Introduction to movement

Animal tracking 25/26

Giuliano Colosimo

University of Rome Tor Vergata

Table of contents I

Overview

Overview

- Discretionary course for master level students enrolled in "Biologia Ambientale" degree at the University of Rome Tor Vergata. It is worth **2 CFU** for a total of 16 hours
- All the material and the literature used will be in English
- No specific prior knowledge of is required, but rudiments of basic GIS will definitely help. Students will be extensively exposed to various software and web-tools. Problem-solving skills and a good knowledge of your own computer OSs structure and function will definitely be useful
- Classes are Wednesday and Thursday (09:00-11:00) in "Aula televisore" (Laboratori di Ecologia Sperimentale ed Acquacoltura)

Hardware set up

- To visualize and analyse data we will be using **R** and **RStudio**

```
> sessionInfo()
R version 4.5.1 (2025-06-13)
Platform: x86_64-pc-linux-gnu
Running under: Ubuntu 24.04.3 LTS
```

Figure 1: The R version, hardware, and OS I am using on my personal computer. We will be using R and RStudio throughout the course, so please go ahead and install them on your computers. We will add specific libraries little by little.

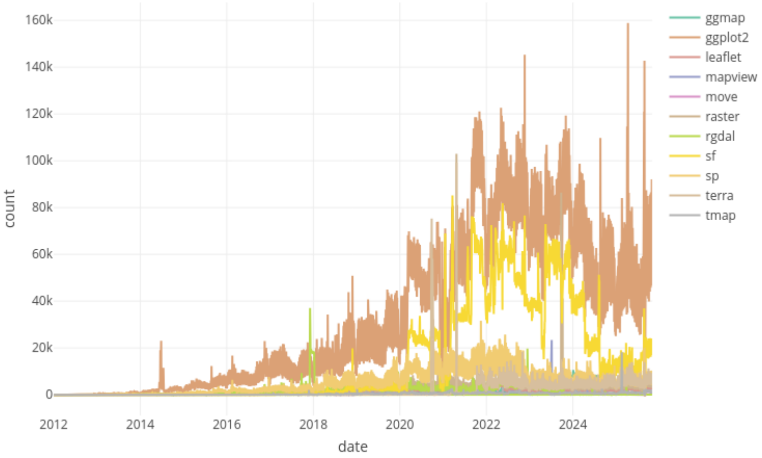


Figure 2: Trend of “movement related” packages downloaded from CRAN

A tag to track

A tag to track

- Animal Tracking is a discipline allowing to gather information about the biology, ecology, behavior and life history of animals starting from data on their position in the natural environment. Major requirements:
  - the capability to uniquely identify individuals, populations or species (Costa, Foody, Jiménez, & Silva, 2015);
  - the availability of position data for that individual (population or species) and a geographic reference system that helps minimizing errors when making calculations (Guisan & Zimmermann, 2000)
  - the availability of reliable environmental data!

Tagging systems

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

- A tag is a label!
- A tagging system is a way of labeling “something” to provide that something with an unique identifier. People have been tagging animals (wild and captive) for hundreds of years
- An animal tag can be as simple as a piece of metal or plastic with a number carved on it or with a standardized meaning

Figure 3: A male *Cyclura carinata* with colored bead tags. Photo credits: Giuliano Colosimo.

Passive Integrated Transponders (PIT)

- These tags are widely used for wildlife fauna, especially in long-term capture-mark-recapture studies. They uniquely identify individuals. They generally do not carry any other information but the individual's ID. They are based on the RFID (Radio-Frequency-Identification) system. When the tag is within reach of a specific radio frequency, it emits a signal containing an alpha-numeric code unique to the animal it has been implanted.

Figure 4: A Passive Integrated Transponder by Trovan®. Photo credits: Giuliano Colosimo.

Patterns tagging

Toes and nail clipping

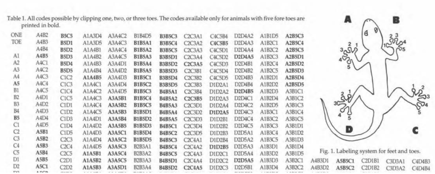


Table 1. All codes possible by clipping one, two, or three toes. The codes available only for animals with five fore toes are printed in bold.

ONE	A4B2	**B5C5**	A1A3D4	A3A4C2	B1B4D5	**B3B5C3**	C2C3A1	C4C5B4	D2D4A2	A1B1D5	**A2B5C3**						
TOE	A4B3	**B5D1**	A1A3D5	A3A4C3	**B1B5A1**	**B3B5C4**	C2C3A2	**C4C5B5**	D2D4A3	A1B2C1	**A2B5C4**						
	A4B4	**B5D2**	A1A4B1	A3A4C4	**B1B5A2**	**B3B5C5**	C2C3A3	C4C5D1	D2D4A4	A1B2C2	**A2B5C5**						
A1	**A4B5**	**B5D3**	A1A4B2	A3A4C5	**B1B5A3**	**B3B5D1**	C2C3A4	C4C5D2	**D2D4A5**	A1B2C3	**A2B5D1**						
A2	A4C1	**B5D4**	A1A4B3	A3A4D1	**B1B5A4**	**B3B5D2**	**C2C3A5**	C4C5D3	D2D4B1	A1B2C4	**A2B5D2**						
A3	A4C2	**B5D5**	A1A4B4	A3A4D2	**B1B5A5**	**B3B5D3**	C2C3B1	C4C5D4	D2D4B2	A1B2C5	**A2B5D3**						
A4	A4C3	C1C2	**A1A4B5**	A3A4D3	**B1B5C1**	**B3B5D4**	C2C3B2	C4C5D5	D2D4B3	A1B2D1	**A2B5D4**						
A5	A4C4	C1C3	A1A4C1	A3A4D4	**B1B5C2**	**B3B5D5**	C2C3B3	D1D2A1	D2D4B4	A1B2D2	**A2B5D5**						
B1	A4C5	C1C4	A1A4C2	A3A4D5	**B1B5C3**	**B4B5A1**	C2C3B4	D1D2A2	**D2D4B5**	A1B2D3	A3B1C1						
B2	A4D1	C1C5	A1A4C3	**A3A5B1**	**B1B5C4**	**B4B5A2**	**C2C3B5**	D1D2A3	D2D4C1	A1B2D4	A3B1C2						
B3	A4D2	C1D1	A1A4C4	**A3A5B2**	**B1B5C5**	**B4B5A3**	C2C3D1	D1D2A4	D2D4C2	A1B2D5	A3B1C3						
B4	A4D3	C1D2	A1A4C5	**A3A5B3**	**B1B5D1**	**B4B5A4**	C2C3D2	**D1D2A5**	D2D4C3	A1B3C1	A3B1C4						
B5	A4D4	C1D3	A1A4D1	**A3A5B4**	**B1B5D2**	**B4B5A5**	C2C3D3	D1D2B1	D2D4C4	A1B3C2	A3B1C5						
C1	A4D5	C1D4	A1A4D2	**A3A5B5**	**B1B5D3**	**B4B5C1**	C2C3D4	D1D2B2	D2D4C5	A1B3C3	A3B1D1						
C2	**A5B1**	C1D5	A1A4D3	**A3A5C1**	**B1B5D4**	**B4B5C2**	C2C3D5	D1D2B3	D2D5A1	A1B3C4	A3B1D2						
C3	**A5B2**	C2C3	A1A4D4	**A3A5C2**	**B1B5D5**	**B4B5C3**	C2C4A1	D1D2B4	D2D5A2	A1B3C5	A3B1D3						
C4	**A5B3**	C2C4	A1A4D5	**A3A5C3**	B2B3A1	**B4B5C4**	C2C4A2	**D1D2B5**	D2D5A3	A1B3D1	A3B1D4						
C5	**A5B4**	C2C5	**A1A5B1**	**A3A5C4**	B2B3A2	**B4B5C5**	C2C4A3	D1D2C1	D2D5A4	A1B3D2	A3B1D5						
D1	**A5B5**	C2D1	**A1A5B2**	**A3A5C5**	B2B3A3	**B4B5D1**	C2C4A4	D1D2C2	**D2D5A5**	A1B3D3	A3B2C1	A4B3D1	**A5B5C1**	C2D1B1	C3D3A1	C4D4B3	
D2	**A5C1**	C2D2	**A1A5B3**	**A3A5D1**	B2B3A4	**B4B5D2**	**C2C4A5**	D1D2C3	D2D5B1	A1B3D4	A3B2C2	A4B3D2	A5B5C2	C2D1B2	C3D3A2	C4D4B4	

Fig. 1. Labeling system for feet and toes.

Figure 5: This image is from Waichman (1992). The author describes all possible combination of toe clipping to uniquely identify individuals

Features tag

Figure 6: Toads of the genus *Bombina* have unique spotted patterns. Photo credits: marioeffe

Photo tagging

- More modern approaches rely on the use of morphometric cues to identify individuals!
- These techniques are more complex, but somewhat similar to the FaceID technology on your phones

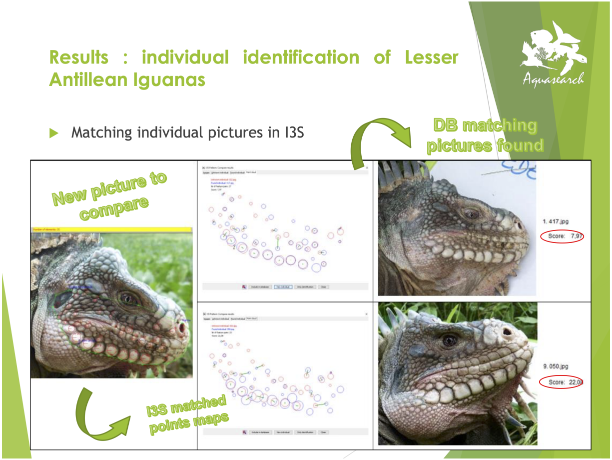


Figure 7: Development of a photo recognition software to identify iguanas in the wild. Image courtesy of Nathalie Duporge. A nice example and protocol of the use of photografies for the identification of unique individuals is presented in

Molecular tags

- From the USGS website:
  - Molecular tagging is a new application of molecular genetic techniques to traditional mark-recapture methodology designed to address situations where traditional methods fail. In such studies, non-invasively collected samples (such as feces, feathers, or fur) are used as a source of DNA that is then genotyped at multiple loci such that each individual animal can be uniquely identified. Thus, each individual's DNA represents a unique tag analogous to a band or other mark used in traditional mark-recapture studies.

Figure 8: Selected species and locations for which genetic tagging for demographic insights into population density, growth rates, direct measures of connectivity, or human–wildlife conflict has been successfully applied. Projects using genetic tagging are biased toward mid-large sized mobile mammals. After Lamb et al. (2019)

Telemetry study

- Small devices transmitting specific radio frequencies have been, and still are, widely used to track animals. Telemetry (tele = far, metron = measurement) is a technique that allows to retrieve real time data and information using an array of wireless data transfer protocols.

Figure 9: Barrell transmitter implanted in a female Turks and Caicos Rainbow Boa (*Chilabothrus chrysogaster*). Photo credits: Giuliano Colosimo.

Figure 10: Radio-telemetry has been, and still is, widely used to retrieve information about the whereabouts of tagged individuals. Photo credits: Giuliano Colosimo.

Satellite tags

Figure 11: A male *Conolophus marthae* equipped with a Wireless Sensor Node (WSN). This tag allows to identify the individual and to collect important information such as GPS location, temperature and UV light. Photo credits: Giuliano Colosimo.

Data visualization

- Eventually, data can be organized and analyzed to produce informative animations
- Example 1
- Example 2
- Example 3

Coordinate Reference Systems (CRS)

Coordinate Reference Systems (CRS)

- A coordinate reference system allows us to use coordinates to locate features on a map. It is a rather important component of tracking, especially when dealing with animals that move significant distances.
- One of the main issue is that ultimately what we try to do is to represent locations measured on a 3D surface (the earth) to a 2D map. This introduces distortions and errors.
- Another issue is represented by the fact that the earth is not smooth surface. We can visualize the problem here!
- We recognize two big classes of coordinate systems:

Geographic coordinates

- The earth is represented by a spherical or ellipsoidal surface. The geometric representation of the earth that is used is called *datum*. Distances between points cannot be measured out with geographical coordinates.
- Latitude: denoted by the Greek letter phi (☒). It is given as an angle that ranges from $-90°$ at the south pole to $90°$ at the north pole, with $0°$ at the Equator.
- Longitude: denoted by the Greek letter lambda (☒). It is given as an angle that ranges from -180° to 180° from east to west and the 0°.

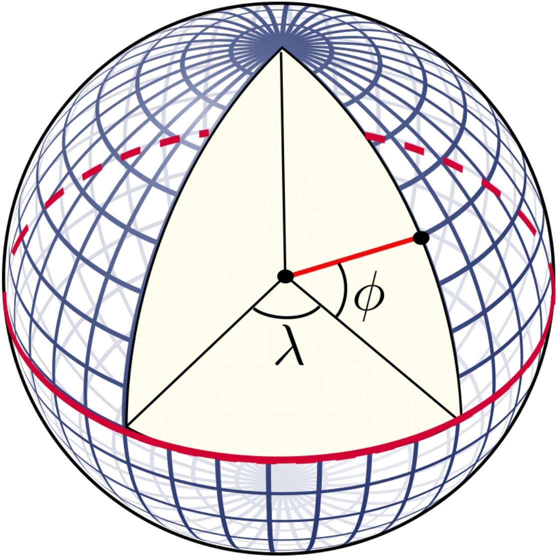


Figure 12: Angles (degrees; longitude and latitude), pointing out locations on a spherical or ellipsoidal surface. Image source.

Projected coordinates

- Measured on a two-dimensional flat space (e.g. in meters; x and y), related to an ellipsoid by projection. In the transition from geometric coordinates to projected ones, a deformation of the images occurs.

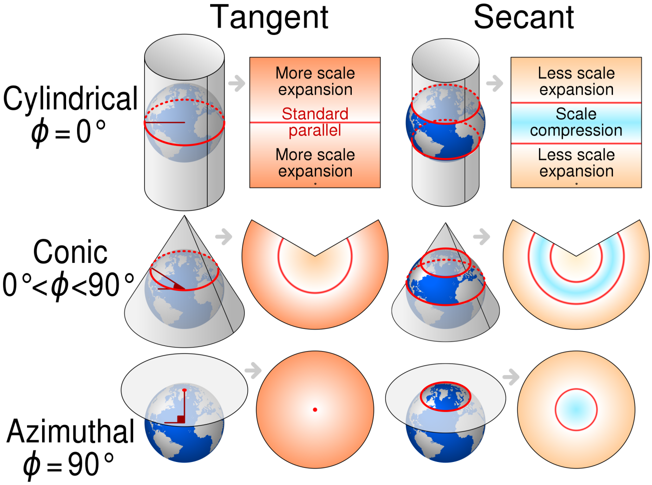


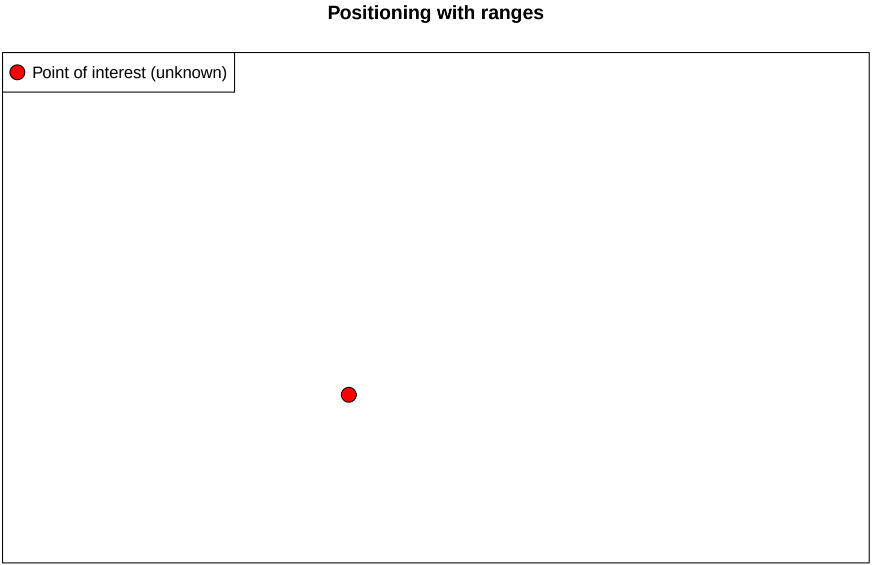
Figure 13: There is no system of projections that is not affected by errors and distortions. Image source.

Telemetry e GPS

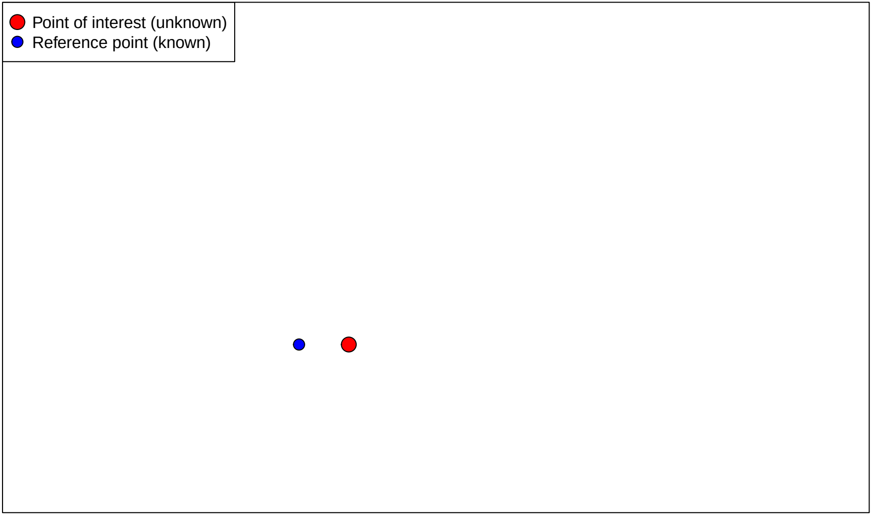
Telemetry e GPS

- The term telemetry (tele = far, metron = measurement) refers to an ensemble of techniques that allow to retrieve real time data and information using an array of wireless data transfer protocols.
- The acronym GPS stands for Global Positioning System GPS
  - NAVSTAR = NAVigation System with Timing And Ranging
  - $n \geq 4$ satellites
  - $m \geq 1$ receivers
  - Pseudo-ranges
- Check this out. Downloaded from the Wikipedia page.

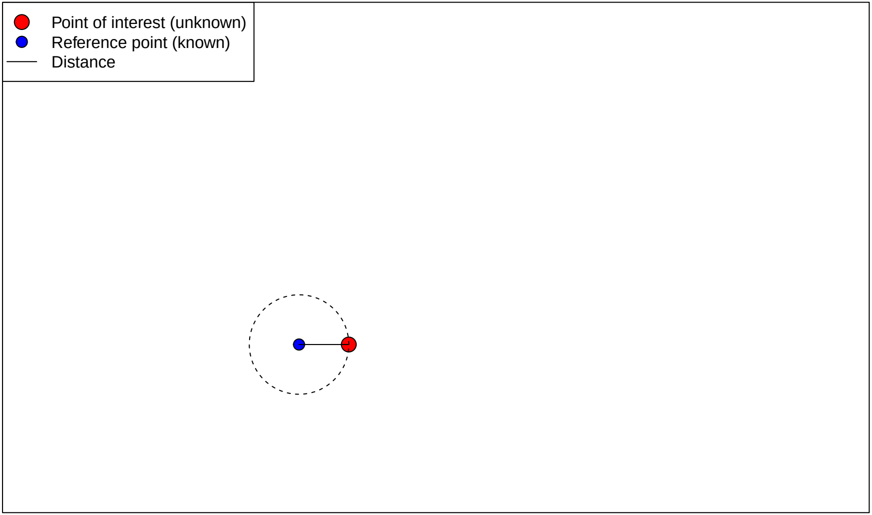
How does positioning with range works?



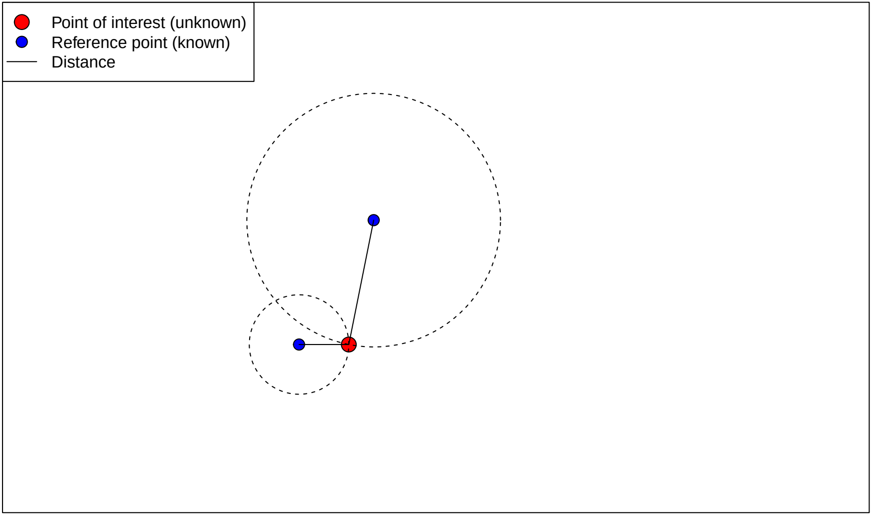
Positioning with ranges



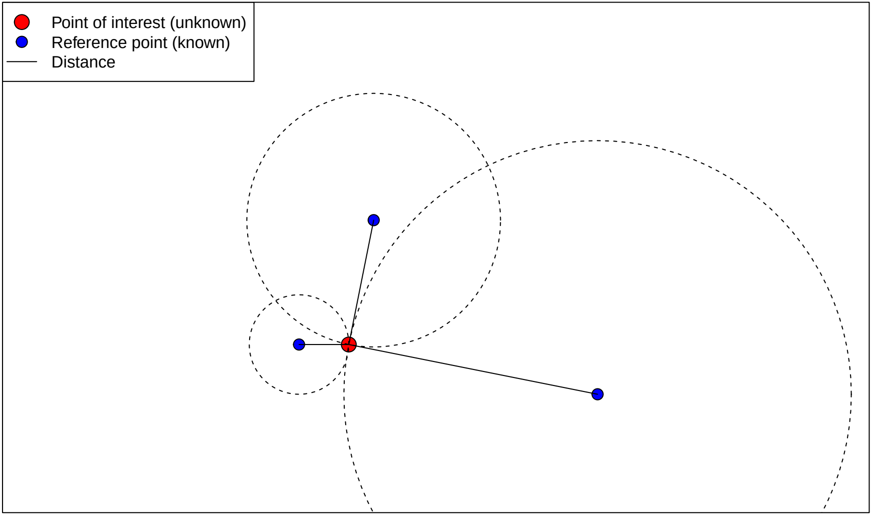
Positioning with ranges



Positioning with ranges



Positioning with ranges



- As you know, distance is a function of time and speed. We can assume with a certain degree of confidence that the speed of our radio signal is fairly constant ($3 * 10^5$Km/s). If our estimate of time is error-prone, the associated estimate of distance may also be affected by errors. That is why the distance is actually called pseudo-distance.
- To minimize this error a forth reference point (satellite) is necessary!
- The GPS receiver knows the position of the satellite because it is the satellite itself that sends it by communicating its orbit in a navigation message (ephemeris)

Movement data

Lagragian data

- Usually we think of and work with movement data where the position of an animal is collected through a device attached to the animal. This device should allow, in principle, to know where the animal is at any time: Lagragian data!
  - Radio tracking
  - Satellite tracking
  - GPS
  - Geo-Locators
- The methods differ mainly in their precision

Eulerian data

- Eulerian methods violate the unbiased sampling assumption in the spatial domain
  - Camera traps
  - RFID Tags
  - Microphon arrays
  - Rings and band
- The data they provide allow often in specific systems quite a reliable reconstruction of paths

What is movement?

- Movement is defined as **locations through time**. We can think of movement as a spatio-temporal object. Therefore, a proper definition of space and time is fundamental to analyse data in the proper way

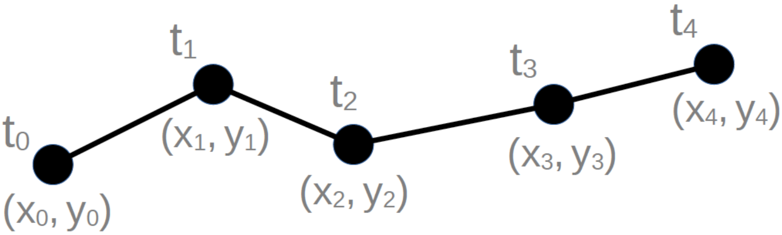


Figure 14: Brief example of how “movement” could be formalized

Space problem

- We have already talked about the space problem...

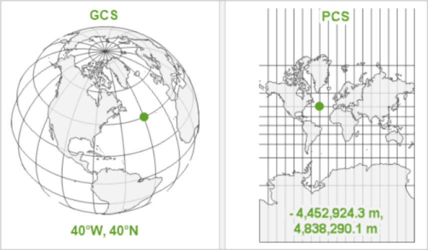


Figure 15: Image from ESRI website

Figure 16: Image from ESRI website

Time problem

- Time settings are crucial
- You need to know what your device uses as time
- Many handheld GPS use and report local time, others use UTC
- Time in R is relatively easy to work with

```r
Sys.time()
```

```
[1] "2025-11-12 06:29:02 CET"
```

```r
(t <- as.POSIXct("2022-09-12 14:00:00",
                 "%Y-%m-%d %H:%M:%S", tz="CET"))
```

```
[1] "2022-09-12 14:00:00 CEST"
```

References

References I

Costa, H., Foody, G., Jiménez, S., & Silva, L. (2015). Impacts of species misidentification on species distribution modeling with presence-only data. *ISPRS International Journal of Geo-Information*, *4*(4), 2496–2518. MDPI AG. Retrieved from https://doi.org/10.3390%2Fijgi4042496

Guisan, A., & Zimmermann, N. E. (2000). Predictive habitat distribution models in ecology. *Ecological Modelling*, *135*(2), 147–186. Retrieved from https://www.sciencedirect.com/science/article/pii/S0304380000003549

Lamb, C. T., Ford, A. T., Proctor, M. F., Royle, J. A., Mowat, G., & Boutin, S. (2019). Genetic tagging in the anthropocene: Scaling ecology from alleles to ecosystems. *Ecological Applications*, *29*(4), e01876. Wiley. Retrieved from https://doi.org/10.1002%2Feap.1876

References II

Waichman, A. (1992). An alphanumeric code for toe clipping amphibians and reptiles. *Herpetological Review*, *23*, 19–21.