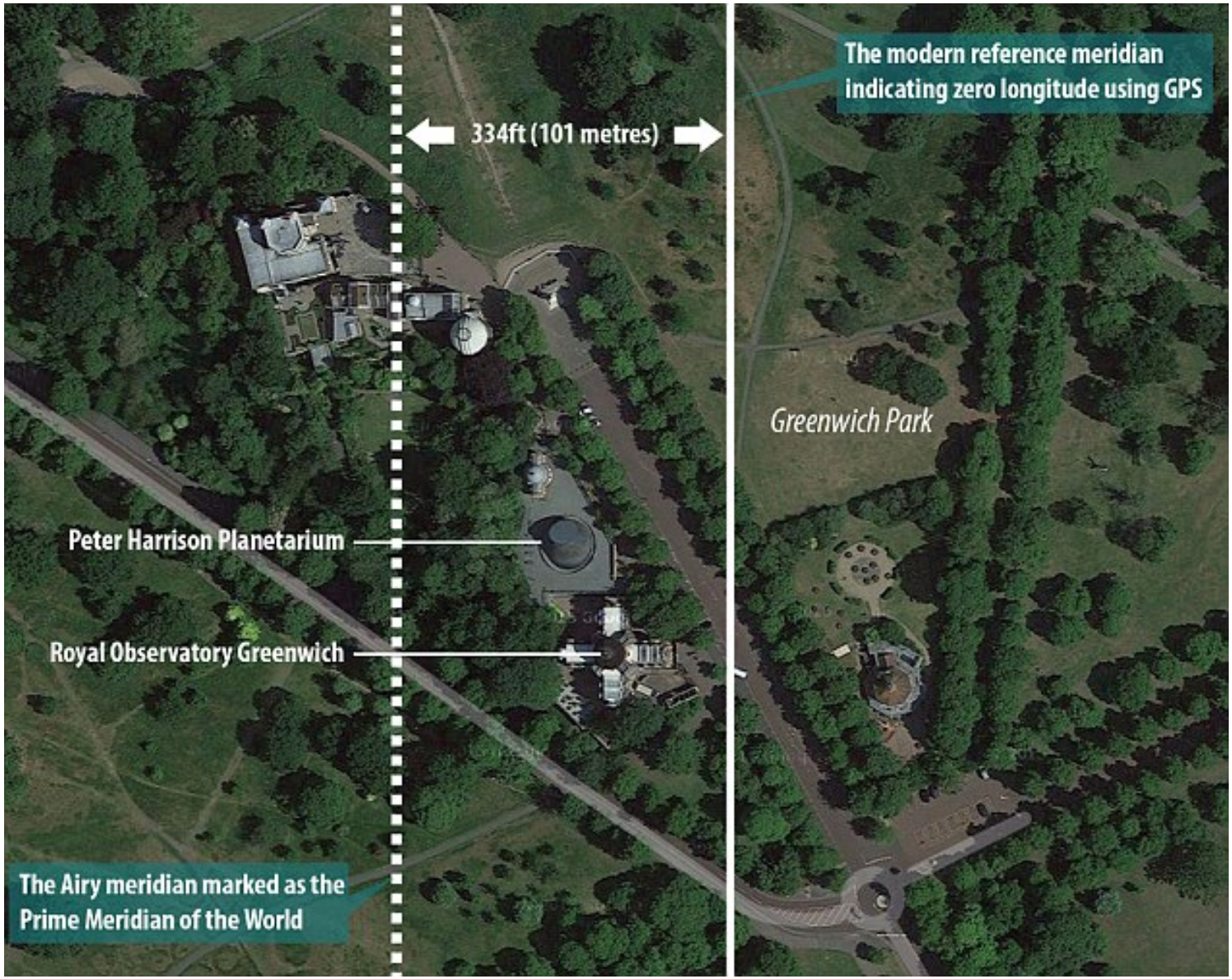
Coordinates, areas, distances

Geolocation of a spatial entity depends on :

- **Reference ellipsoid** : Clarke1880, Ellipsoide1909, IAG-GRS80
- **Geoid** : gravity field equipotential surface
- **Projection** : Mercator, Lambert, Mollweide, etc.

A **Geodetic system** (or datum) is the combination of these 3 elements (e.g. WGS84)

Coordinates, areas, distances



Coordinates, areas, distances

A sphere (globe) is a **non-developable** surface, i.e. cannot be represented as a plane (map) without **deformation**.

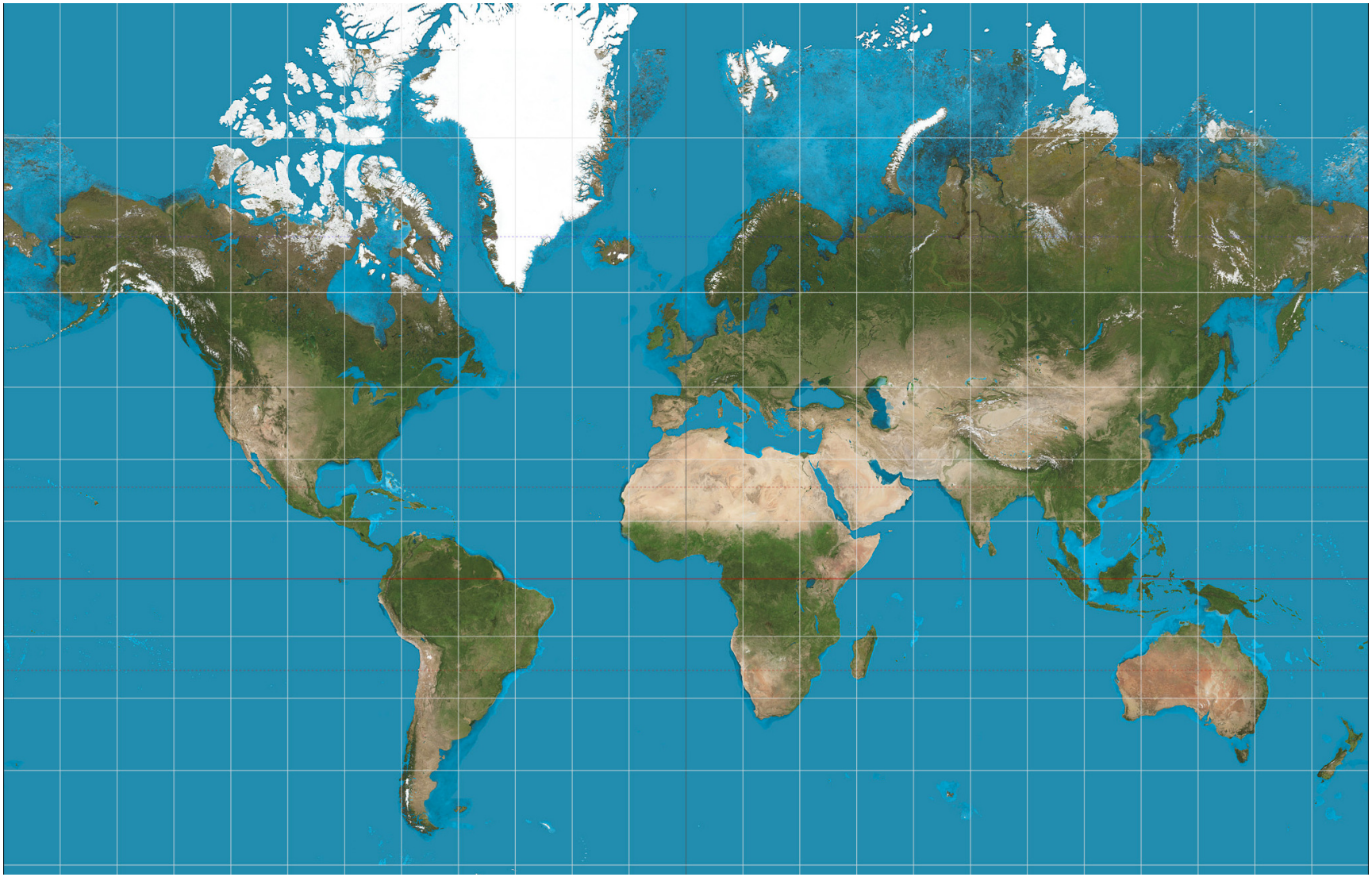
Some projections preserve some features

- **conformal** : conserve angles (shape)
- **equivalent** : conserve areas
- **equidistant** : conserve distances

Some others don't.

UTM (Universal Transverse Mercator, conformal) allows almost everywhere an acceptable projection.
What is the recommandation for India ? Specific ? Kalianpur 5 zones ?

Coordinates, areas, distances

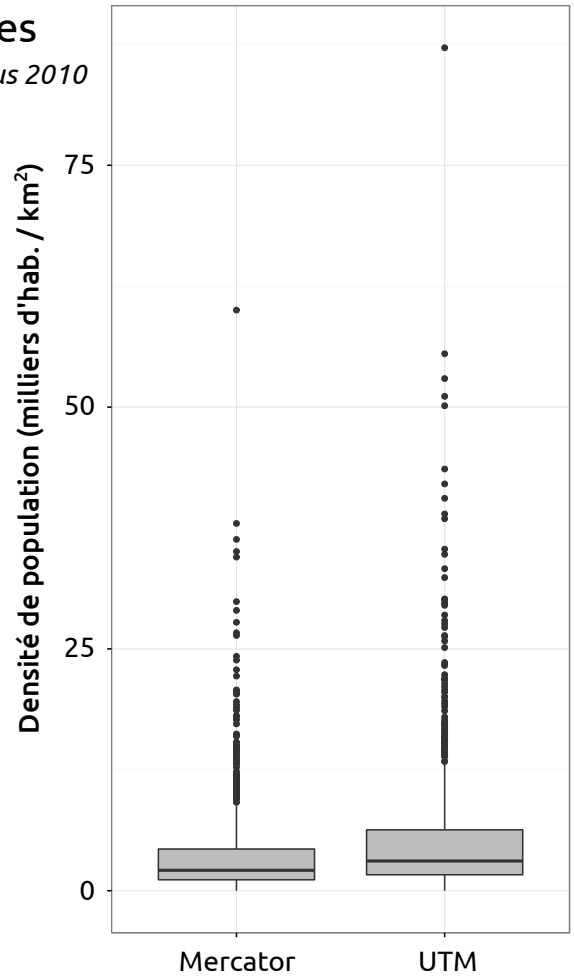


Source : Wikimedia, Mercator projection

Coordinates, areas, distances

Cape Town - Subplaces

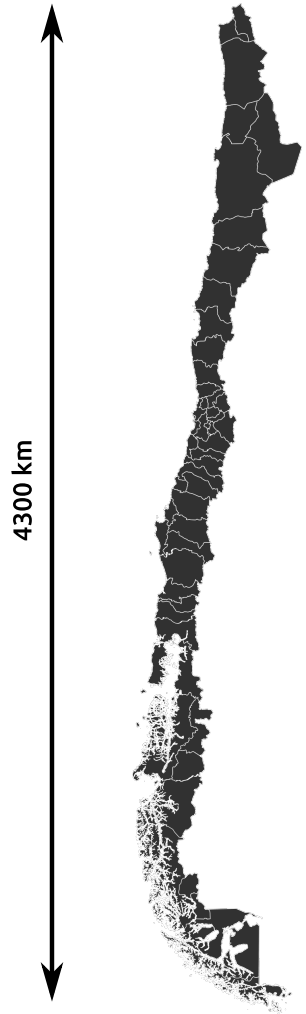
Source : Statistics South Africa, Census 2010



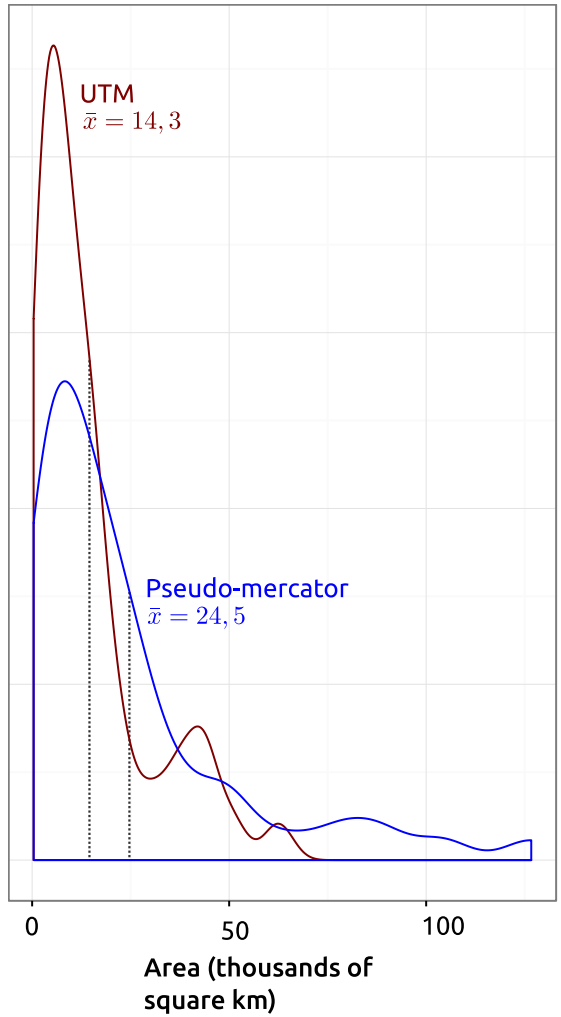
Med. 2111	**Med.** 3069
Moy. 3764	**Moy.** 5483

Paris : 22 000 hab./km²
Île-de-France : 1 000 hab./km²

Coordinates, areas, distances



Chile's provinces area



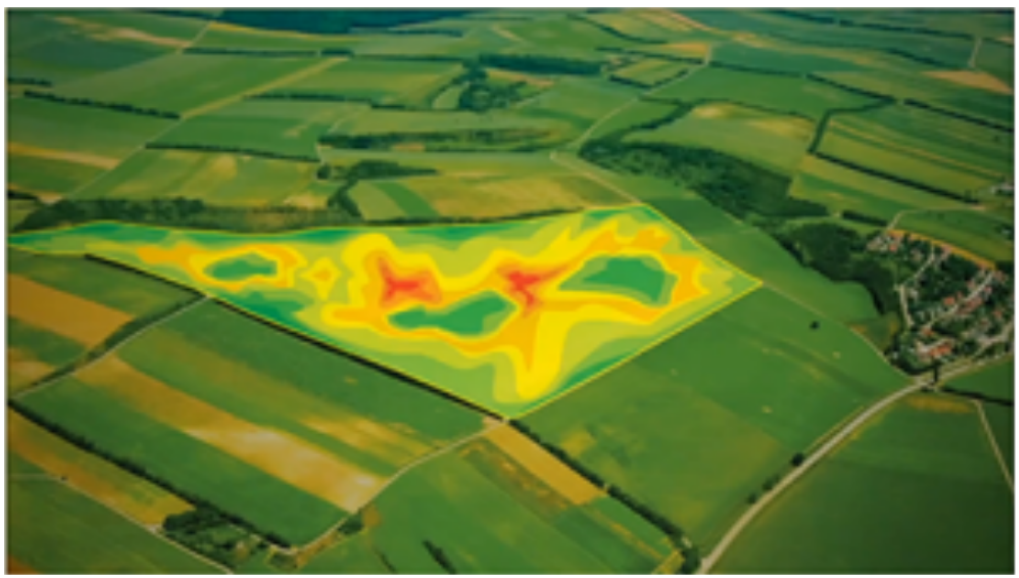
Coordinates, areas, distances

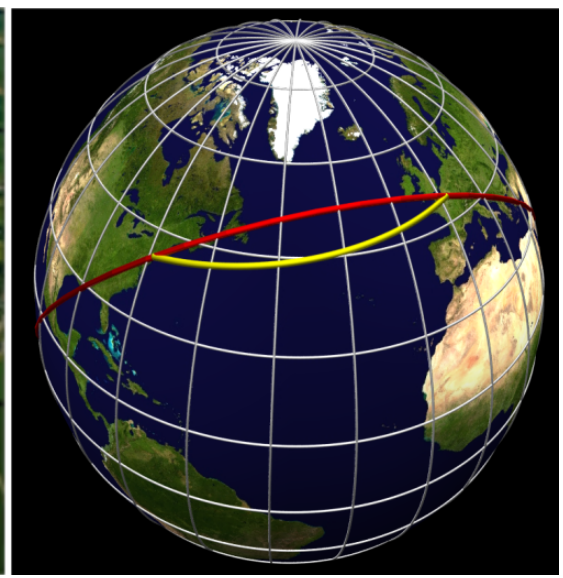
Basic precautions regarding projection :

- Density $\rightarrow$ any areas alteration ?
- Distance $\rightarrow$ any length alteration ?

Regarding measures : It depends on the scale ! (and the devices)

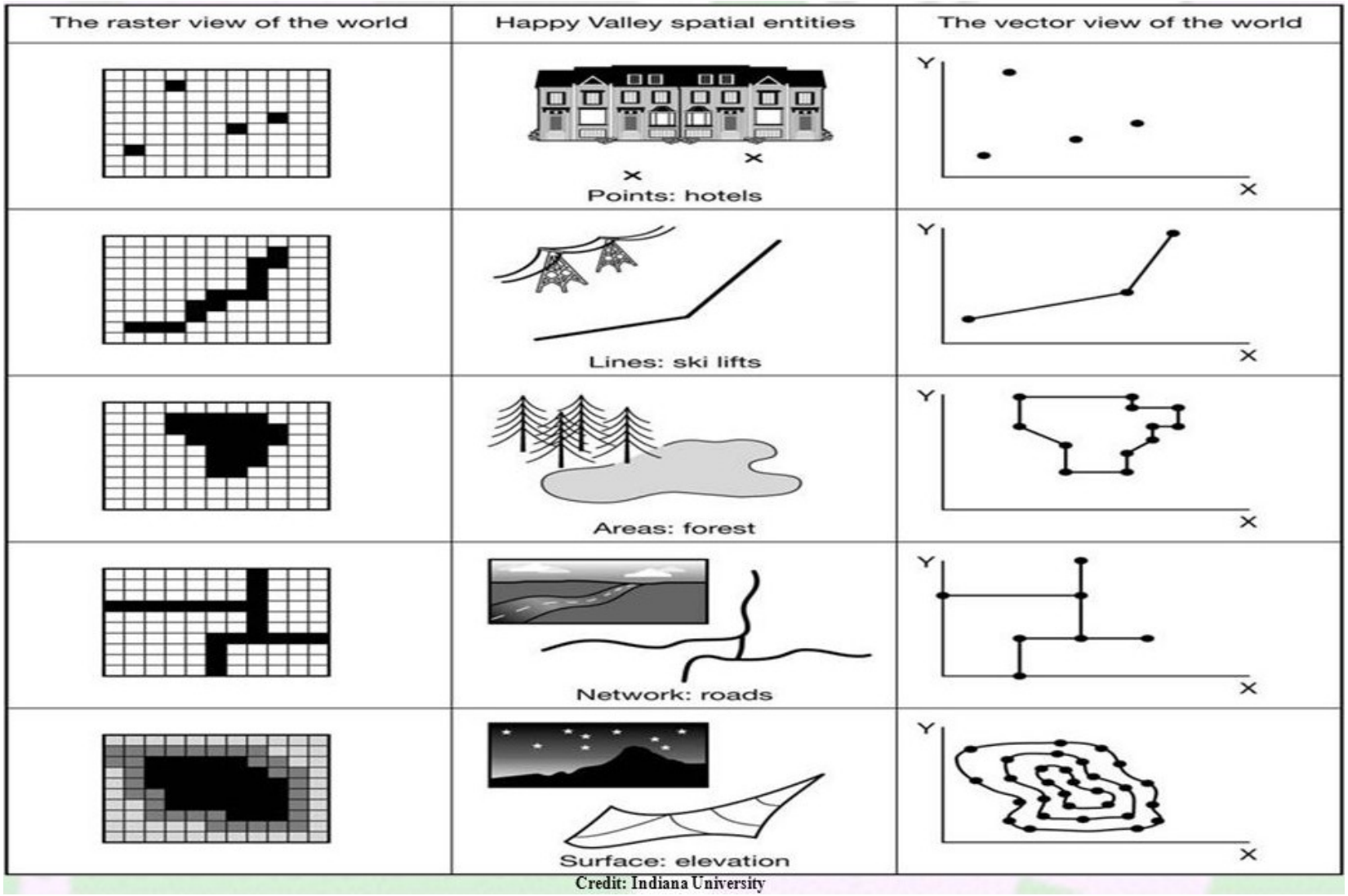
GPS-RTK (centimetric precision) or Great-circle distance ?





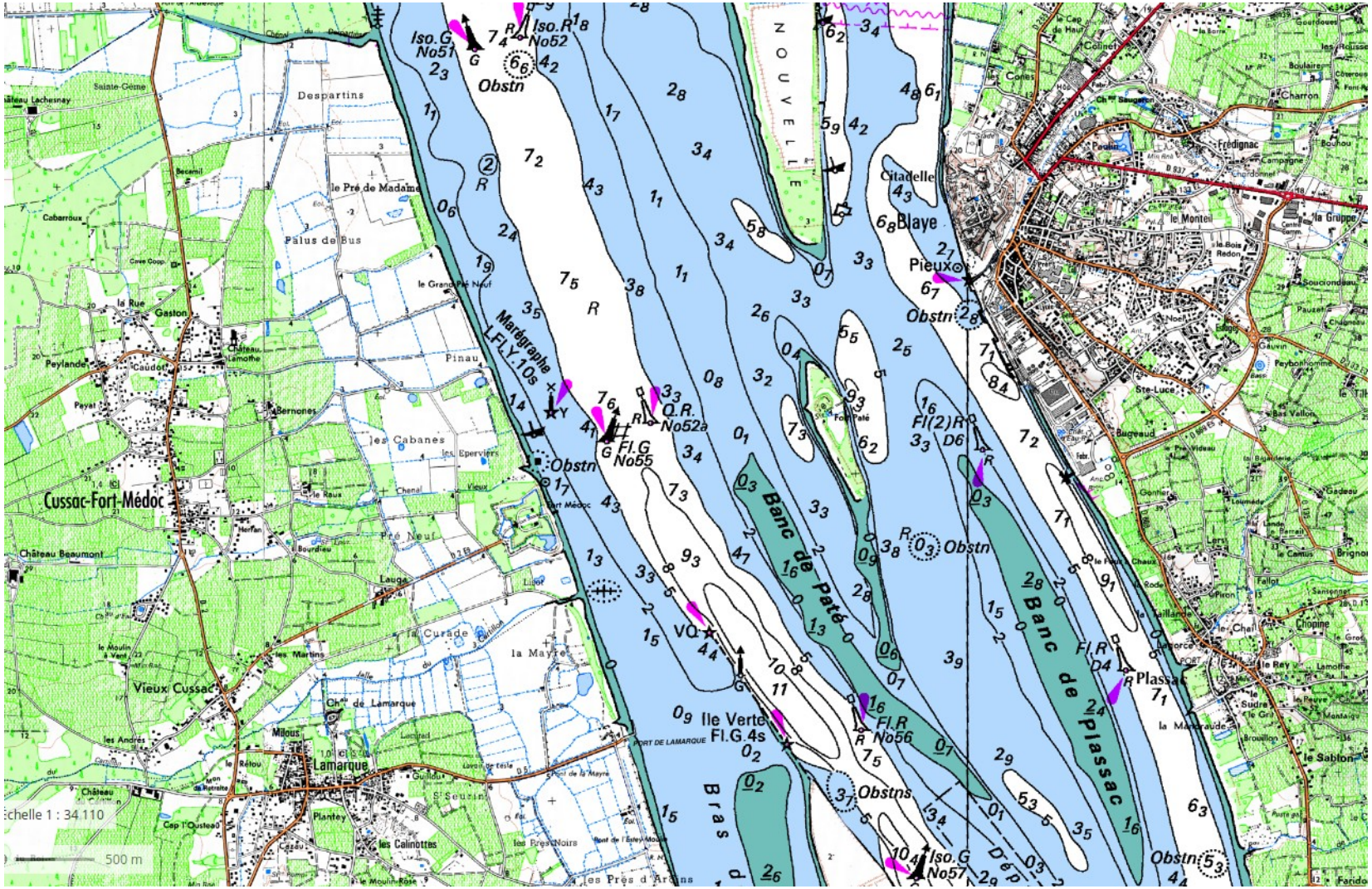
Modeling and representation

to model (here), is defining **categories** of objects **depicting** real-world objects (somehow linked to ontologies).



Modeling and representation

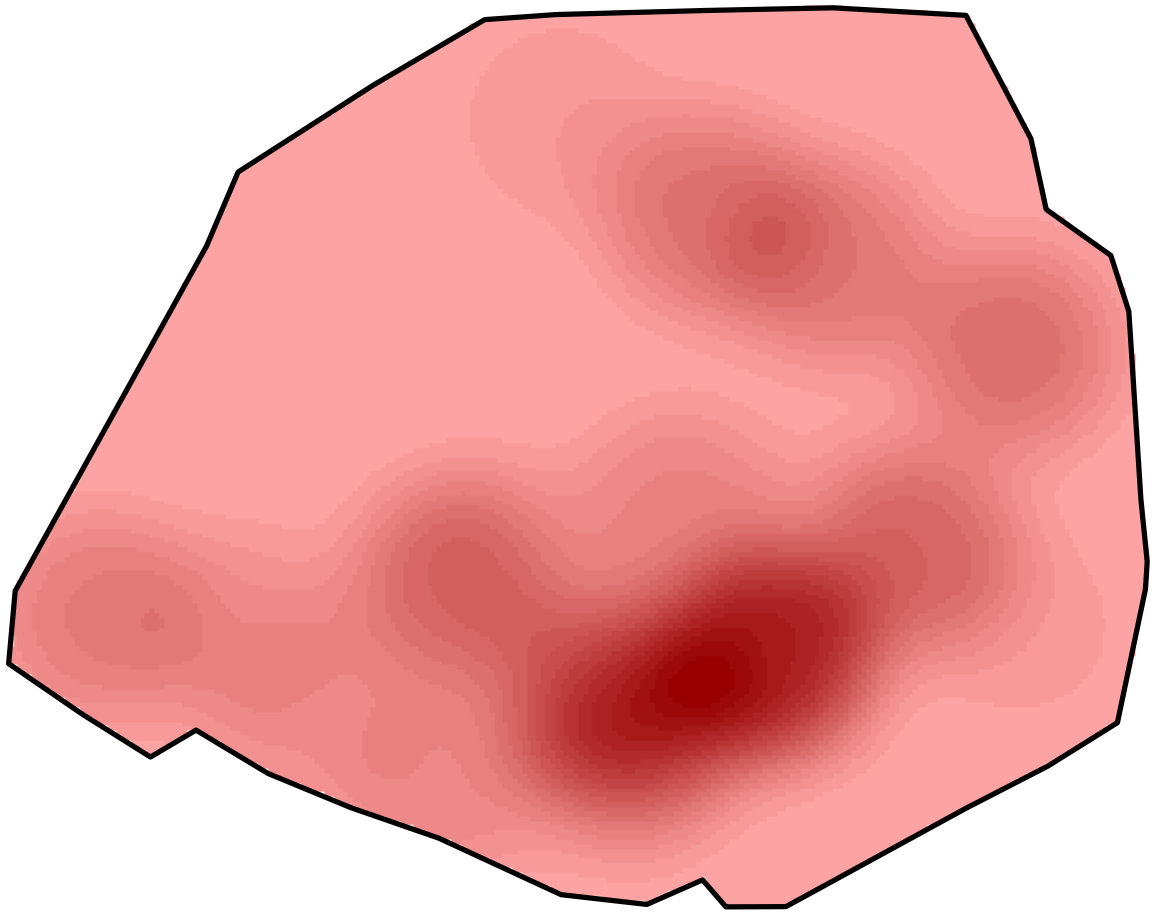
Objects and **Fields**.



Sources : IGN and SHOM

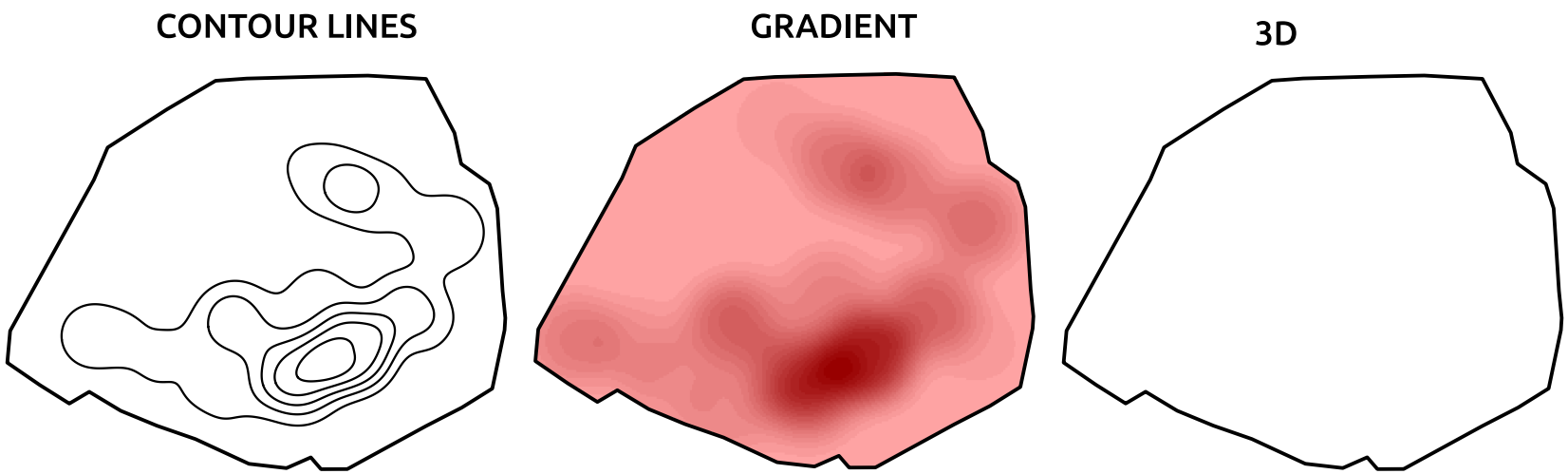
Fields

What does this field represent ?



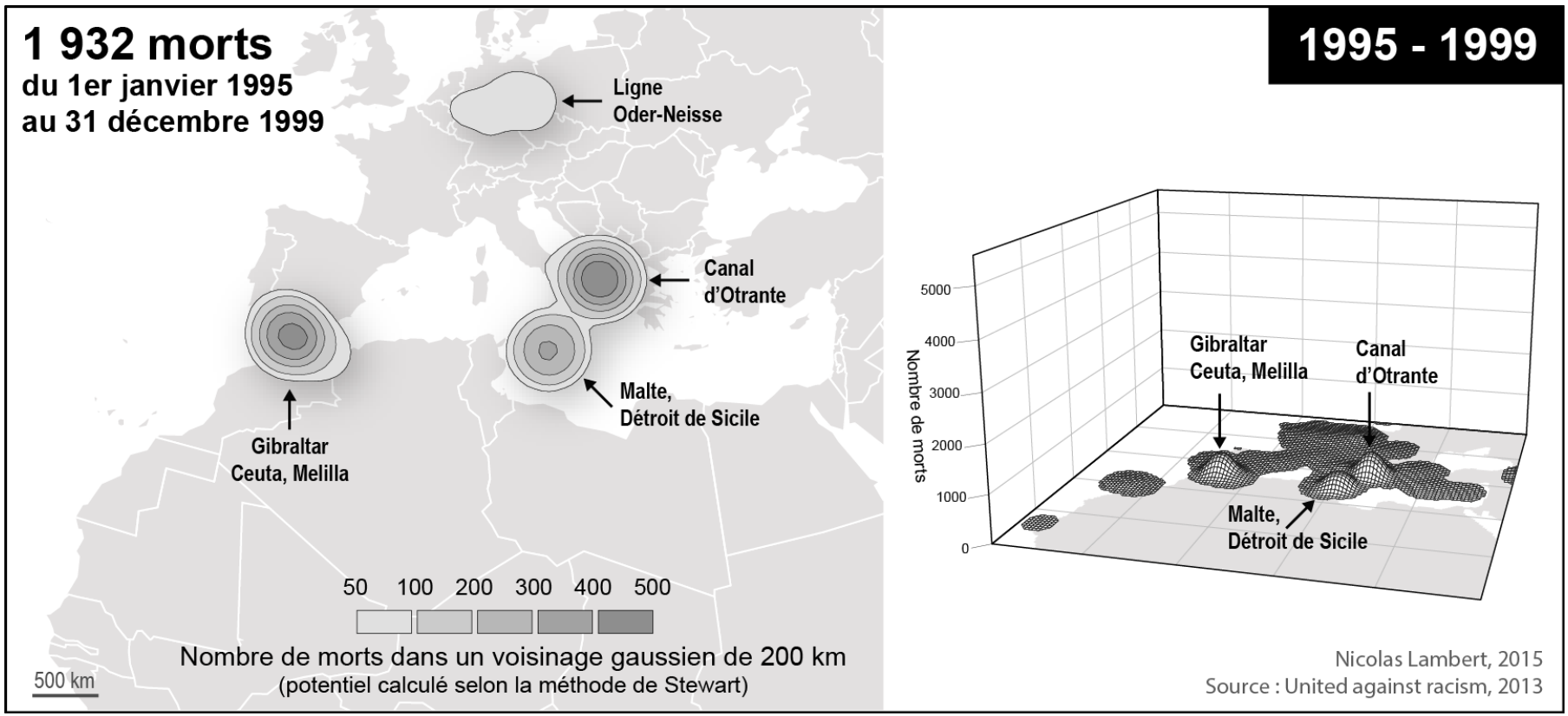
Fields

Representation modes



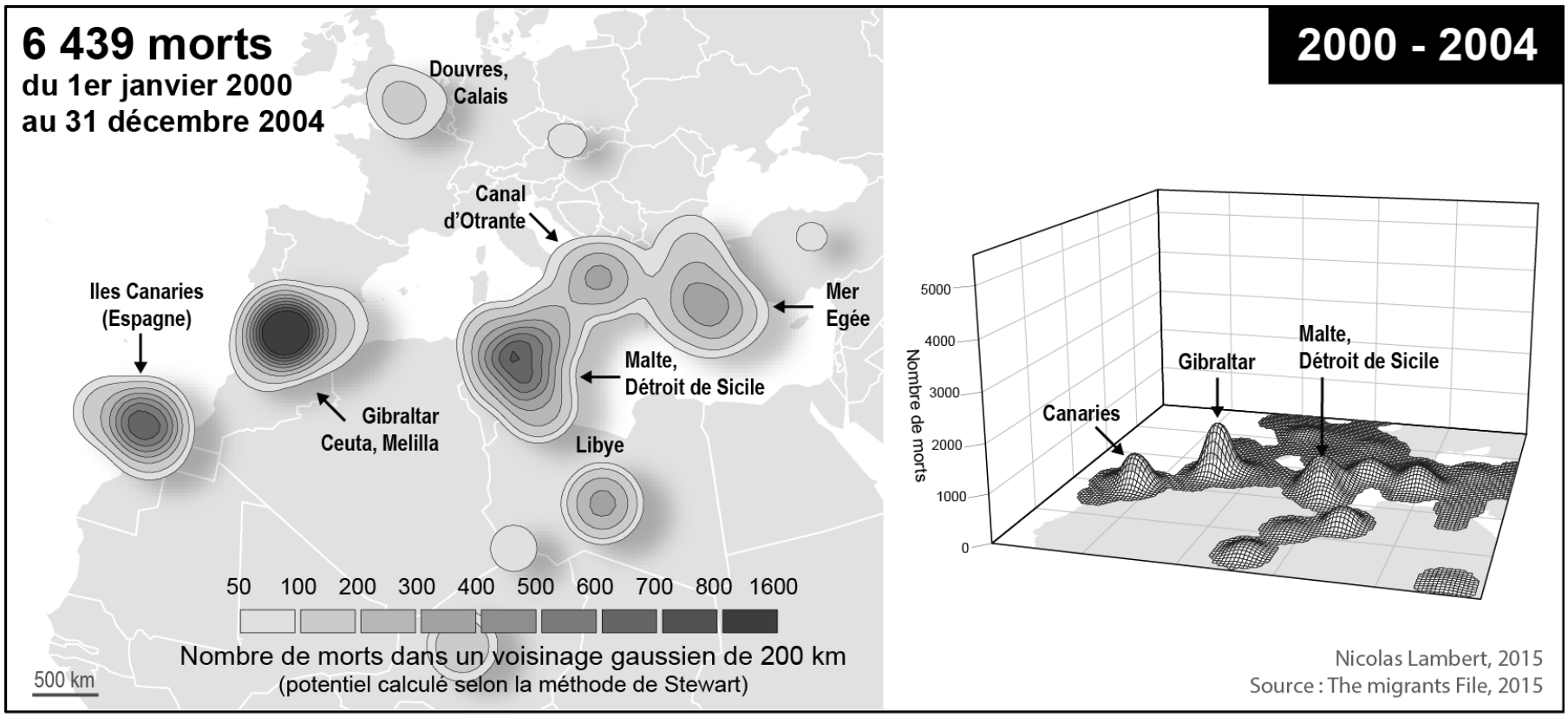
Fields

Representation modes examples



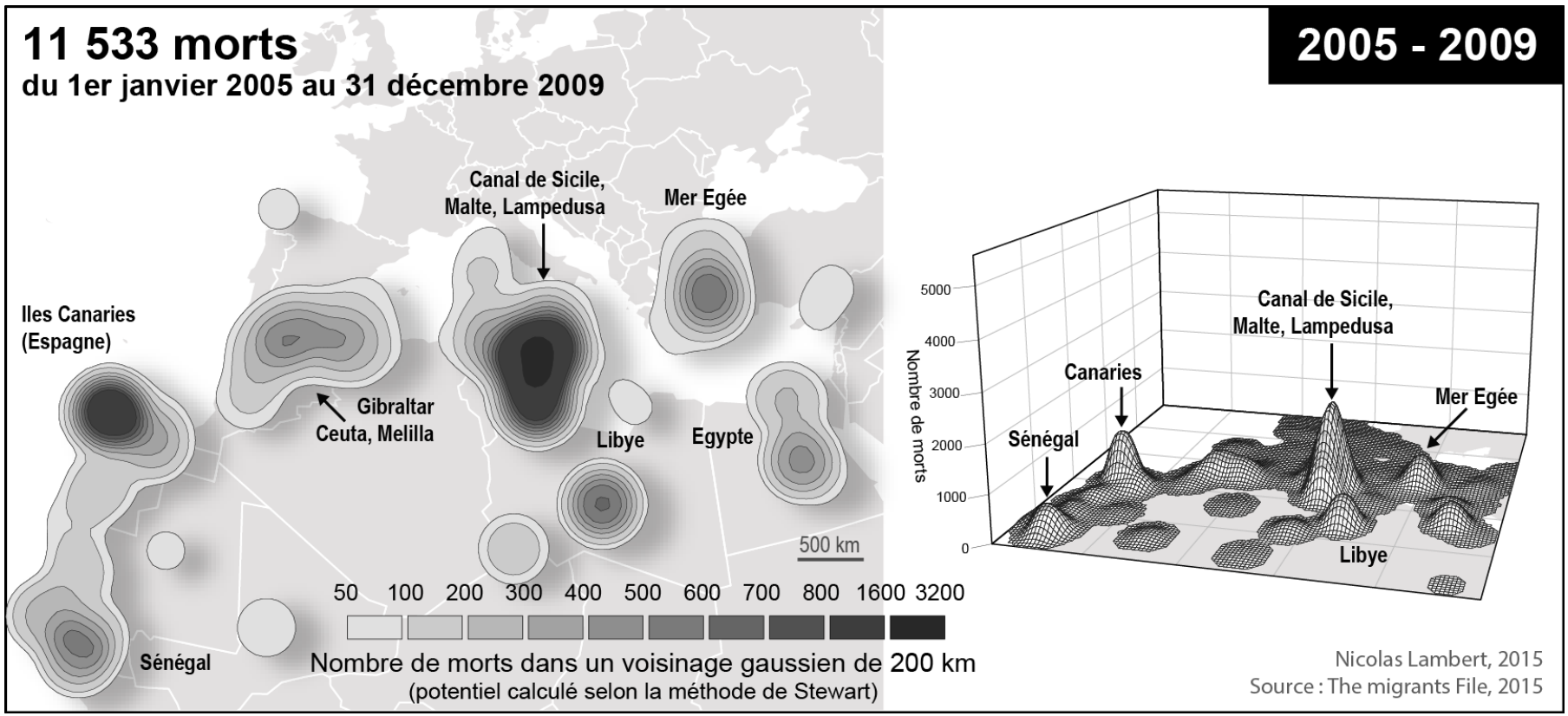
Fields

Representation modes examples



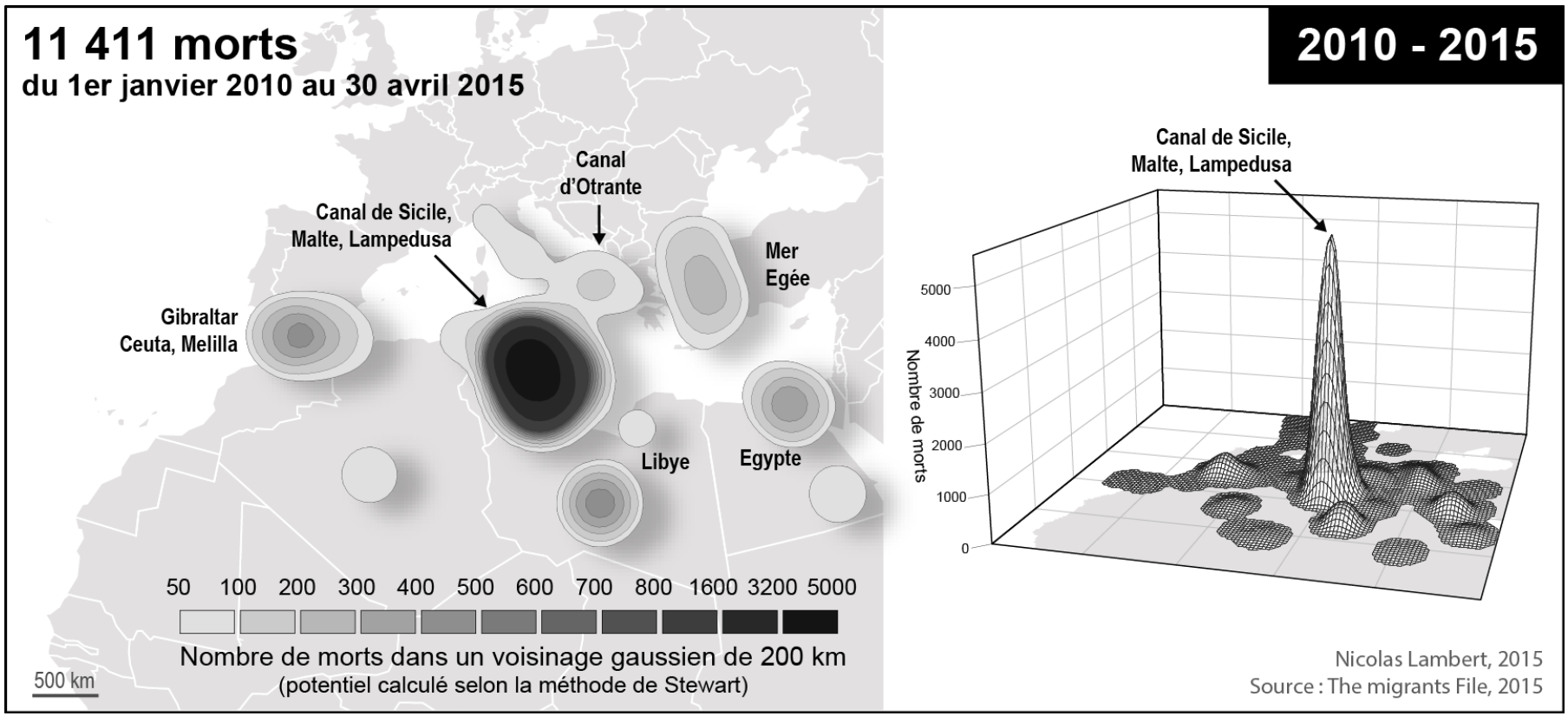
Fields

Representation modes examples



Fields

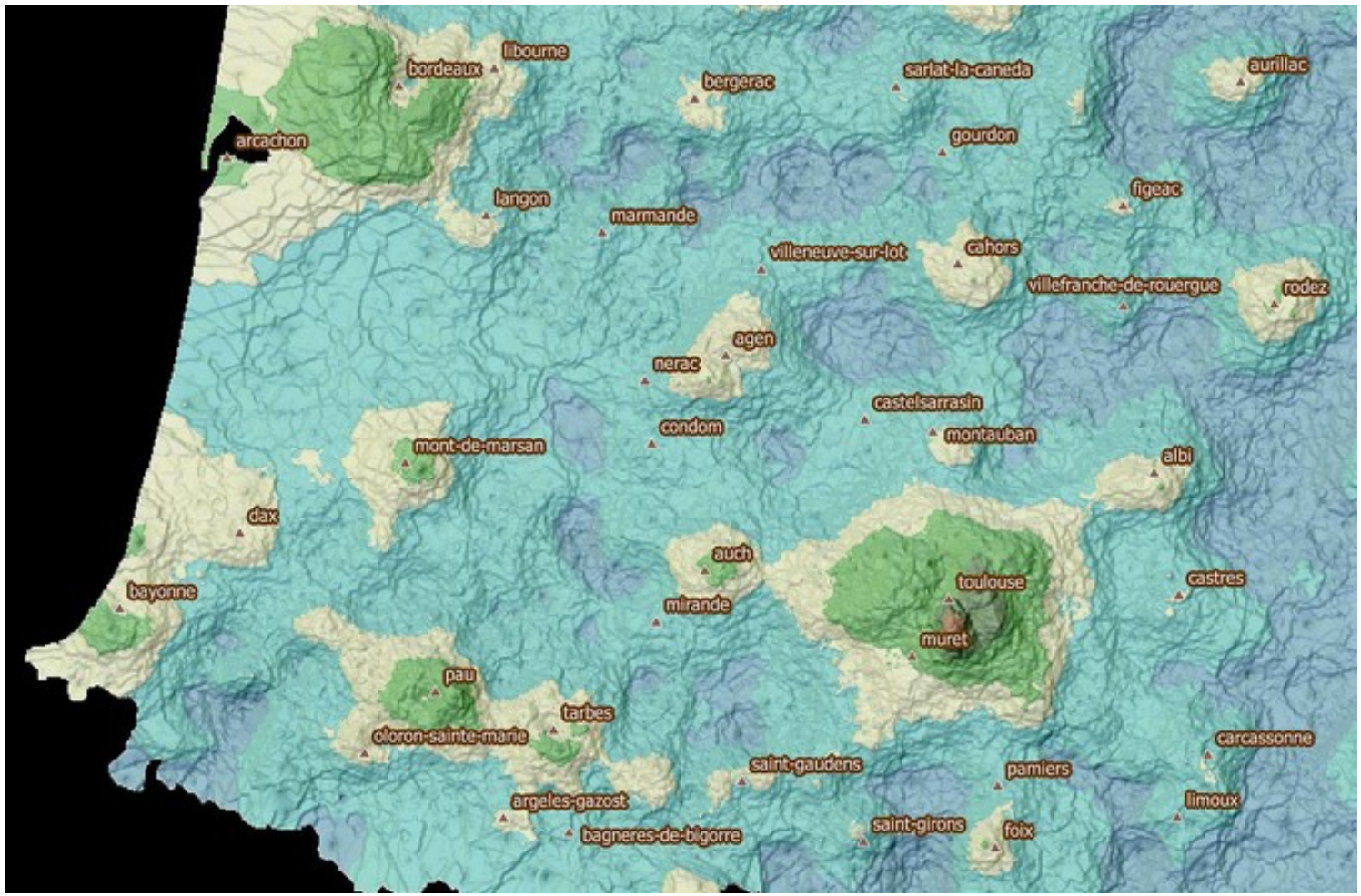
Representation modes examples



Fields

Source : Rajerison, Les archipels de la prospérité

Fields



Source : Rajerison, Les archipels de la prospérité

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Simulation

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Stochastic simulation

Stochastic simulation : data generation using **randomly drawn values**.

- **Monte Carlo :** generic term refering to process involving random process repetition.
- **Bootstrap :** re-sampling methods (usually to estimate distribution)
- **Permutation :** reordering elements of a set

Why ?

Most of the time : to approach a distribution

- (often) because the analytical way is hard
- because (sometimes) there is no analytical way
- because we look for robust estimation adequate to the use case data

Monte Carlo

→ **Example :** iterated dice rolls

→ **Goal :** examplify the Law of Large Numbers

Expected value μ of a dice roll :

$$\mu = \frac{1}{6} \times 1 + \frac{1}{6} \times 2 + \frac{1}{6} \times 3 + \frac{1}{6} \times 4 + \frac{1}{6} \times 5 + \frac{1}{6} \times 6$$

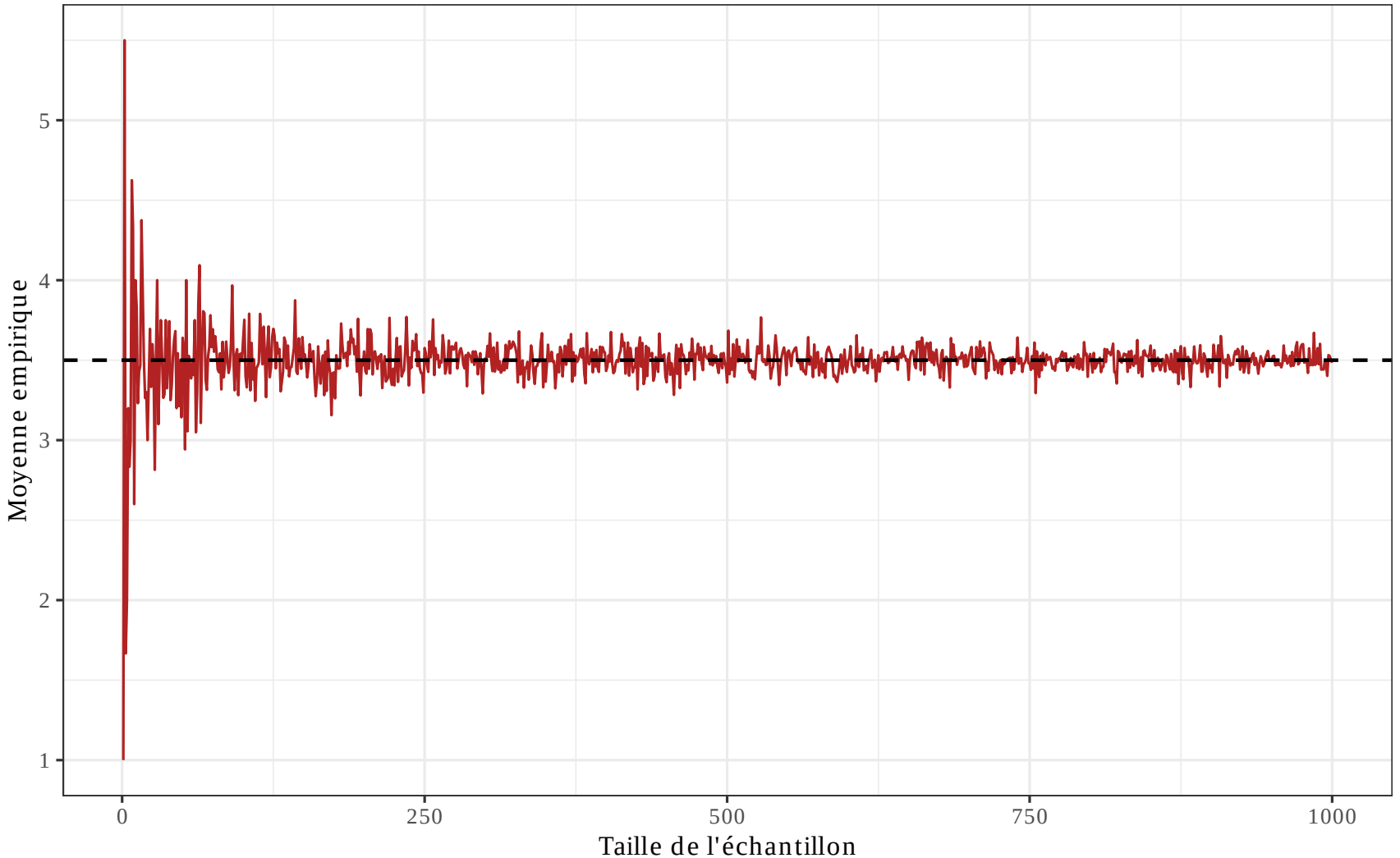
$$\mu = \frac{1+2+3+4+5+6}{6} = 3,5$$

(weak) Law of Large Numbers :

$$\bar{X}_n \to \mu \text{ when } n \to \infty$$

(sample average converges toward the expected value, for a sufficiently large sample)

Monte Carlo


Moyenne empirique
5
4
3
2
1
0
250
500
750
1000
Taille de l'échantillon

Bootstrap

Classical inference :

- Goal : approach μ and σ **parameters** of a distribution
- $\bar{X}$ and σ_X are computed on a **sample** X
- Sampling of X and $\bar{X}$ / σ_X computation are repeated

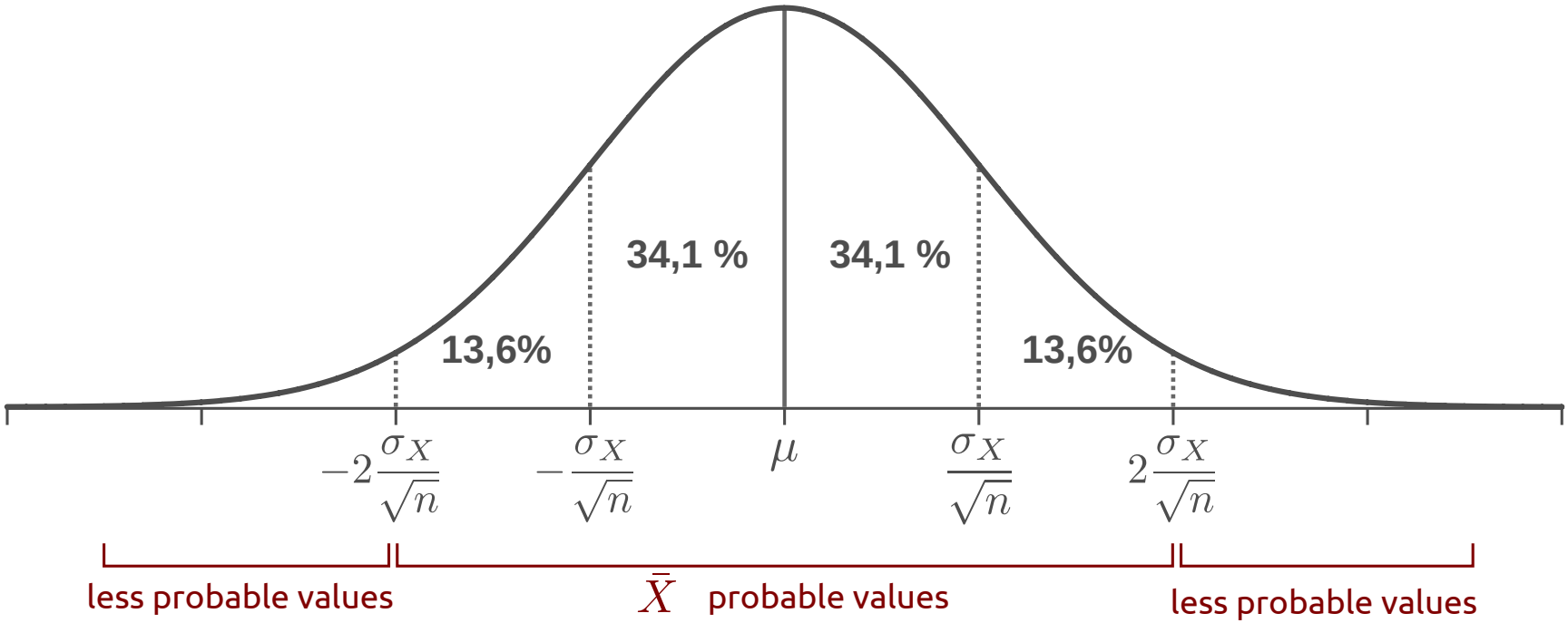
Example :

- For a 12M population (people from Île-de-France).
- People travel daily between 0 and 200 km.
- 500 samples are drawn, 100 people each.
- For each sample, the average travel distance ($\bar{X}$) is computed .

$\rightarrow$ these 500 average values form a *distribution* : the **sampling distribution of the mean**

Bootstrap

Sampling distribution of the mean (500 mean values) :



where μ et σ are the **parameters** – real mean and standard deviation of the population – and n is the **sample size**.

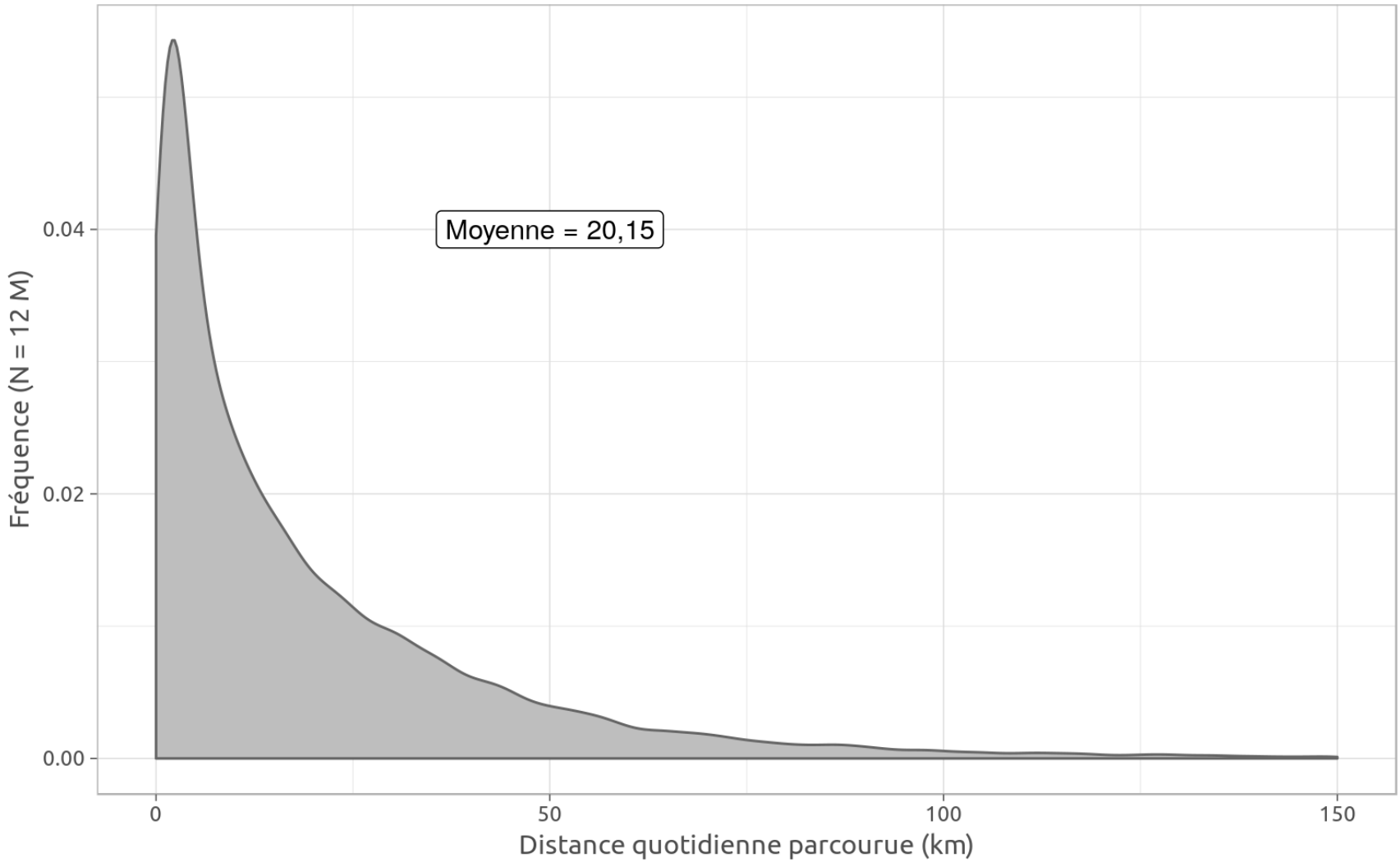
$\rightarrow$ This is **central limit theorem** (**CLT**).

Bootstrap

- **General inference idea :** the sample (which is known) allows to approach the parameters of the population distribution (which is unknown)
- **General bootstrap idea :** re-sampling (which is known) from the sample (which is known) give insights about what would sampling look like on the whole population.
- **Example :** to estimate the variance of the sampling distribution , we compute the variance of the re-sampling distribution of the mean.

Bootstrap

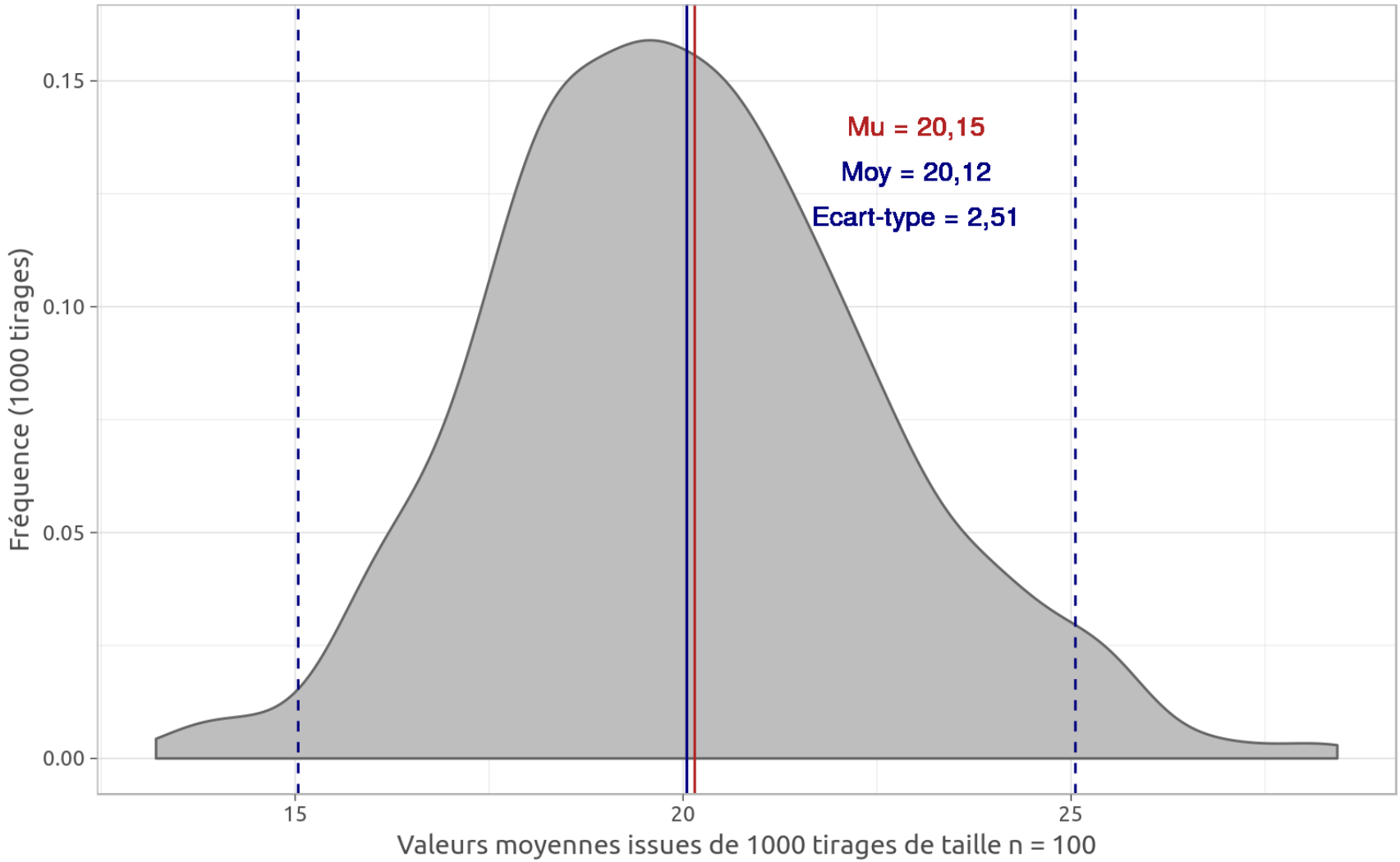
Daily travel distance for Île-de-France people



Source : Enquête Globale Transport 2010 (French transportation national census)

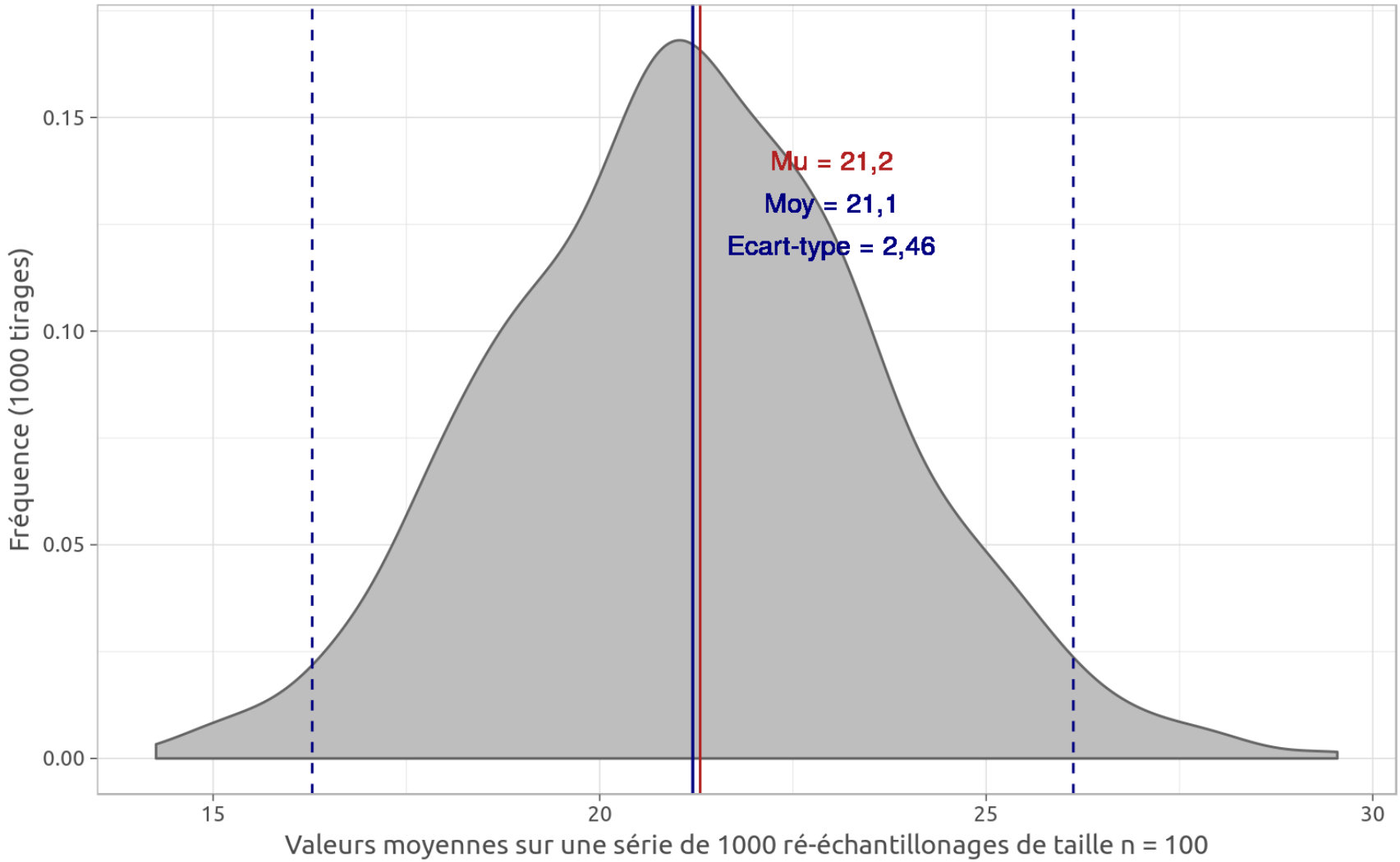
Bootstrap

Sampling distribution of the mean



Bootstrap

Re-sampling of the mean on a sample



Bootstrap

Power of the Bootstrap : this technique offers

- compute estimates (mean, variance) without any hypothesis or *a priori* knowledge on the population
- compute estimates variability (confidence interval) without any hypothesis or *a priori* knowledge on the population (*distribution-free confidence intervals*)
- assess the stability of some model results (*cross-validation*)

Density

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Use case

Density

Density is a **spatial variable** depicting the **spatial variation** of some observations (concentration and dispersion) in 1, 2 or *n* dimensions.

- Mass / Volume ratio (volumetric mass), mass per volume unit, sometimes ratio between an object volumetric mass and a reference volumetric mass.
- Ratio between a **count** and its **extent** : a variable's density (1D), population density (2D, so **spatial extent**), etc.

What kind of geographical information is concerned ?

→ *TYPE 1 - Geographical Objects*

→ *TYPE 2 - Occurrences*

Goals

Main uses :

1. Describe a point pattern
2. Estimate the probability of an event to occur at a given point
3. Estimate the probability that a spatial distribution of events is random.

Spatial distribution parameters

Centrality and **dispersion** can be computed in a 1, 2 2 or n dimensions space.

Current analysis of these parameters :

- Description of a distribution : mean and standard deviation
- Evolution of these parameters over time
- Parameters weight

Spatial distribution parameters

2-Dimensions **mean** : **barycenter** (or **balancing point**).

$$x_g = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \qquad y_g = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}$$

$\rightarrow$ weights w_i might be constant or varying, depicting localized stocks variations.

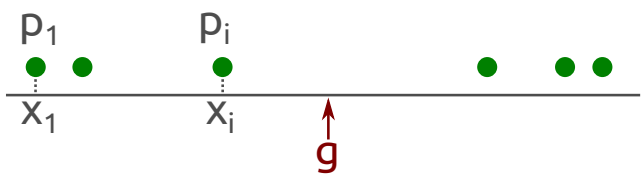
Spatial distribution parameters

2-Dimensions **variance** $\approx$ **inertia**.

General formula
-> squared distances mean

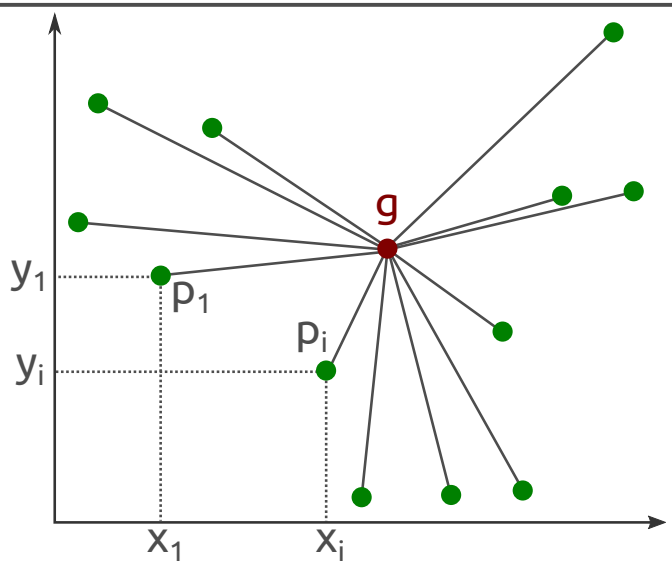
$$I = \frac{1}{n} \sum_{i=1}^{n} d^2(p_i, g)$$

1D



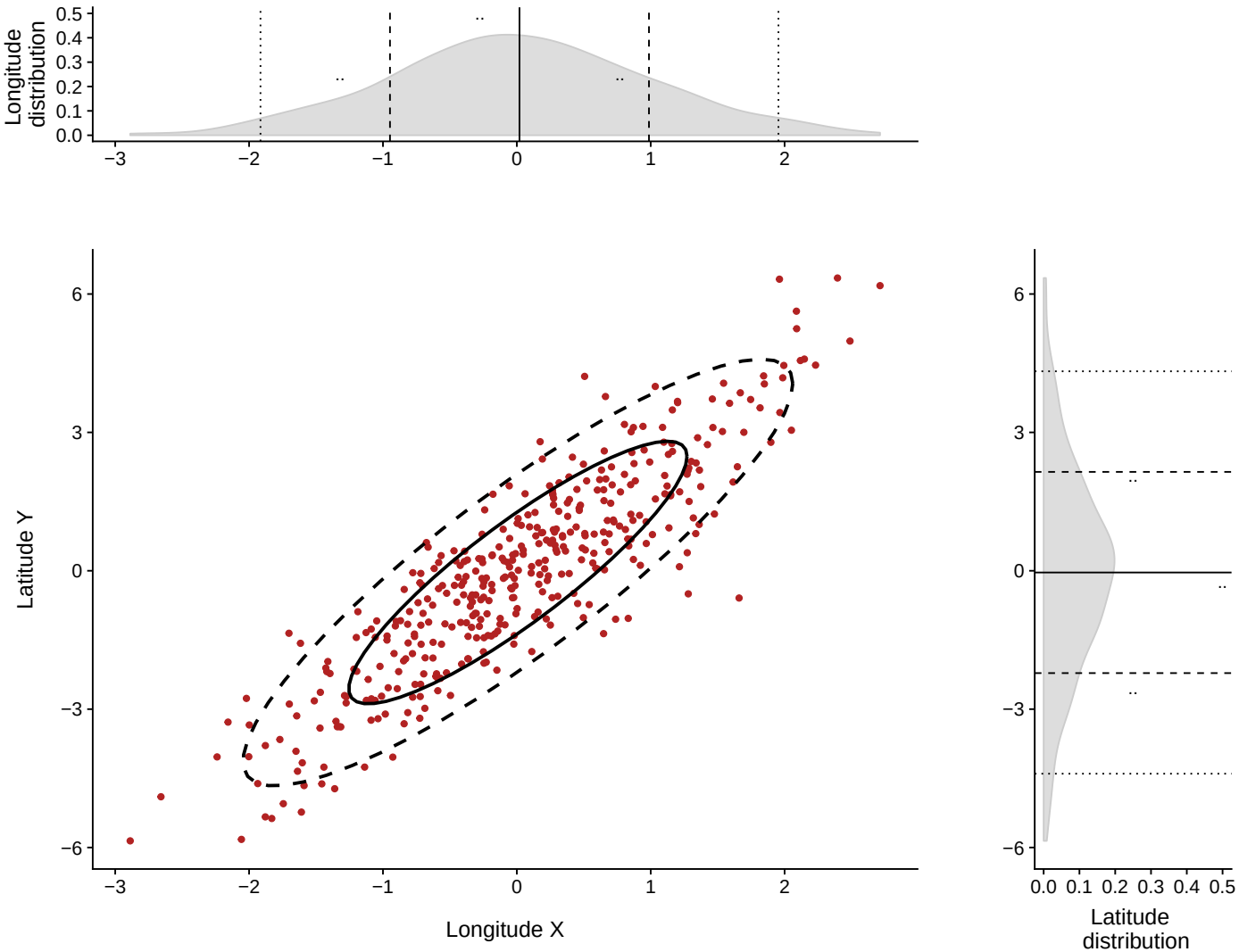
$$I = \frac{1}{n} \sum_{i=1}^{n} (x_i - x_g)^2$$

2D

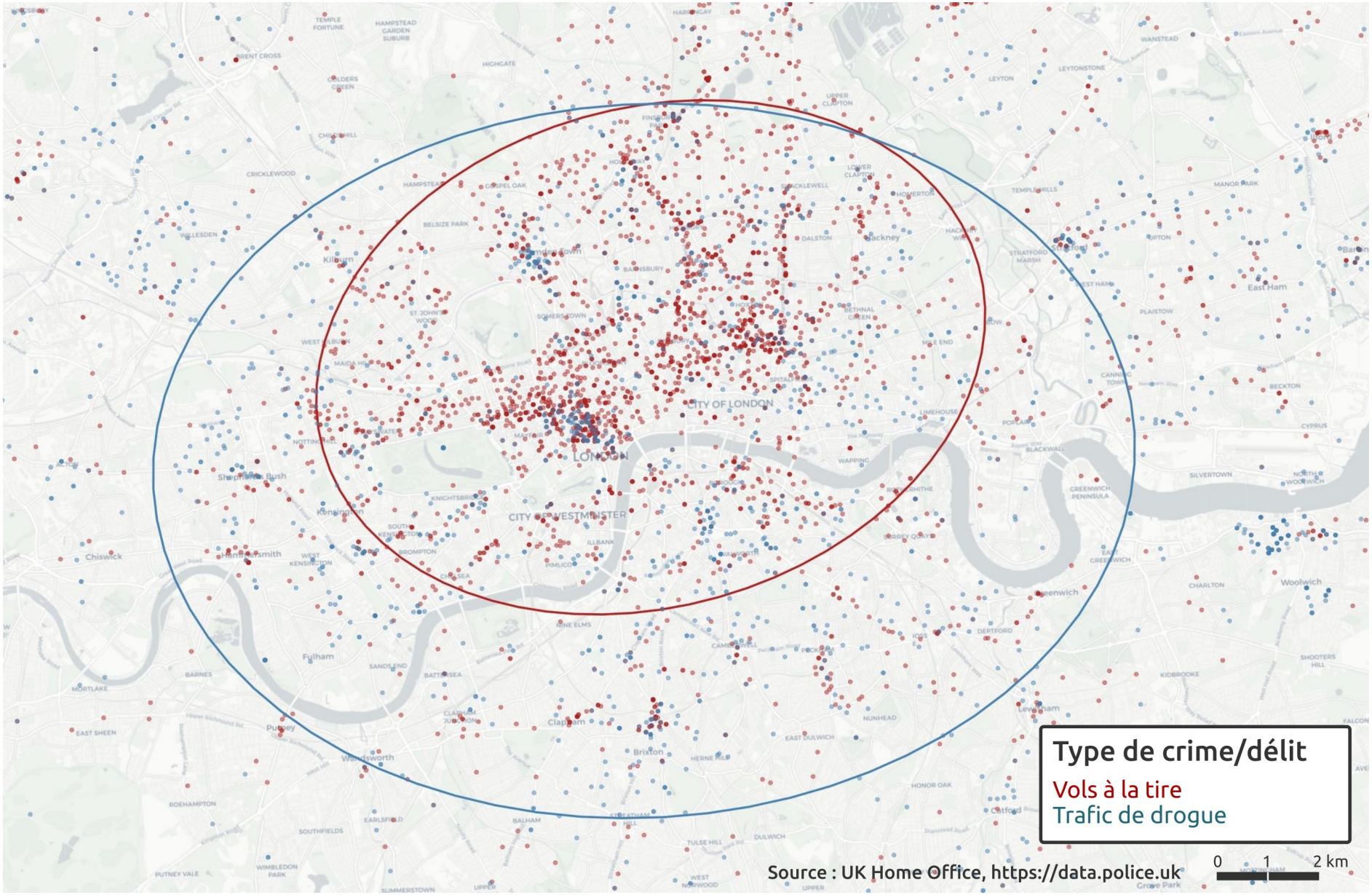


$$I = \frac{1}{n} \sum_{i=1}^{n} \left[(x_i - x_g)^2 + (y_i - y_g)^2 \right]$$

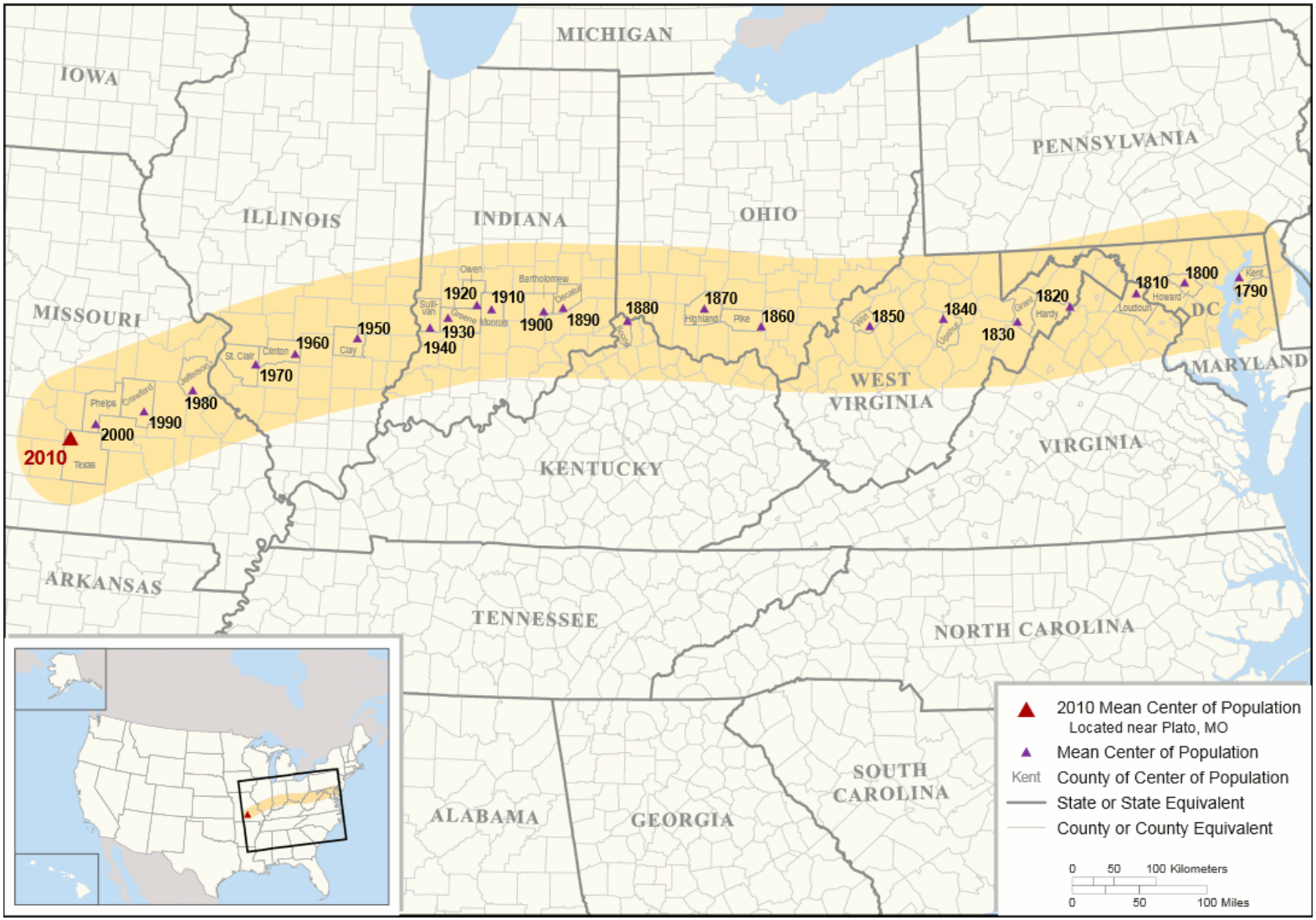
Spatial distribution parameters



Spatial distribution parameters



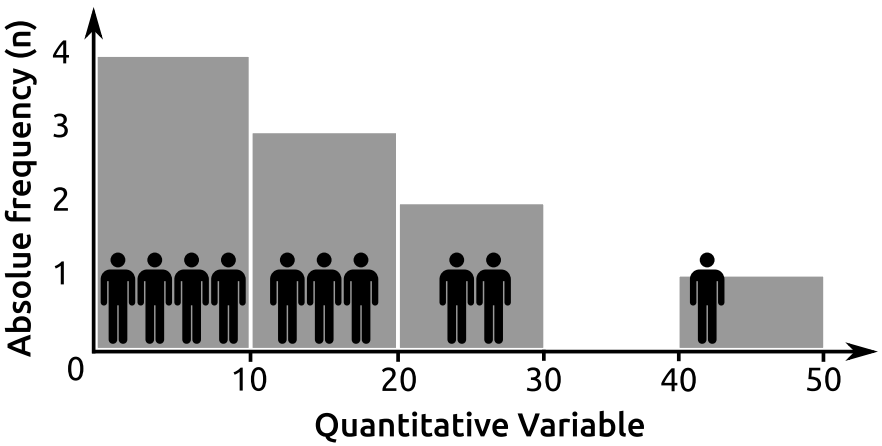
Spatial distribution parameters

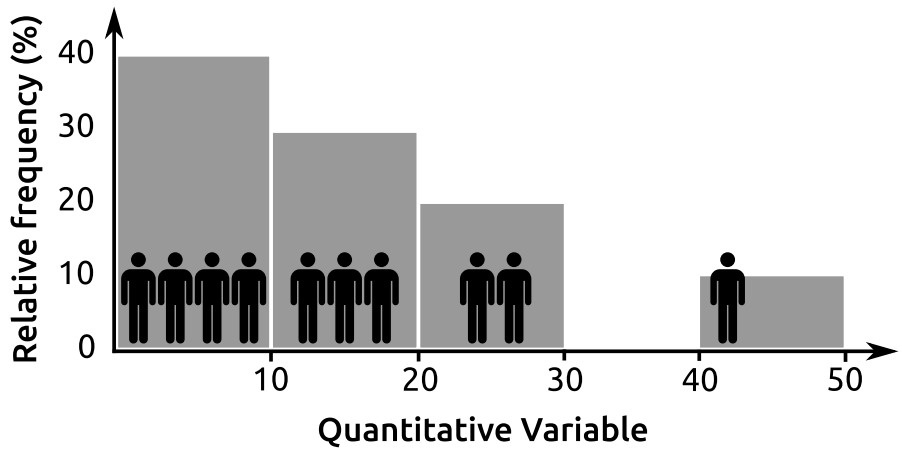


Source : US Census, `https://www.census.gov/geo/reference/centersofpop.html`

1D distribution graph (discrete)

Histogram

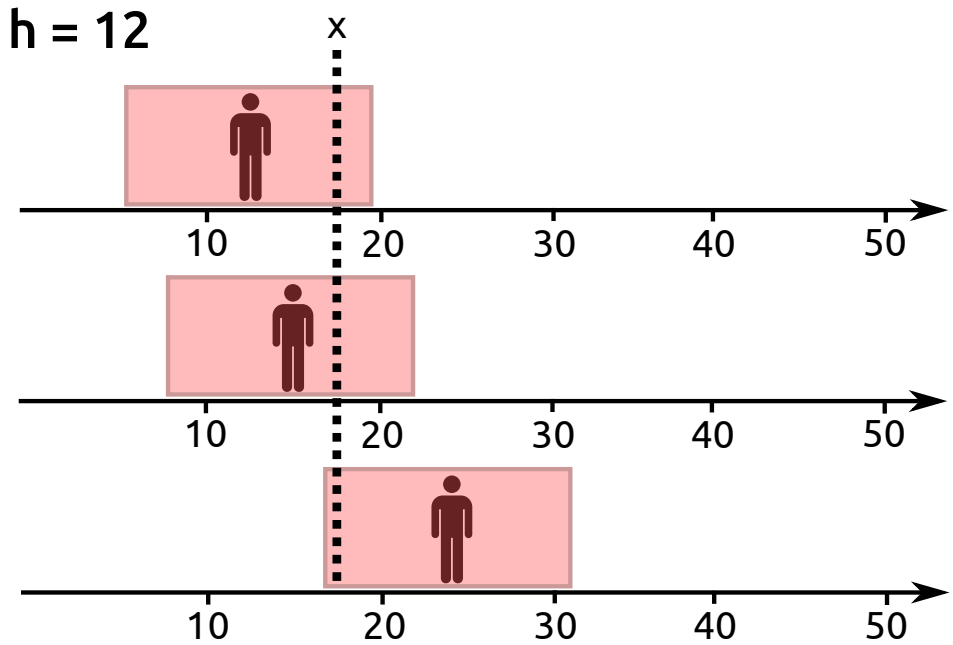




$\rightarrow$ histogram estimated density is **discrete** by construction.

Distribution graph (Parzen)

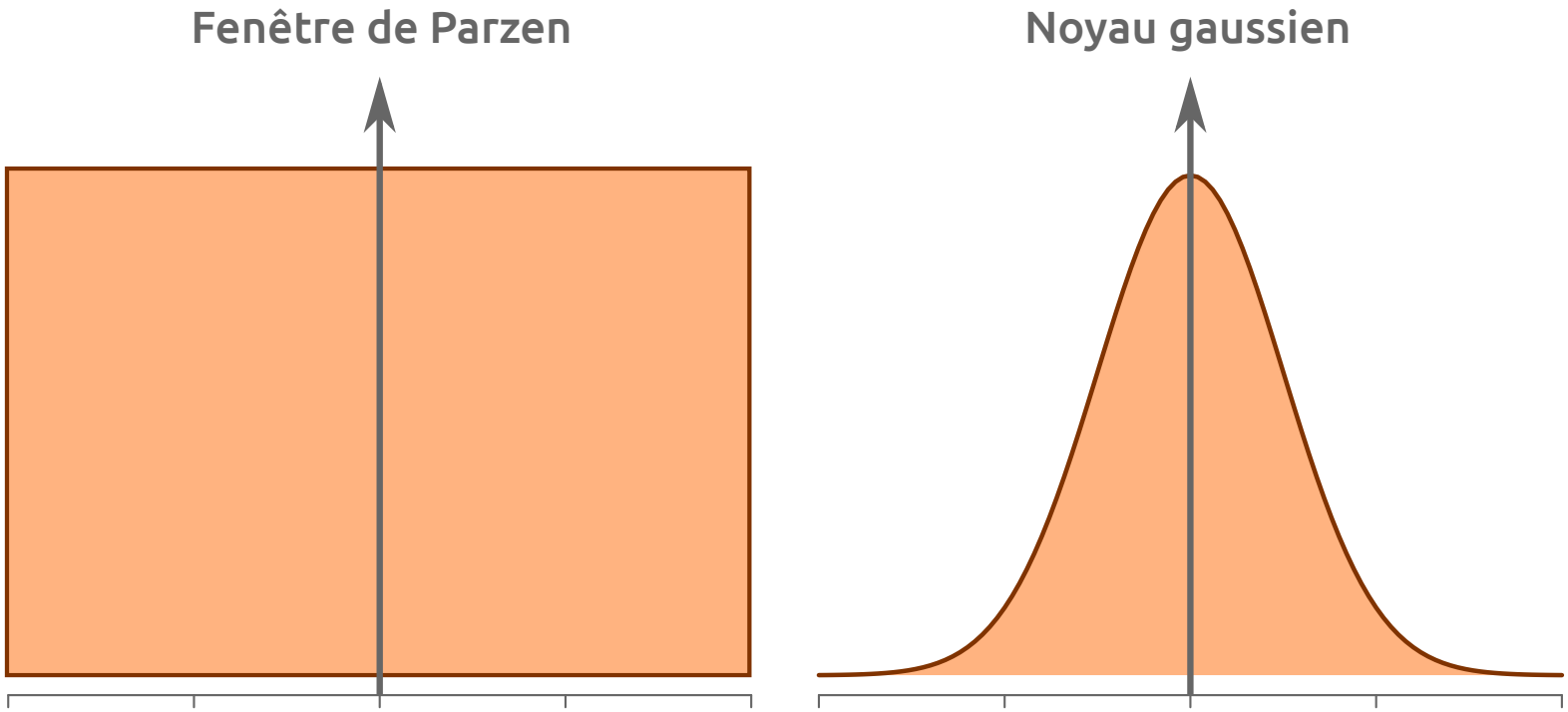
Histogram generalization : Parzen window



$$D(x) = \frac{1}{3 \times 12}(1 + 1 + 1) = \frac{1}{12}$$

Distribution graph (continuous)

Parzen Generalization : Gaussian Kernel



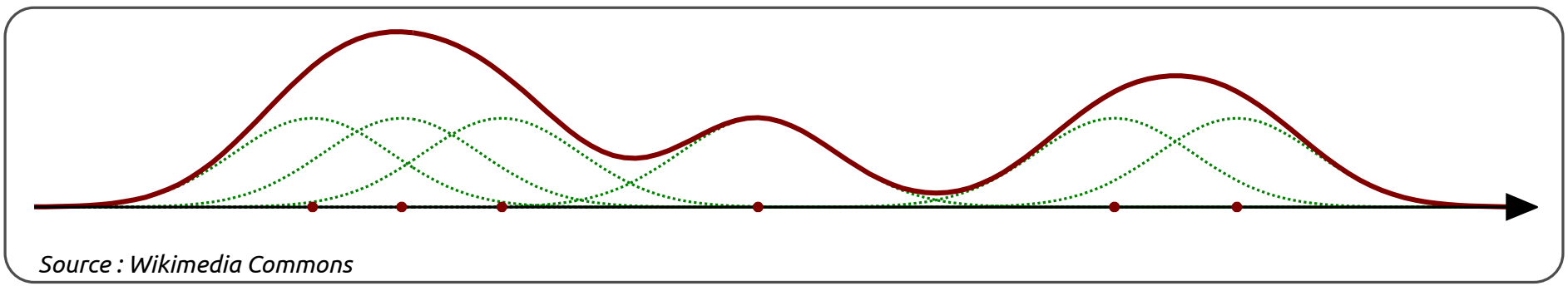
1D distribution graph (continuous)

Kernel Density Estimate

General idea : density for a value x is estimated by the proportion of observation *near* x

«Near» is defined by a certain window described by a **kernel function** (usually gaussian).

Contribution of each observation within the window is given by kernel function value taken for each x. *implies* smoothing



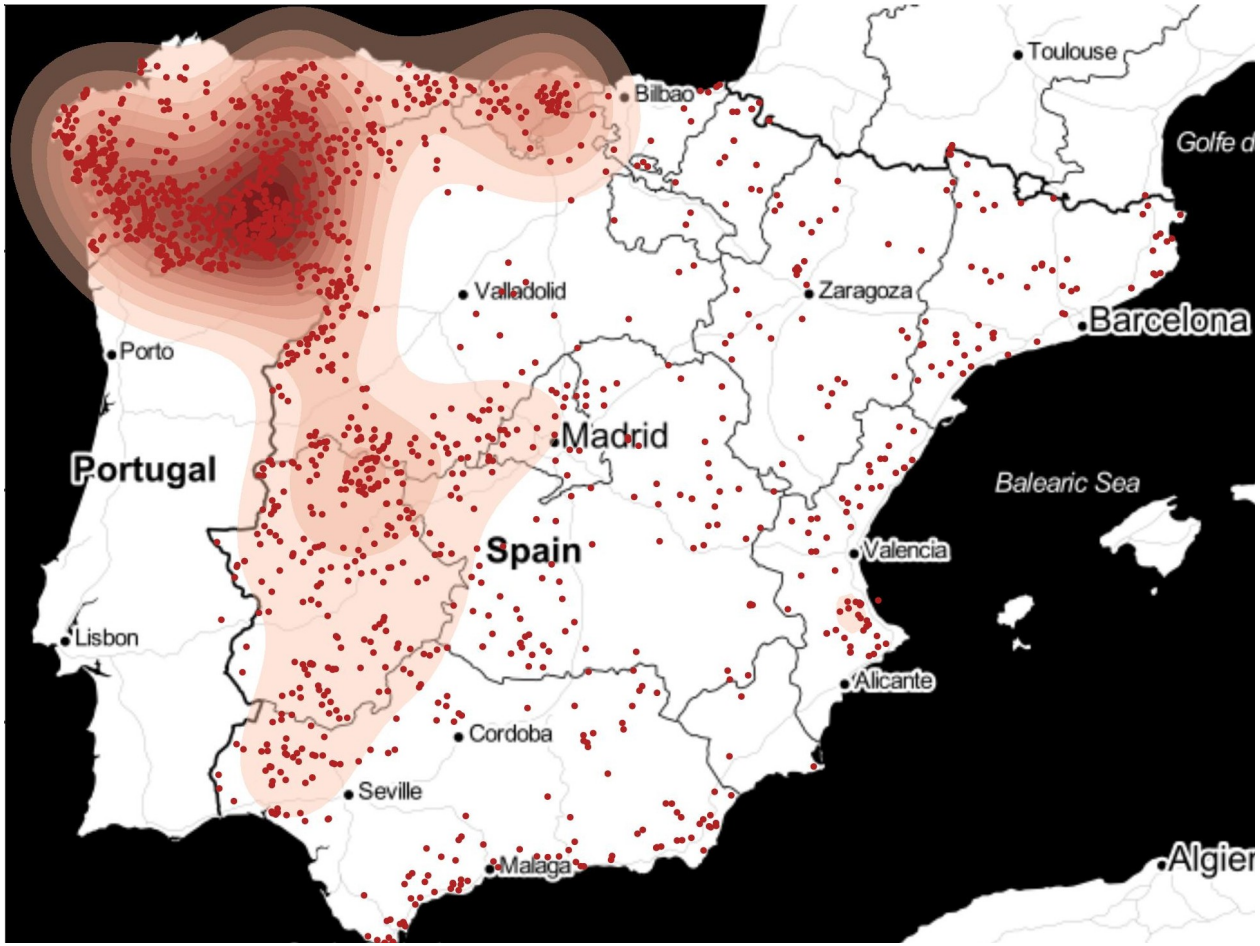
Source : Wikimedia Commons

«Close observations contribute strongly, far ones contribute slightly »

Kernel Density Estimator) may be applied in 1 to n dimensions. For spatial analysis, we use the **2D** version.

Distribution mapping

Density obtained by (KDE) in **2 Dimensions**.



Distribution testing

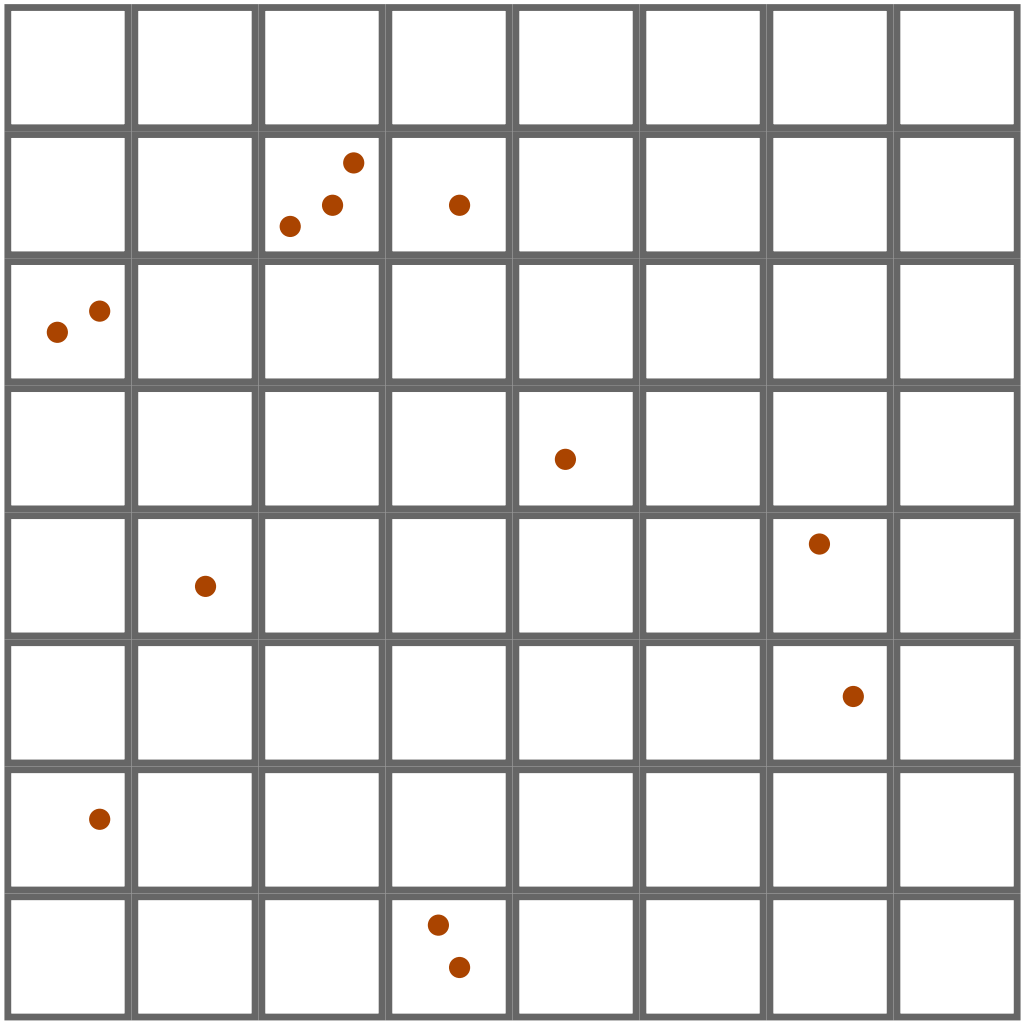
May this distribution have been generated by a stochastic process ?

Number of times victimised	Respondents %	Incidents %
0	59.5	0.0
1	20.3	18.7
2	9.0	16.5
3	4.5	12.4
4	2.4	8.8
5+	4.3	43.5

Source : Farrell, Pease (1993) Once bitten, twice bitten, Police Research Group, London.

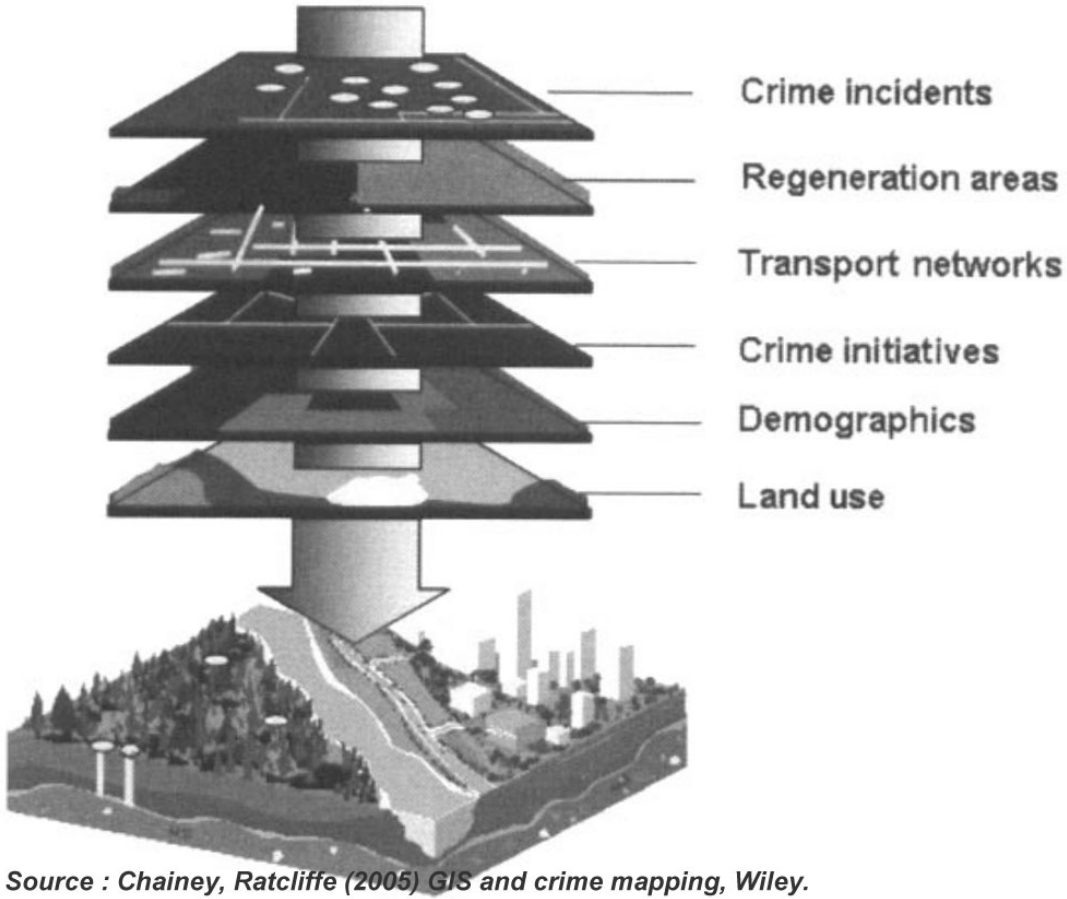
Distribution testing

May this distribution have been generated by a stochastic process ?



Distribution testing

May this distribution have been generated by a stochastic process ?

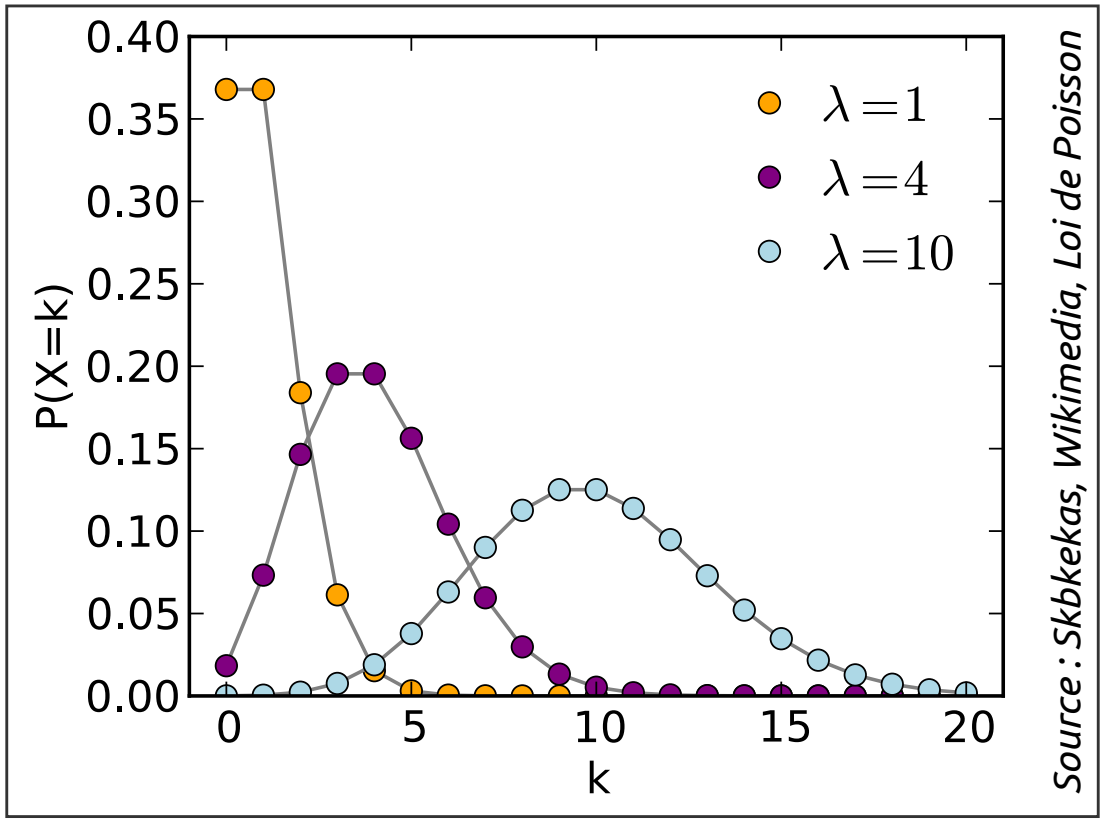


Source : Chainey, Ratcliffe (2005) GIS and crime mapping, Wiley.

Poisson distribution

Poisson's distribution λ parameter is both the **mean** and the **variance** of the distribution.

$$P(X = k) = \frac{\lambda^k e^{-\lambda}}{k!}$$



Poisson spatial distribution

A **Poisson spatial process** is a **spatial stochastic process**, sometimes labelled as :

- *spatial Poisson process*
- *homogeneous Poisson process*
- *complete spatial randomness* (CSR)

Given a partitioned space Z, the probability of a given number of occurences in a zone z is modeled by a Poisson distribution whose mean is $\lambda \times area(z)$.

Dispersion index

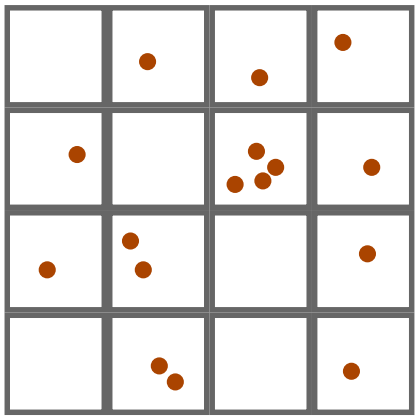
VMR *Variance-to-Mean Ratio* $= \frac{\mu}{\sigma^2}$

- Construct a regular grid
- Count occurrences
- Compute variance, mean and VMR

VMR intrepretation

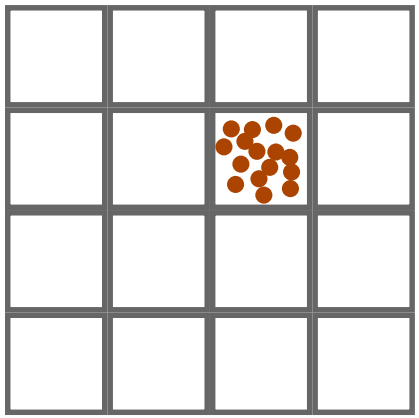
- VMR $= 0$: not dispersed
- VMR $= 1$: may have been obtained by a Poisson process
- VMR < 1 : uniform / periodic
- VMR > 1 : concentrated / clusters

Dispersion index



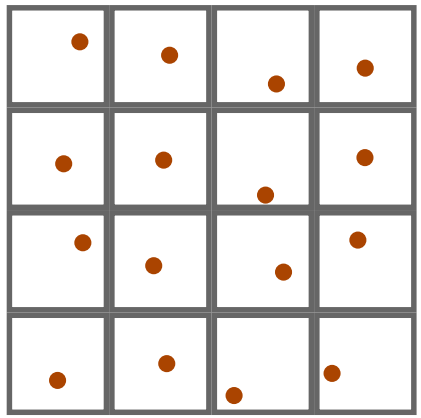
X (nbr. occurrences)
[0 1 1 1 1 0 4 1 1 2 0 1 0 2 0 1]

Var(X) = 1,1
$\overline{X}$ = 1
VMR = 1,1



X (nbr. occurrences)
[0 0 0 0 0 0 16 0 0 0 0 0 0 0 0 0]

Var(X) = 16
$\overline{X}$ = 1
VMR = 16



X (nbr. occurrences)
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]

Var(X) = 0
$\overline{X}$ = 1
VMR = 0

→ **test :** does VMR differs from 1 significantly ? (Student)

Quadrat methods

« A spatial χ^2»

- Construct a regulard grid (quadrats) : observed distribution
- Theoretical distribution (null model) is given by a spatial Poisson process.
- Contingency tables with observed and expected occurrences

$\rightarrow$ **test :** Observations differ significantly from expected values ? (χ^2 test)

Interactions

DELHI GIS-R School

9-12th April 2019

Hadrien Commenges & Paul Chapron

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Use case

Interaction

Relationship among objects. An interaction may be unidirectional, bi-directional or multi-directional . If the entities are spatial objects, interaction always integrate a spatial dimension.

Relationships come in many forms

- Environment : migratory birds, climate refugees, home-to-work commutes, etc.
- «Material realm» : commercial exchanges, percolation,
- «Immaterial realm» : twin-towns, Facebook friendship, co-authorship, etc.

What kind of geographical information is concerned ?

→ *TYPE 1 - Geographical Objects*

→ *TYPE 2 - Occurrences*

Relations Modeling

Interacting systems can be represented by the **relations** between constitutive **entities** , either as an **(adjacency) matrix** or as a **list of links**, weighted or not. (cf Graphs)

liste de liens

ori	des	poids
A	B	2
A	C	5
B	A	3
B	C	4
C	A	0
C	B	0

matrice d'interaction

	A	B	C
A	0	2	5
B	3	0	4
C	0	0	0

Distance and Interaction

Spatial interactions imply **distance**.

- Spatial interaction considers **travel as an effort** .
- Spatial interaction confront **connecting entities** and the **distance induced decay**.
- Spatial interaction comes in two flavors : **relationships between locations** or **attraction/influence of a location on the others**.
  - The first relies on **flow analysis**
  - The second relies on **position analysis**(*Accessibility*)

What is distance ?

In Geography, distance is a separation, requiring **effort** to be crossed. Distance is a **friction**, a barrier :

- *«Everything is related to everything else, but near things are more related than distant things»* (Tobler)

In Maths, a distance is a function satisfying the following conditions

- Symmetry $d(a, b) = d(b, a)$
- Identity of indicernibles : $d(a, b) = 0 \iff a = b$
- Triangle inequality : $d(a, c) \leq d(a, b) + d(b, c)$

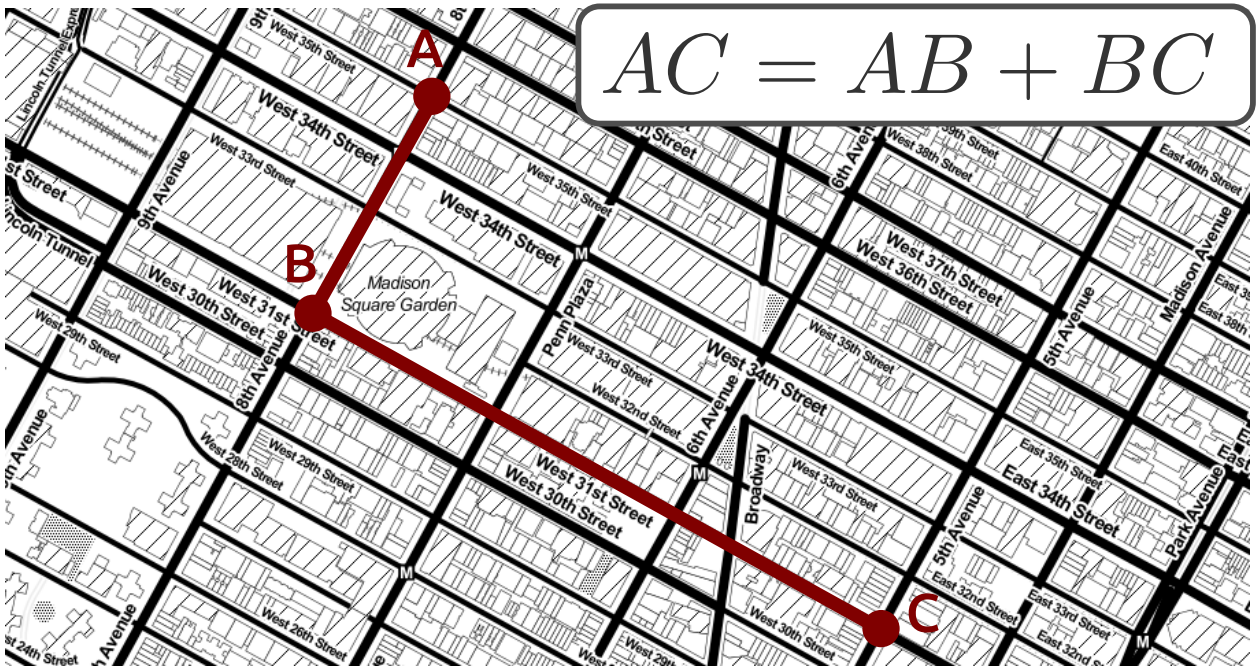
Euclidean Distance

For a n-dimensional vector :

$$d(a, b) = \sqrt{\sum_{i=1}^{n} (a_i - b_i)^2}$$

Manhattan Distance

2D vector :



For a n-dimensional vector :

$$d(a, b) = \sum_{i=1}^{n} |a_i - b_i|$$

Flow modeling

Original gravity model :

$$T_{ij} = k \frac{P_i P_j}{D_{ij}^2}$$

With T_{ij}, the flow from location i to j.
k a constant
P_i the mass of location i
D_{ij} the distance between location i and j.

Many variations exist according to the choice of the terms :

- **Masses :** populations, jobs , emissions, attractions
- **Masses weights :** multiplying factors or exponents
- **Friction function (distance) :** negative powers, negative exponent
- **Margin Constraints :** double, simple, none
- **Numeric Resolution**

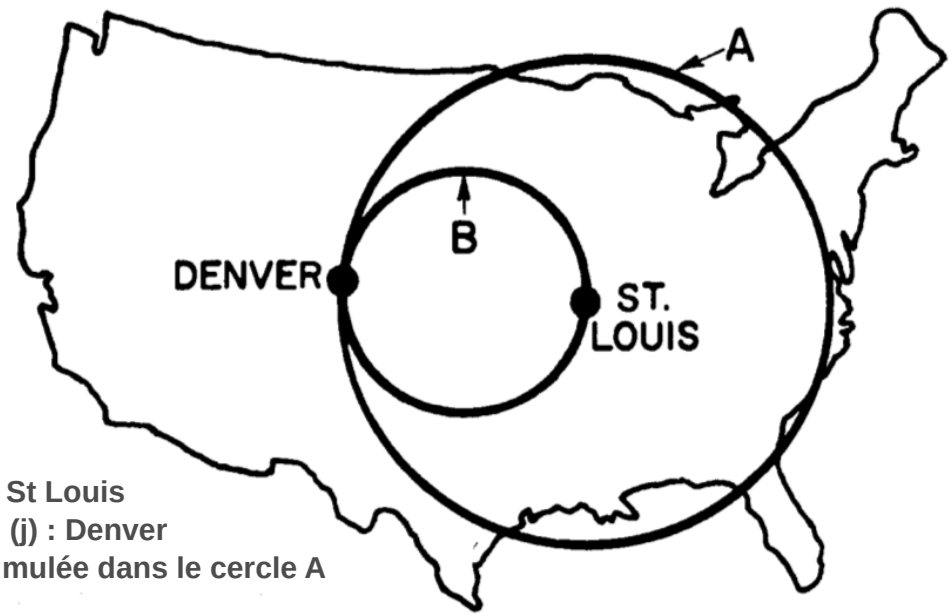
Modélisation des flux : formalisation

Le modèle d'opportunités interposées (Stouffer 1960) s'écrit :

$$T_{ij} = k_i O_i \left[\exp(-\alpha x_{j-1}) - \exp(-\alpha x_j)\right]$$

Le modèle de radiation (Simini *et al.* 2012) s'écrit :

$$T_{ij} = T_i \frac{P_i P_j}{(P_i + S_{ij})(P_i + P_j + S_{ij})}$$

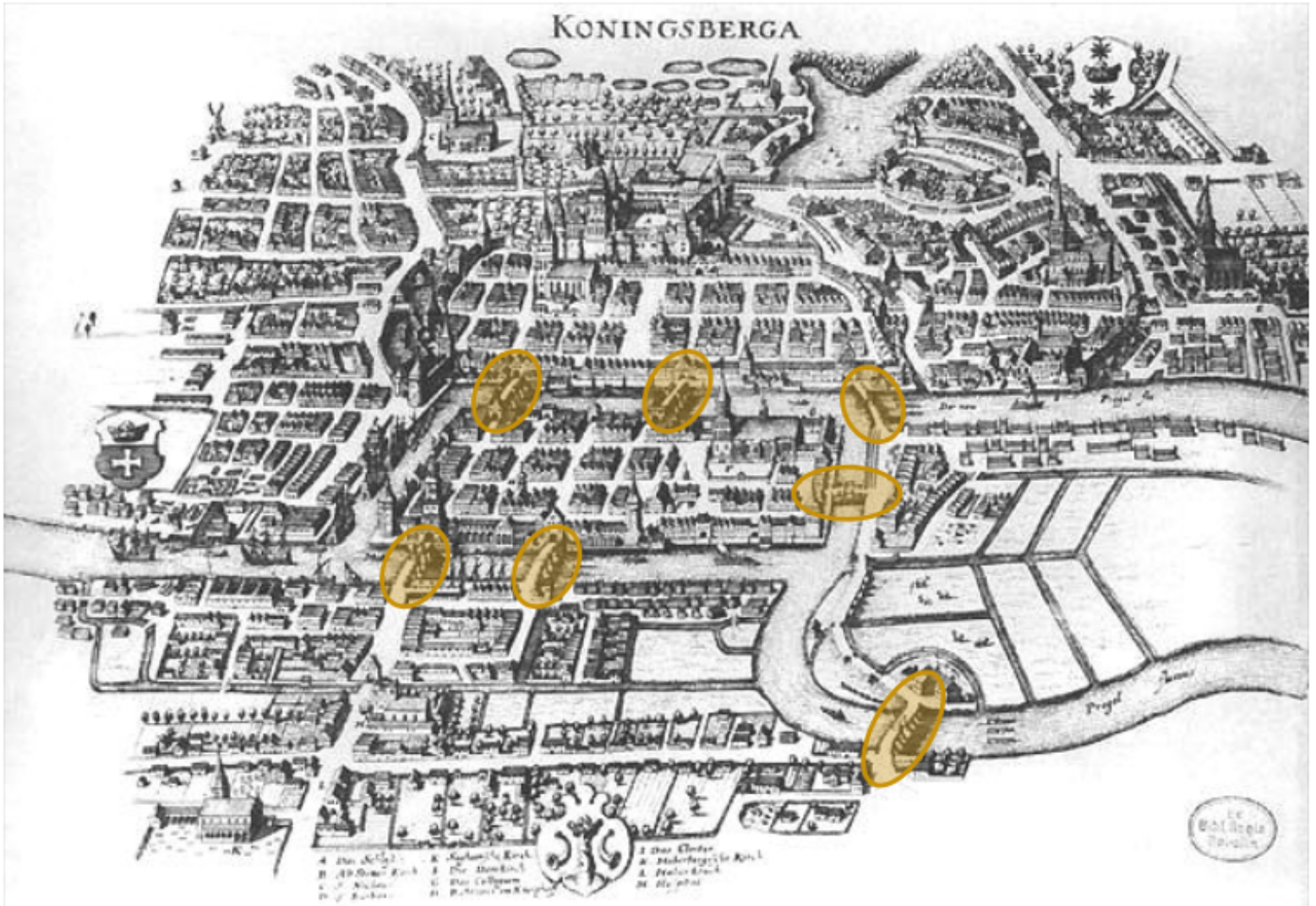


Origine (i) : St Louis
Destination (j) : Denver
S_{ij} : pop. cumulée dans le cercle A

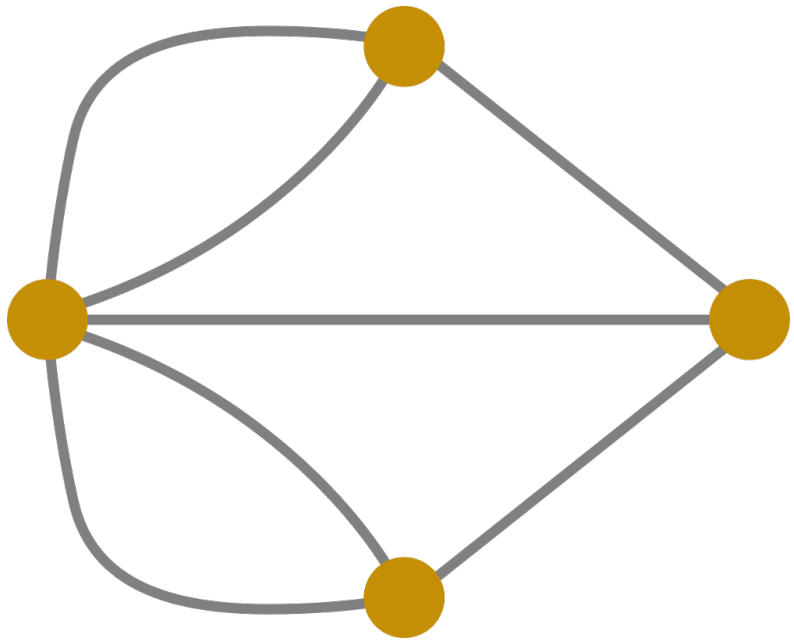
Source : Stouffer S.A. (1960) "Intervening opportunities and competing migrants", *J. Reg. Sc.*

Network Analysis

Leonhard Euler and the **Seven Bridges of Königsberg** (Kaliningrad).



Network analysis



- No **cycle eulérien** (parité des liens incidents)
- Pas de **chaîne eulérienne** (continuité du tracé)

Graphs

A graph is a set of *vertices*) connected by **edges**.
Examples :

- **Transportation networks :** e.g. Subway : nodes are stations, edges are lines.
- **Social networks :** individuals (nodes) , social interactions (edges)
- **Scientific collaboration networks :** Co-autorship (edges) among researchers (nodes)
- ...

Types of graphs

Undirected graph :

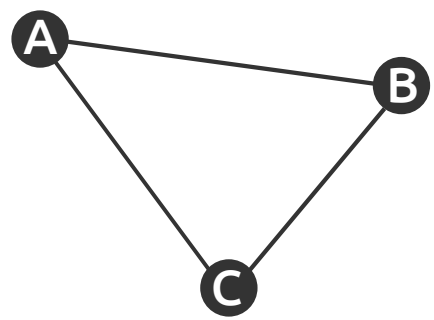
couple de liens
edges list

ori	des
A	B
A	C
B	C

matrice d'adjacence
adjacency matrix

	A	B	C
A	0	1	1
B	1	0	1
C	1	1	0

visualisation du graphe



Types of graphs

Directed graph :

arcs are employed instead of *edges* who are "undirected".

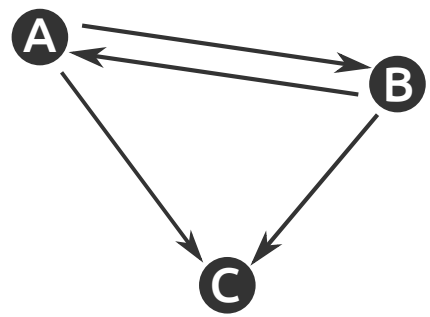
couple de liens
edges list

ori	des
A	B
A	C
B	A
B	C
C	A
C	B

matrice d'adjacence
adjacency matrix

	A	B	C
A	0	1	1
B	1	0	1
C	0	0	0

visualisation du graphe



Types of graphs

Weighted directed graph :

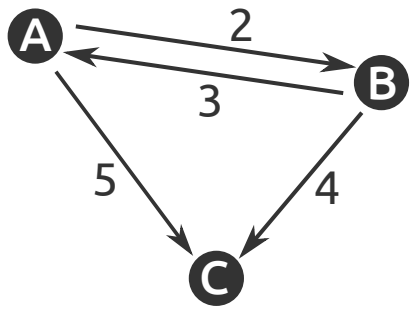
liste de liens
edges list

ori	des	flux
A	B	2
A	C	5
B	A	3
B	C	4
C	A	0
C	B	0

matrice d'adjacence
adjacency matrix

	A	B	C
A	0	2	5
B	3	0	4
C	0	0	0

visualisation du graphe



Also :

- Weighted undirected graphs
- Multi-graph ()
- Multi-partite graphs (several types of nodes)
- Hypergraphs (links between more than 2 nodes)
- ...

Network analysis : measures

Global measures :

- number of nodes
- number of edges
- connected components
- Density (ratio nodes)
- Diameter : length of the longest shortest paths
- Connectivity : number of edges and possible number of edges

$\rightarrow$ **Nombre maximum d'arcs (sans boucle) :**

- pour un graphe planaire : $3V - 6$
- pour un graphe non planaire non orienté : $\frac{V(V-1)}{2}$
- pour un graphe non planaire orienté : $V(V-1)$

Principales mesures descriptives

Mesures locales de centralité :

- Degré : nombre d'arcs incidents (nbr. de voisins)
- Degré pondéré : nbr. d'arcs incidents pondérés
- Centralité de proximité (*closeness*) : inverse de la somme des distances à tous les autres noeuds
- Centralité d'intermédiarité (*betweenness*) : nombre de plus courts chemins passant par un noeud (standardisé)