# Data 4 Mobility

BIG DATA ARCHITECTURES

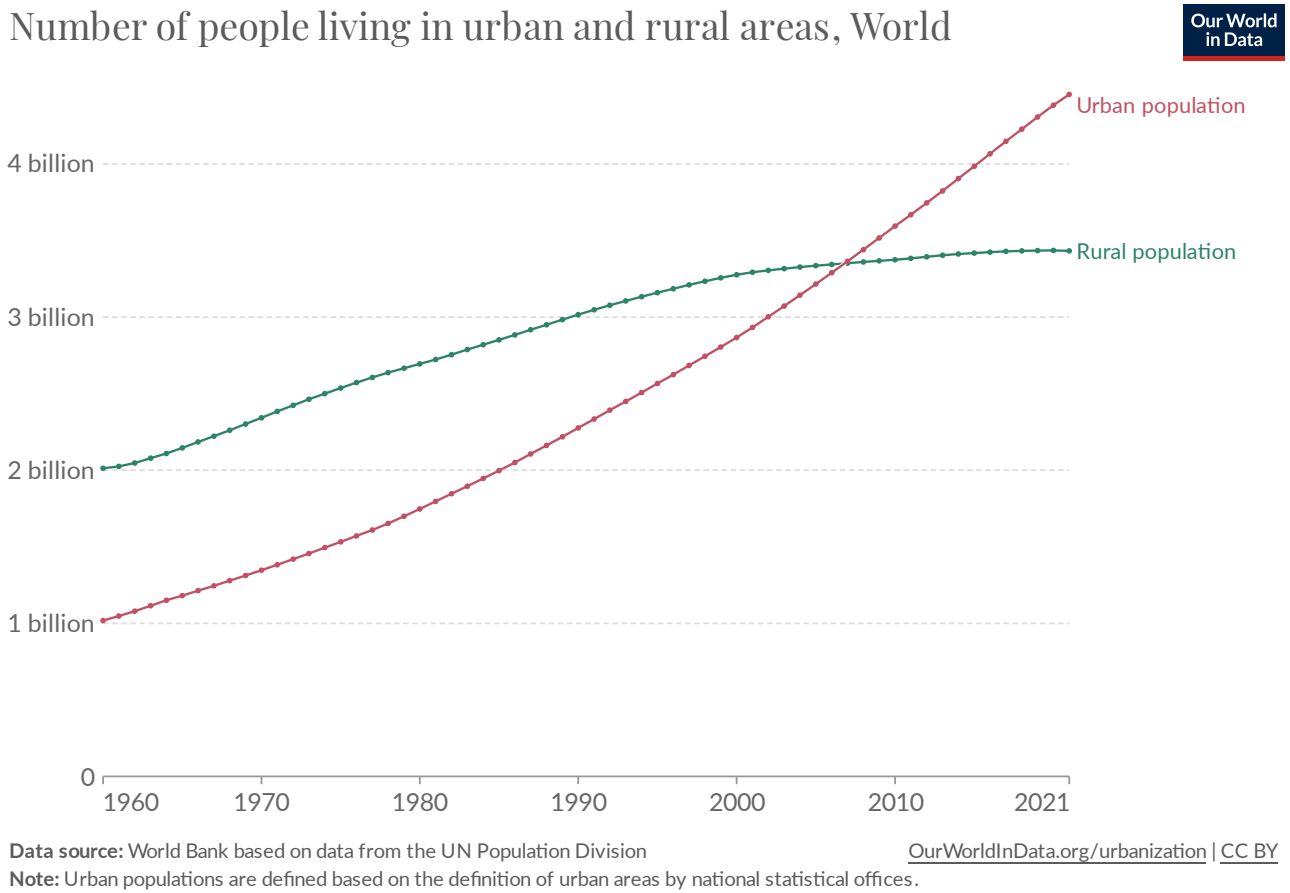
a.a. 2024/2025

Data 4 Mobility

# Introduction

# Urbanization

- Urban population is continuously growing
- Projections indicate that more than two-thirds of the world population will live in highly-dense cities by 2050




Source: https://ourworldindata.org/urbanization

# Urbanization challenges

- Urbanization leads to several challenges
  - Social
  - Environmental
  - Energy
  - Healthcare
  - Infrastructure
  - Mobility and transportation

# Urban mobility

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  - Social
  - Environmental
  - Energy
  - Healthcare
  - Infrastructure
  - **Mobility and transportation**

# Urban mobility – Traffic Congestion

- **Traffic congestion** is a significant challenge in urban areas and leads to
  - delays
  - increased travel times
  - reduced productivity

# Urban mobility – Infrastructure

- Many cities struggle with **limited or outdated infrastructure** to support the growing demand for urban transport:
  - insufficient road capacity
  - inadequate public transport systems
  - lack of cycling and pedestrian infrastructure

# Urban mobility – Environmental Impact

- Urban transport is a significant contributor to **air pollution and greenhouse gas emissions**.
- Private vehicles, particularly those running on fossil fuels, emit pollutants that **harm air quality** and contribute to climate change.

# Urban mobility – Transport Mode Integration

- Fragmented and **poorly integrated transport systems** pose challenges for seamless travel experiences.
- Lack of coordination between **different modes of transport**, such as buses, trains, and bicycles, can result in inconvenient transfers, time-consuming journeys, and reduced efficiency.

# Urban mobility – Affordability, Accessibility

- **Accessibility to affordable transport options** is essential for ensuring equitable mobility within urban areas.
- Limited access to public transport, high fares, and insufficient coverage in certain neighborhoods can lead to **transport poverty and social exclusion**.

# Urban mobility – Safety, Security

- Ensuring the **safety and security of commuters** is a significant challenge in urban transport.
- Issues such as traffic accidents, crime, and harassment can discourage people from using public transport or walking and cycling.

# Urban mobility – Behavioral Change

- Encouraging **behavioral change and shifting travel patterns** from private vehicles to sustainable modes of transport can be challenging.
- Many individuals are accustomed to using **private cars** due to convenience, habit, or lack of viable alternatives.

# Urban mobility – Financial Sustainability

- Developing and maintaining urban transport infrastructure requires significant financial resources.
- Funding constraints can limit the ability of cities to invest in new projects, upgrade existing systems, and ensure ongoing maintenance.
- Exploring innovative financing mechanisms, public-private partnerships, and securing sustainable funding sources are crucial for the long-term financial sustainability of urban transport.

# Urban mobility – Solutions

- Solving the urban mobility challenges requires **multidisciplinary effort**
  - Civil engineering
  - Urban planning
  - Geography
  - Human and social studies
  - Information technologies

# Information technologies for Urban mobility

- IT plays a pivotal role in addressing the urban mobility problem
- A platform is required to enable other experts to work on the mobility problem
- The development of a platform requires three macro-activities
  - **Data** acquisition and modelling
  - Development of **analytical software** to perform reconstruction, prediction, evaluations
  - Development of **graphical interfaces** to show and interact with the system

# Information technologies for Urban mobility

## Monitoring

- **Real-time analysis** of the urban mobility environment using acquired data and produced reconstructions
  - Traffic Flow Reconstruction
  - Public transport quality assessment
  - …
- **Predictive analysis** to observe analytic results on future time windows
- Computation of **Key Performance Indicators** (KPI)
  - SUMI – Sustainable Urban Mobility Indicators
  - PUMS – Piano Urbano di Mobilità Sostenibile

## Planning

- Data, analytics, and KPIs are exploited in **scenarios** with changes w.r.t. the current urban status for **what-if analysis** and **optimizations**

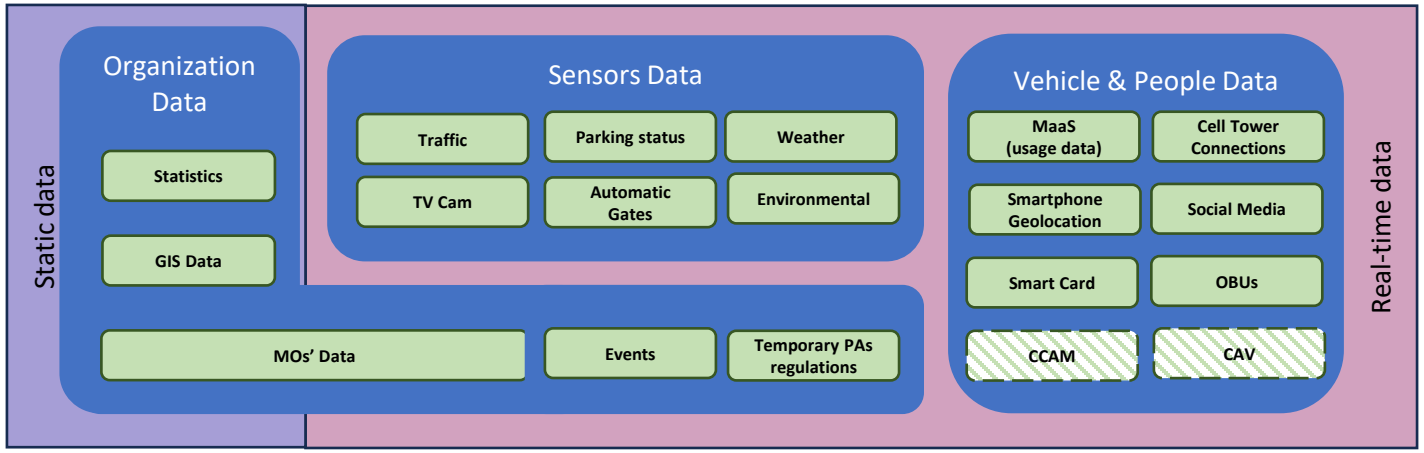
# Which data? In which format?

- We will see an overview of the data required to build a platform for urban mobility management

- We will also discuss about the formats and standards used to distribute such data

# Which data?

- A possible taxonomy of mobility data is to group data **according to their source**
  - Data from public or private organizations
  - Data from IoT sensors
  - Data produced directly by vehicles or people



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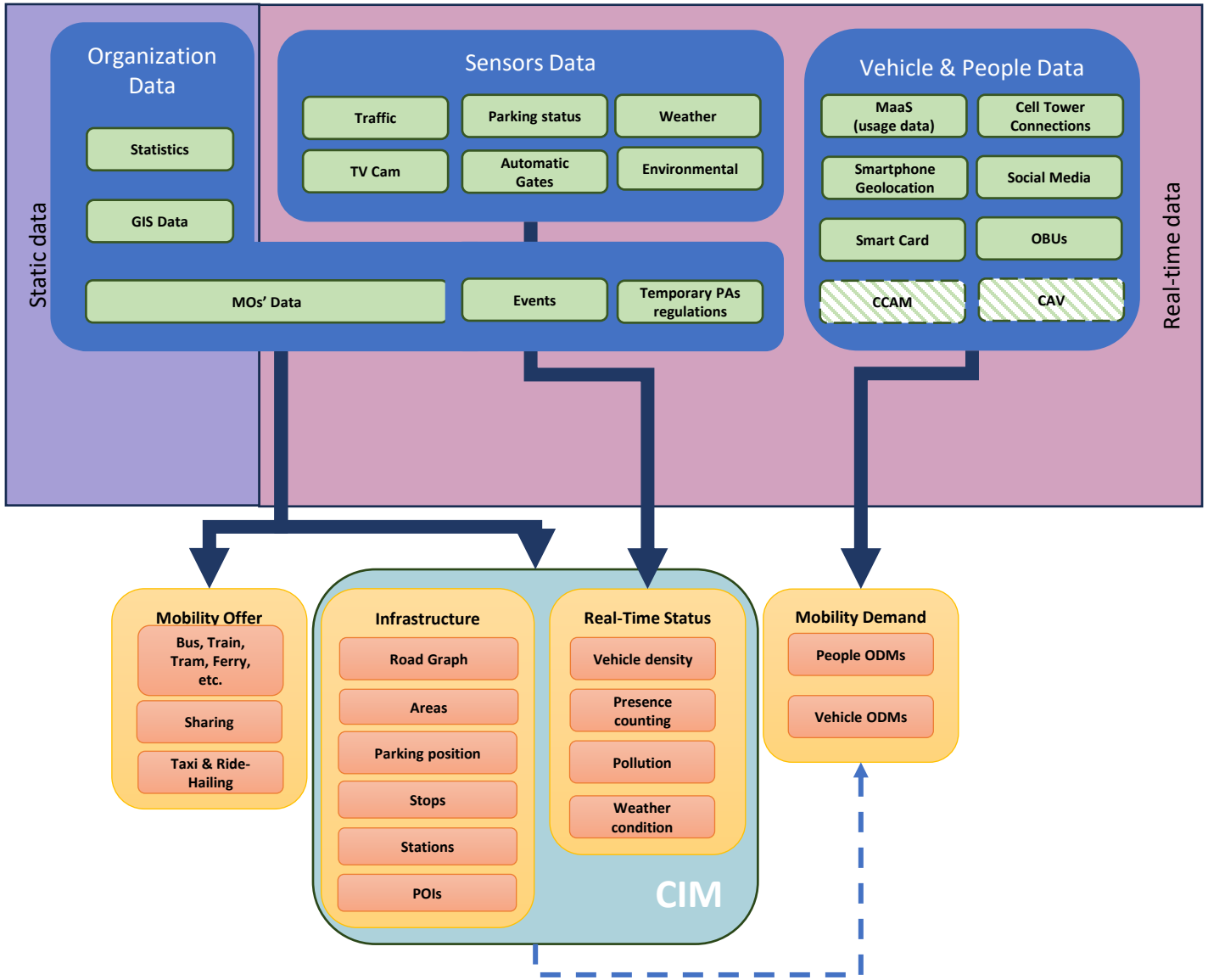
Static data
Organization Data
Statistics
GIS Data
Sensors Data
Traffic
Parking status
Weather
TV Cam
Automatic Gates
Environmental
MOs' Data
Events
Temporary PAs regulations
Vehicle & People Data
MaaS (usage data)
Cell Tower Connections
Smartphone Geolocation
Social Media
Smart Card
OBUs
CCAM
CAV
Real-time data
Mobility Offer
Bus, Train, Tram, Ferry, etc.
Sharing
Taxi & Ride-Hailing
Infrastructure
Road Graph
Areas
Parking position
Stops
Stations
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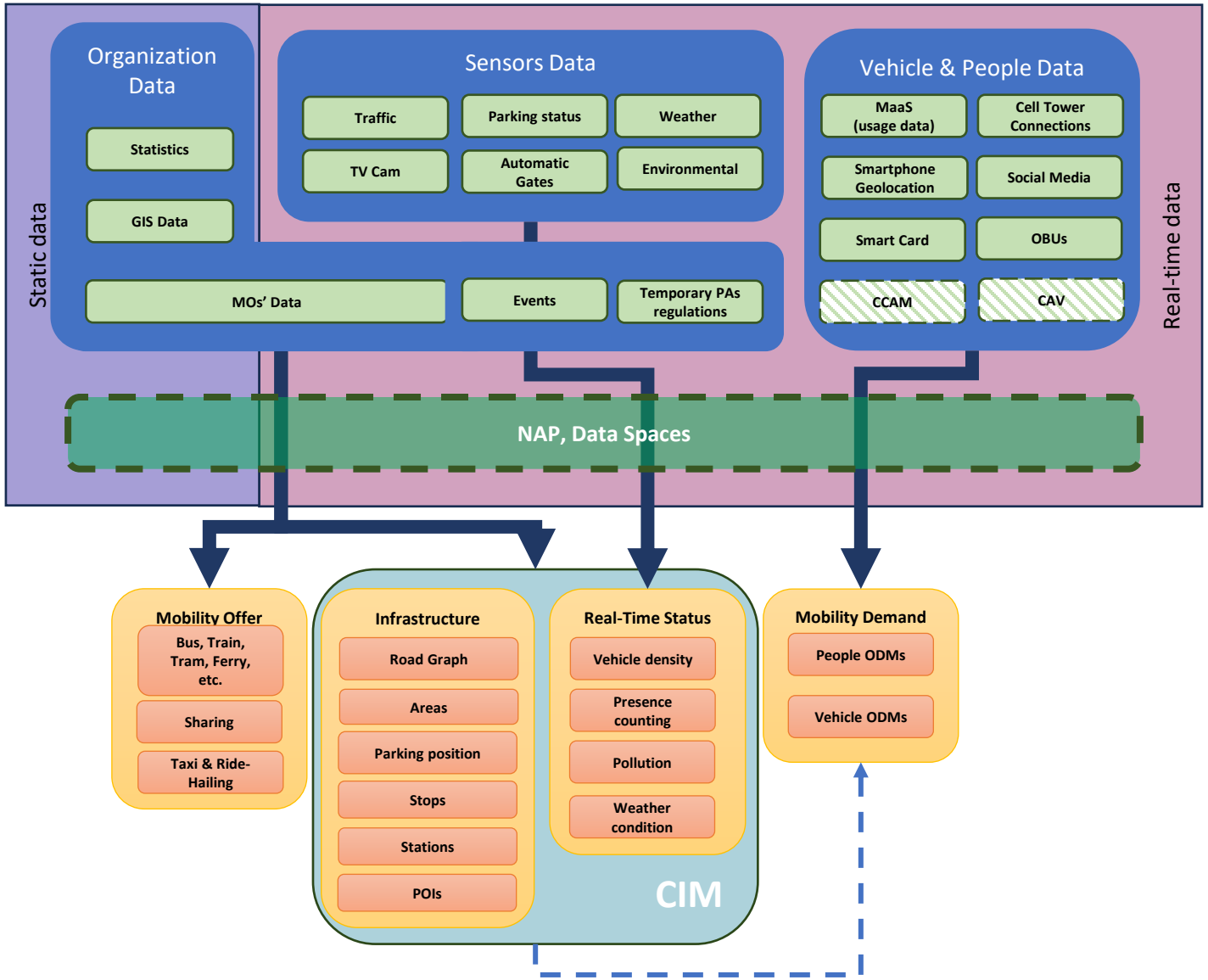
Presence counting
Pollution
Weather condition
CIM
Mobility Demand
People ODMs
Vehicle ODMs

# Which data?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Data 4 Mobility

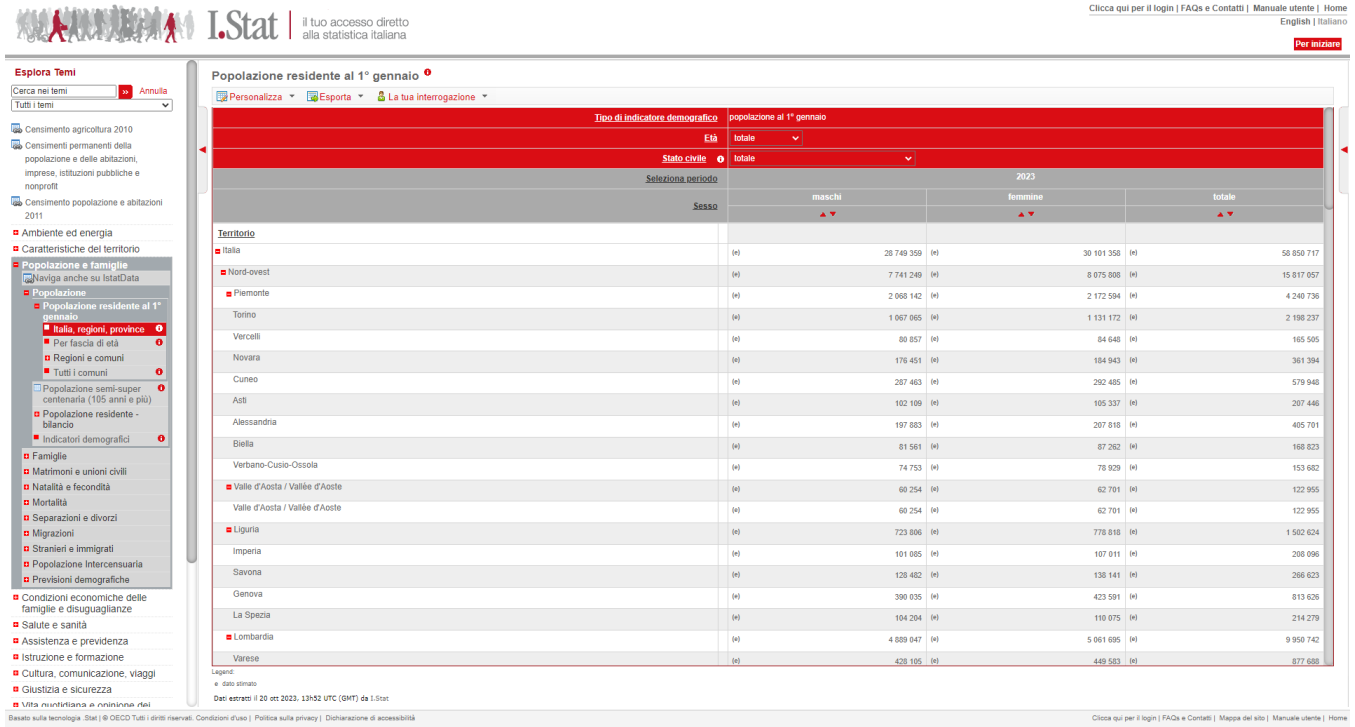
# Organization data

# Statistics

- Statistical data include surveys, reports, census information
- Can be used to obtain a description of the
  - Population, according to gender, age, wealth
  - Vehicle models, motorizations, registration dates
  - Distribution of urban services
  - …
- Statistics are particularly useful to compute the KPIs (e.g., how many people have a bus stop at less than 100m from their home?)
- Statistical data are mainly distributed by national institute of statistics

# Statistics

- In Italy we can use the ISTAT portal (https://www.istat.it/)
- The portal I.Stat (http://dati.istat.it/) let to search and download data about different categories



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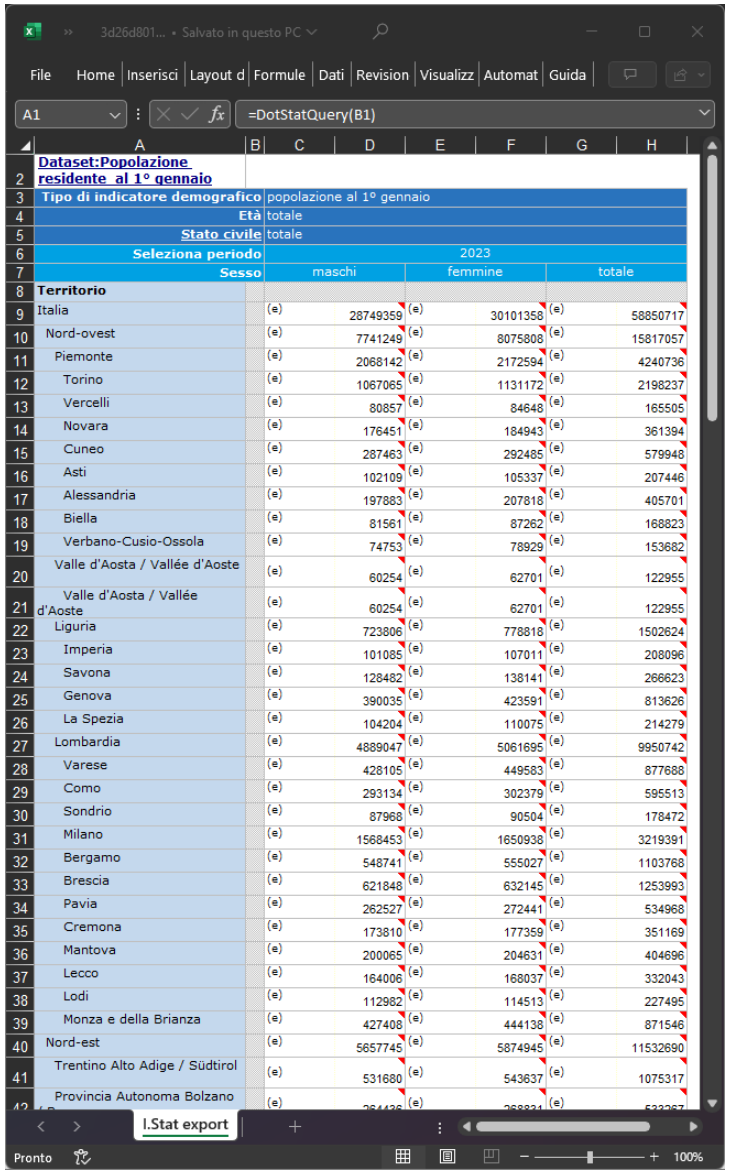
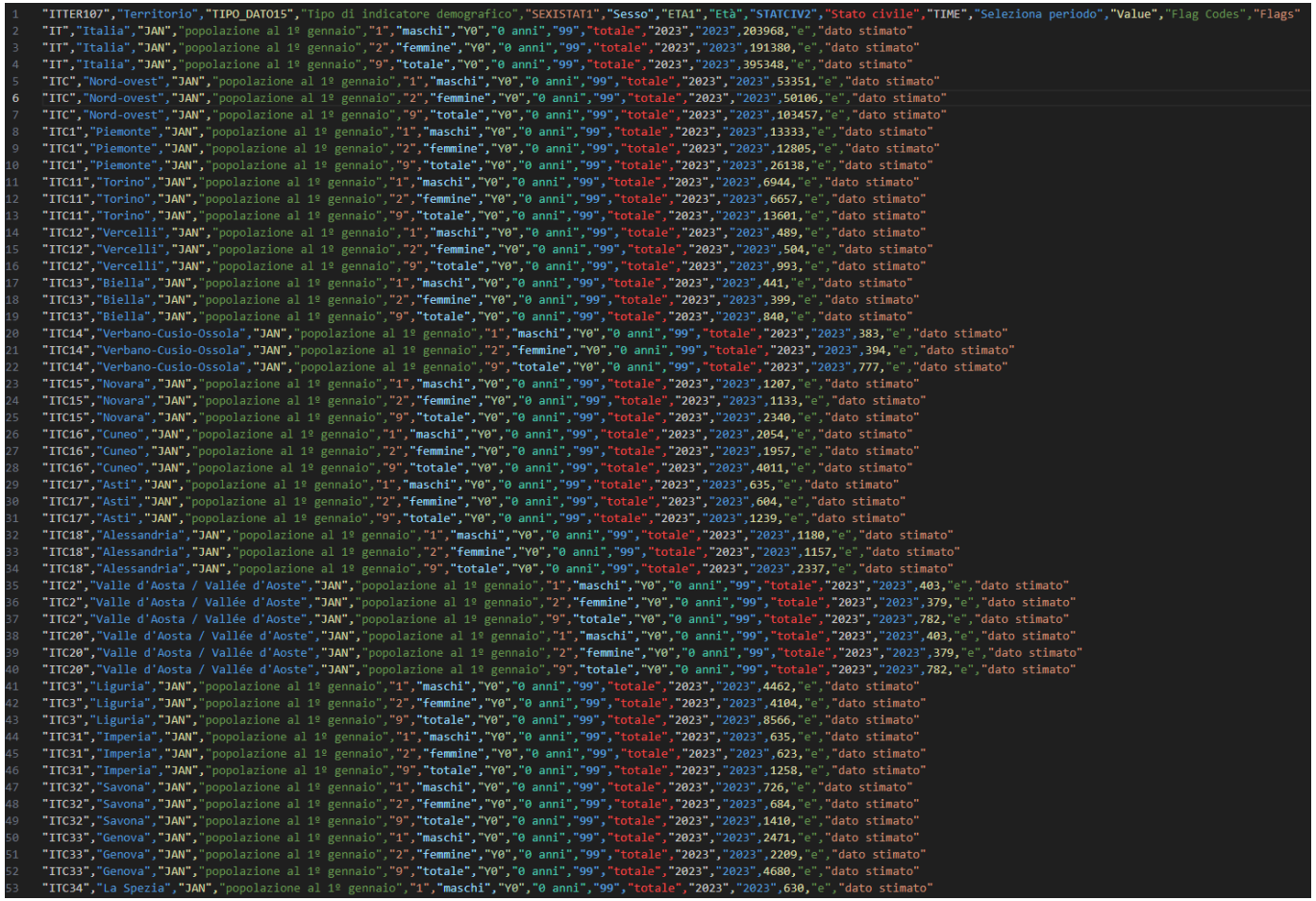


| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 2 | Dataset:Popolazione residente al 1° gennaio | | | | | | | |
| 3 | Tipo di indicatore demografico | popolazione al 1° gennaio | | | | | | |
| 4 | Età | totale | | | | | | |
| 5 | Stato civile | totale | | | | | | |
| 6 | Seleziona periodo | 2023 | | | | | | |
| 7 | Sesso | maschi | | femmine | | totale | | |
| 8 | Territorio | | | | | | | |
| 9 | Italia | (e) | 28749359 | (e) | 30101358 | (e) | 58850717 | |
| 10 | Nord-ovest | (e) | 7741249 | (e) | 8075808 | (e) | 15817057 | |
| 11 | Piemonte | (e) | 2068142 | (e) | 2172594 | (e) | 4240736 | |
| 12 | Torino | (e) | 1067065 | (e) | 1131172 | (e) | 2198237 | |
| 13 | Vercelli | (e) | 80857 | (e) | 84648 | (e) | 165505 | |
| 14 | Novara | (e) | 176451 | (e) | 184943 | (e) | 361394 | |
| 15 | Cuneo | (e) | 287463 | (e) | 292485 | (e) | 579948 | |
| 16 | Asti | (e) | 102109 | (e) | 105337 | (e) | 207446 | |
| 17 | Alessandria | (e) | 197883 | (e) | 207818 | (e) | 405701 | |
| 18 | Biella | (e) | 81561 | (e) | 87262 | (e) | 168823 | |
| 19 | Verbano-Cusio-Ossola | (e) | 74753 | (e) | 78929 | (e) | 153682 | |
| 20 | Valle d'Aosta / Vallée d'Aoste | (e) | 60254 | (e) | 62701 | (e) | 122955 | |
| 21 | Valle d'Aosta / Vallée d'Aoste | (e) | 60254 | (e) | 62701 | (e) | 122955 | |
| 22 | Liguria | (e) | 723806 | (e) | 778818 | (e) | 1502624 | |
| 23 | Imperia | (e) | 101085 | (e) | 107011 | (e) | 208096 | |
| 24 | Savona | (e) | 128482 | (e) | 138141 | (e) | 266623 | |
| 25 | Genova | (e) | 390035 | (e) | 423591 | (e) | 813626 | |
| 26 | La Spezia | (e) | 104204 | (e) | 110075 | (e) | 214279 | |
| 27 | Lombardia | (e) | 4889047 | (e) | 5061695 | (e) | 9950742 | |
| 28 | Varese | (e) | 428105 | (e) | 449583 | (e) | 877688 | |
| 29 | Como | (e) | 293134 | (e) | 302379 | (e) | 595513 | |
| 30 | Sondrio | (e) | 87968 | (e) | 90504 | (e) | 178472 | |
| 31 | Milano | (e) | 1568453 | (e) | 1650938 | (e) | 3219391 | |
| 32 | Bergamo | (e) | 548741 | (e) | 555027 | (e) | 1103768 | |
| 33 | Brescia | (e) | 621848 | (e) | 632145 | (e) | 1253993 | |
| 34 | Pavia | (e) | 262527 | (e) | 272441 | (e) | 534968 | |
| 35 | Cremona | (e) | 173810 | (e) | 177359 | (e) | 351169 | |
| 36 | Mantova | (e) | 200065 | (e) | 204631 | (e) | 404696 | |
| 37 | Lecco | (e) | 164006 | (e) | 168037 | (e) | 332043 | |
| 38 | Lodi | (e) | 112982 | (e) | 114513 | (e) | 227495 | |
| 39 | Monza e della Brianza | (e) | 427408 | (e) | 444138 | (e) | 871546 | |
| 40 | Nord-est | (e) | 5657745 | (e) | 5874945 | (e) | 11532690 | |
| 41 | Trentino Alto Adige / Südtirol | (e) | 531680 | (e) | 543637 | (e) | 1075317 | |
| 42 | Provincia Autonoma Bolzano | (e) | | (e) | | (e) | | |

# Statistics

- Data can be exported in different formats
  - Microsoft Excel
  - **CSV**



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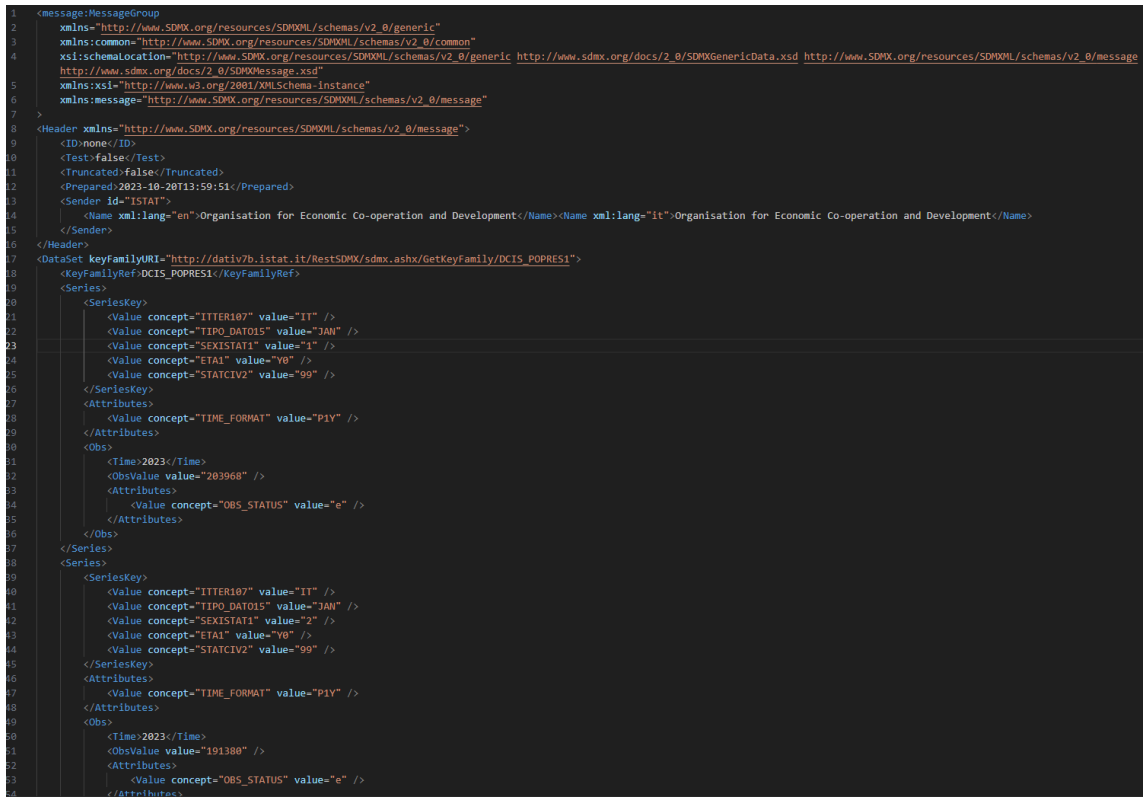
```

# Statistics

- Data can be exported in different formats
  - Microsoft Excel
  - CSV
  - **SDMX** (Statistical Data and Metadata eXchange),
    - see https://sdmx.org/
    - ISTAT seems to implement the SDMX-ML based on XML



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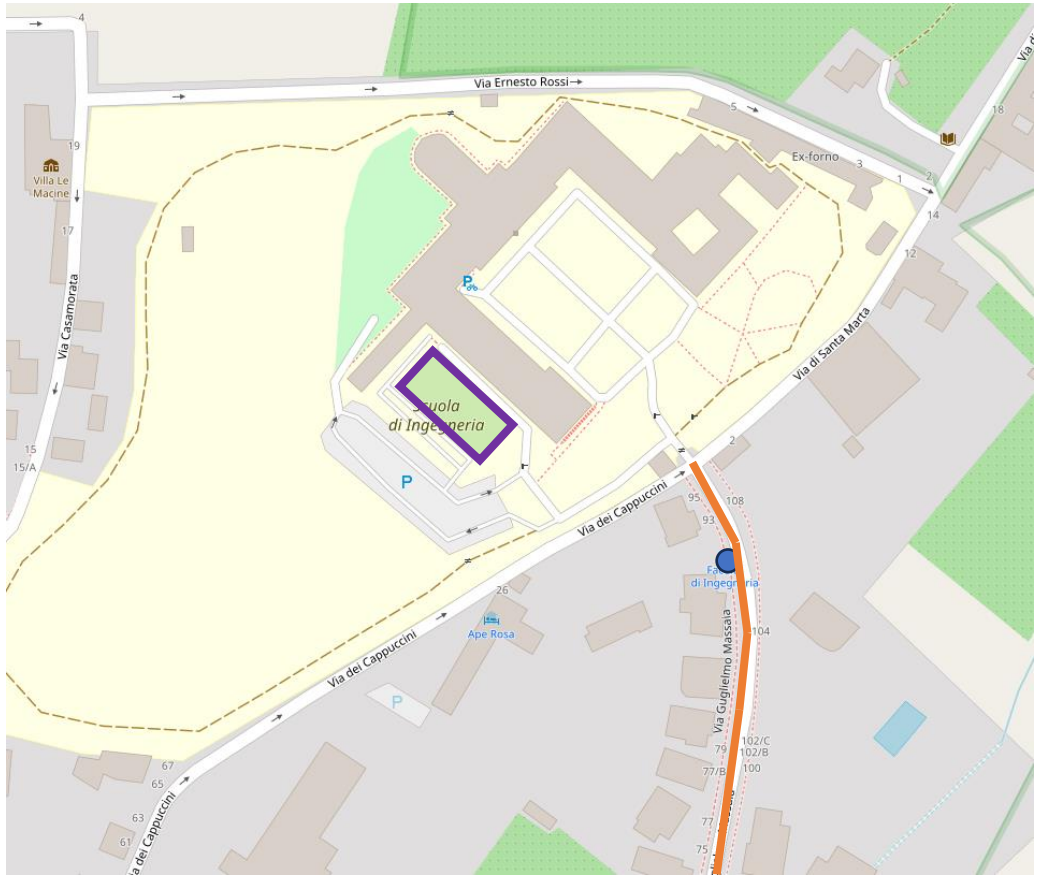

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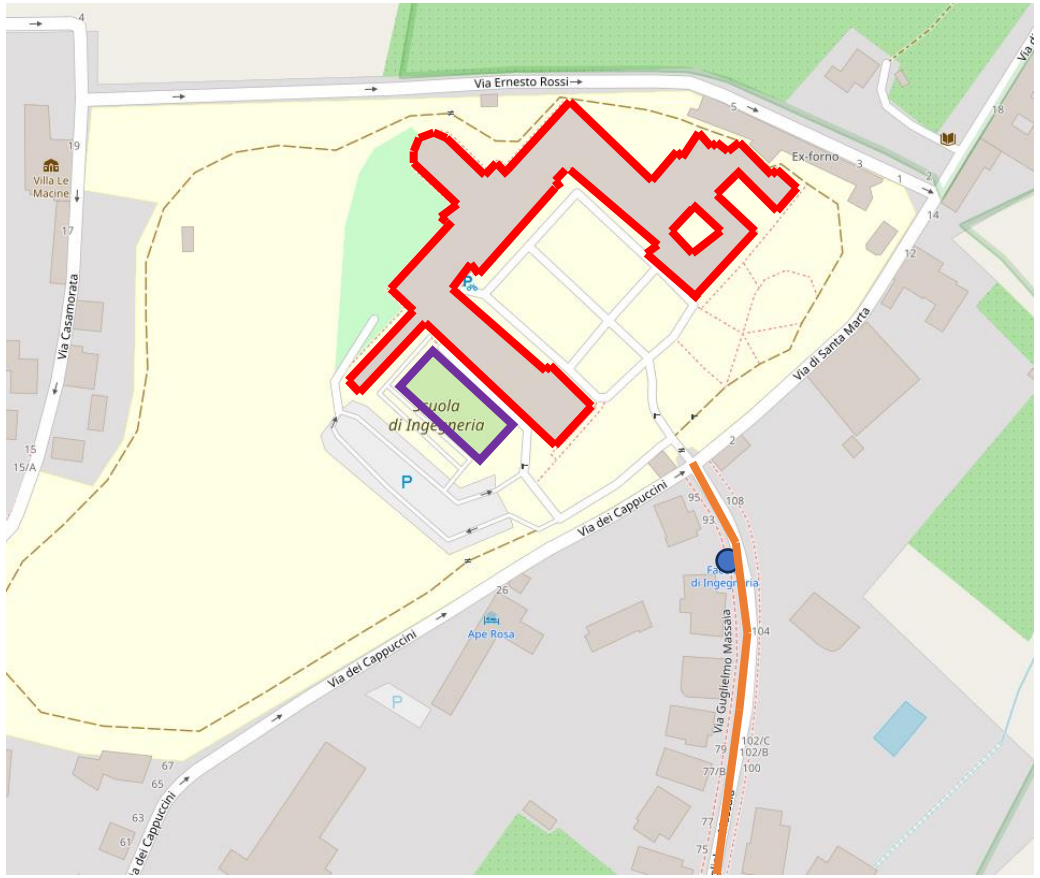
    - **Line**
    - **Polygon**
    - **Multi-polygon**



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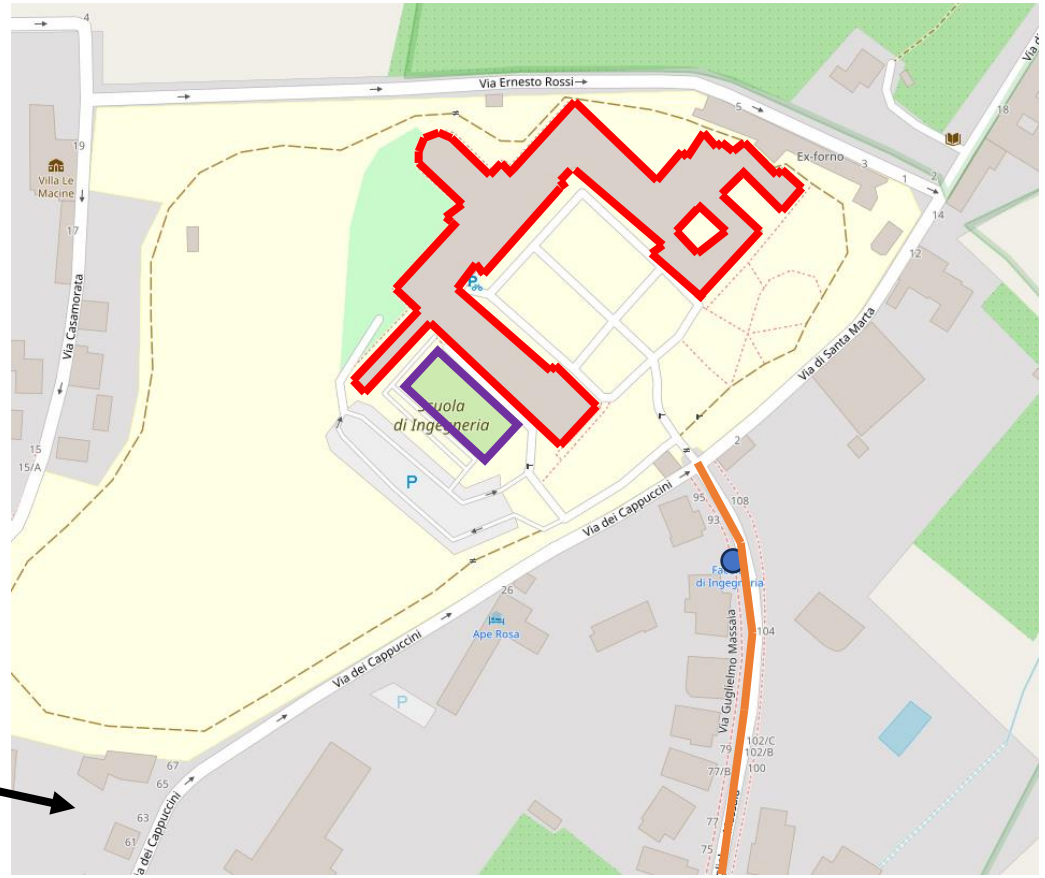
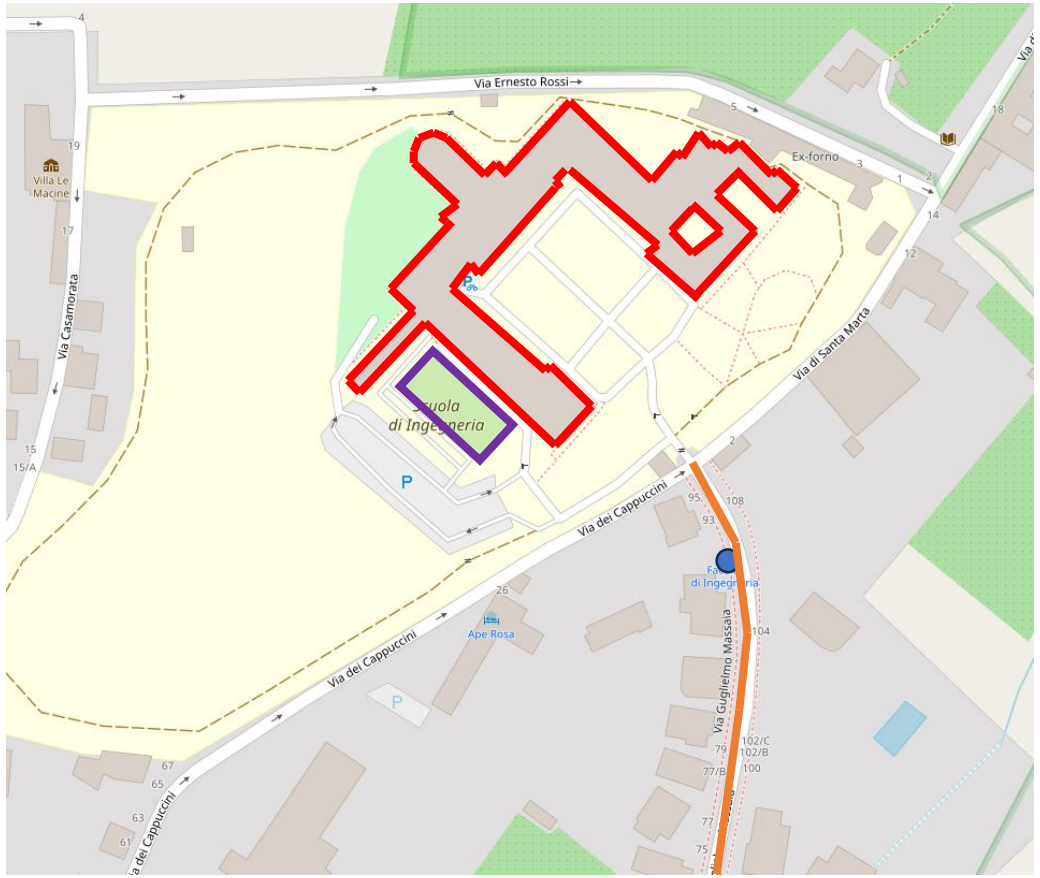
    - **Line**
    - **Polygon**
    - **Multi-polygon**
  - **Raster data**: images with localization information



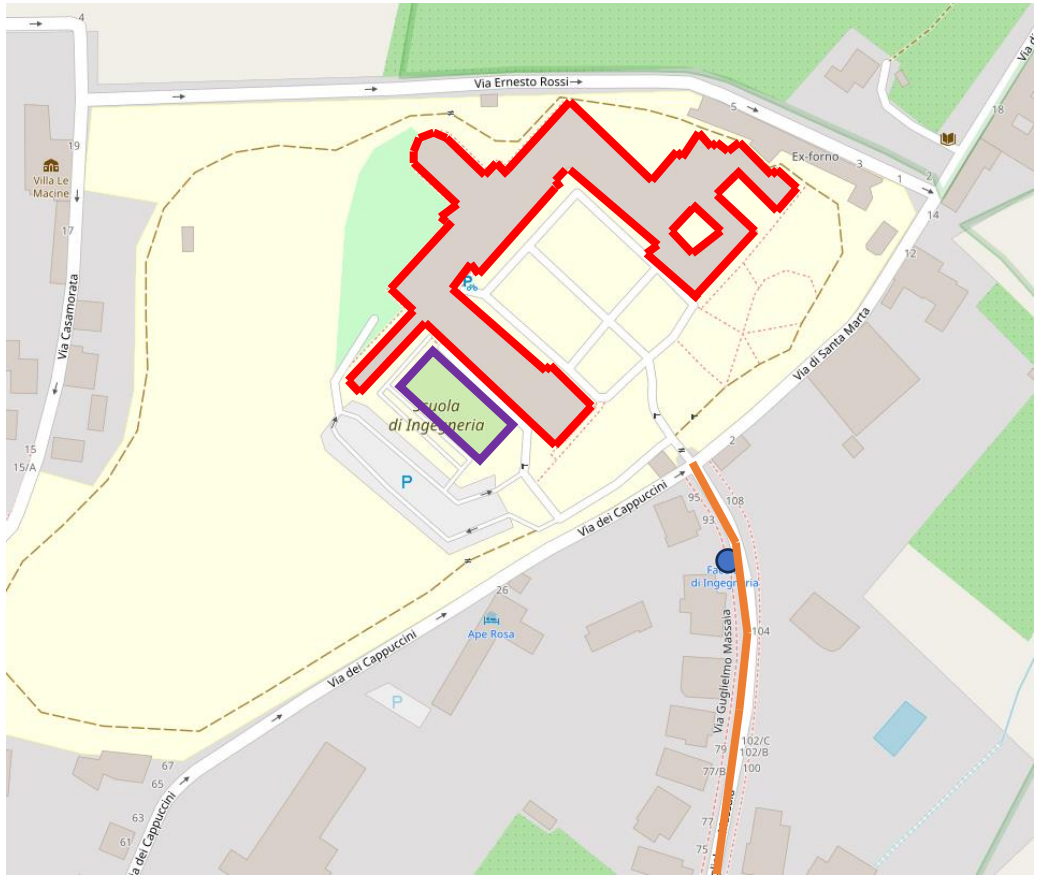
# GIS Data – Vectors

- GIS data are used to represent and describe the infrastructures
  - **Roads** represented as line segments



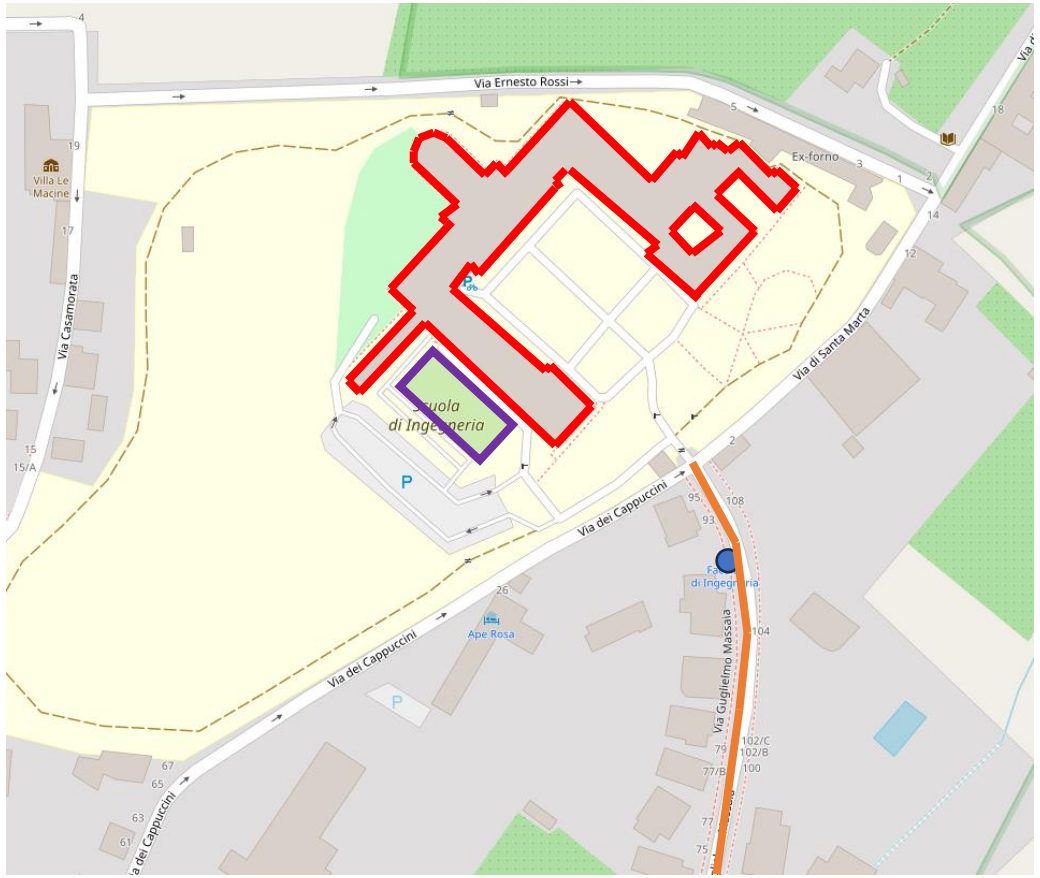
# GIS Data – Vectors

- GIS data are used to represent and describe the infrastructures
  - **Roads** represented as line segments
  - **Areas** represented as polygons



# GIS Data – Vectors

- GIS data are used to represent and describe the infrastructures
  - **Roads** represented as line segments
  - **Areas** represented as polygons
  - **Building ground shapes** represented as polygons or multi-polygons



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- GIS data are used to represent and describe the infrastructures
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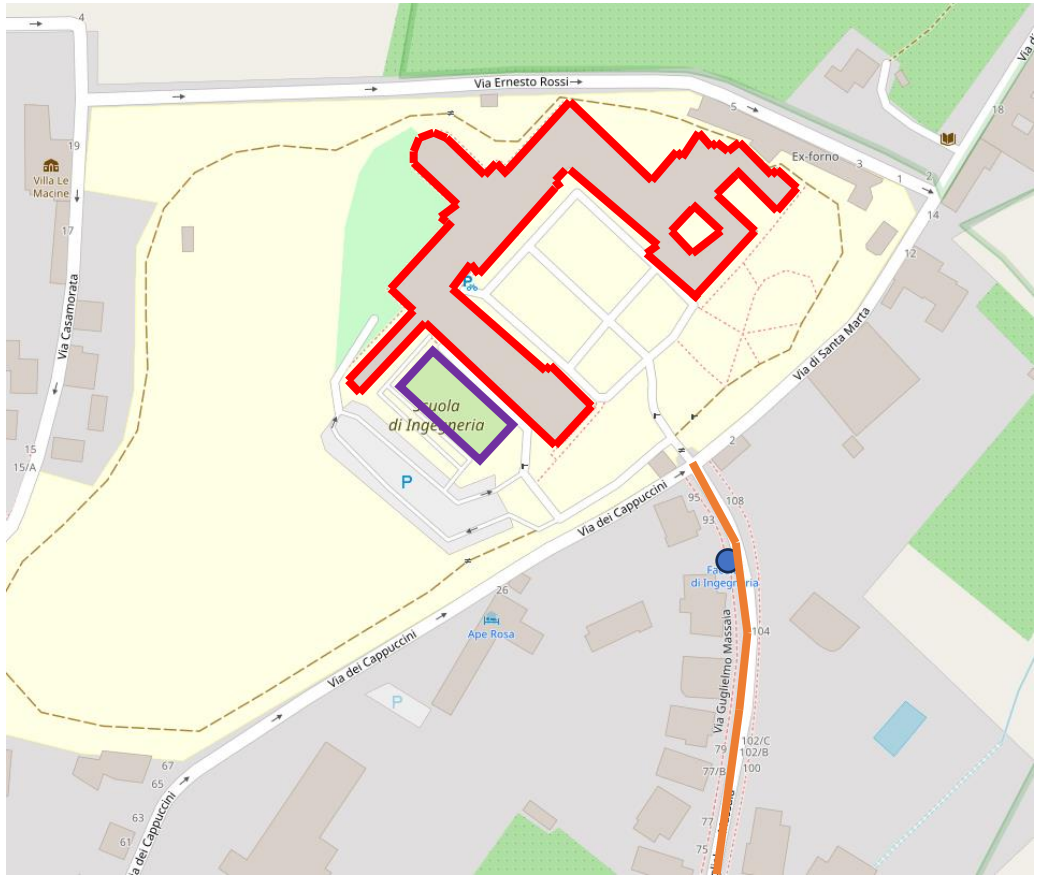
  - **Areas** represented as polygons
  - **Building ground shapes** represented as polygons or multi-polygons
  - **Traffic signs** and **traffic lights** as points



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- GIS data are used to represent and describe the infrastructures
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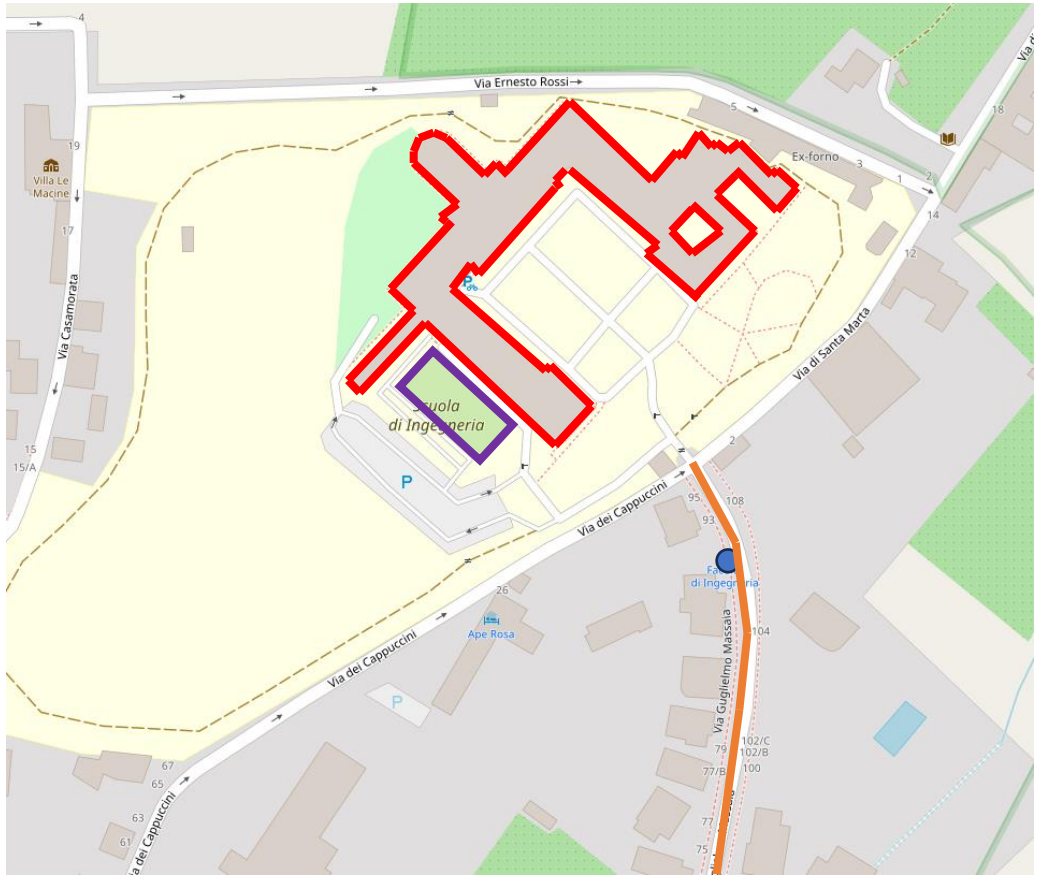
  - **Traffic signs** and **traffic lights** as points
  - **Point of Interest** (POI) as point



# GIS Data – Vectors

- GIS data are used to represent and describe the infrastructures
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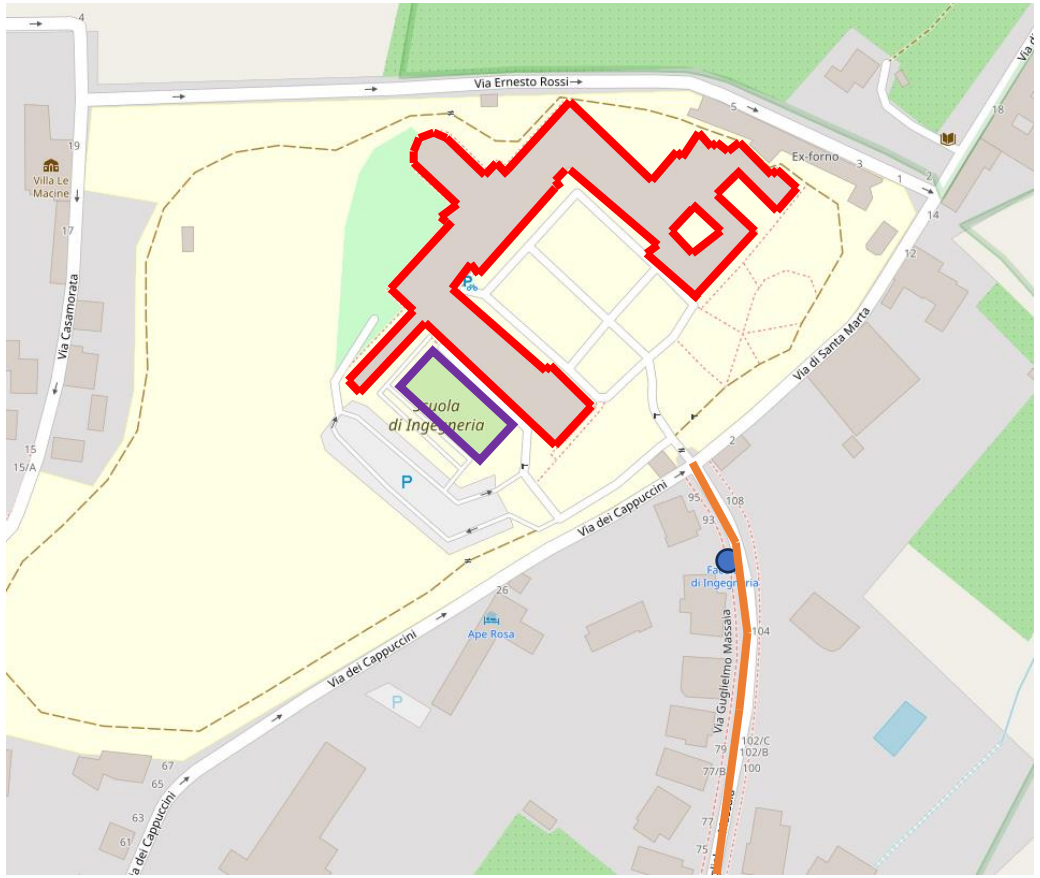
  - **Areas** represented as polygons
  - **Building ground shapes** represented as polygons or multi-polygons
  - **Traffic signs** and **traffic lights** as points
  - **Point of Interest** (POI) as point
  - **Parking** as points or polygons



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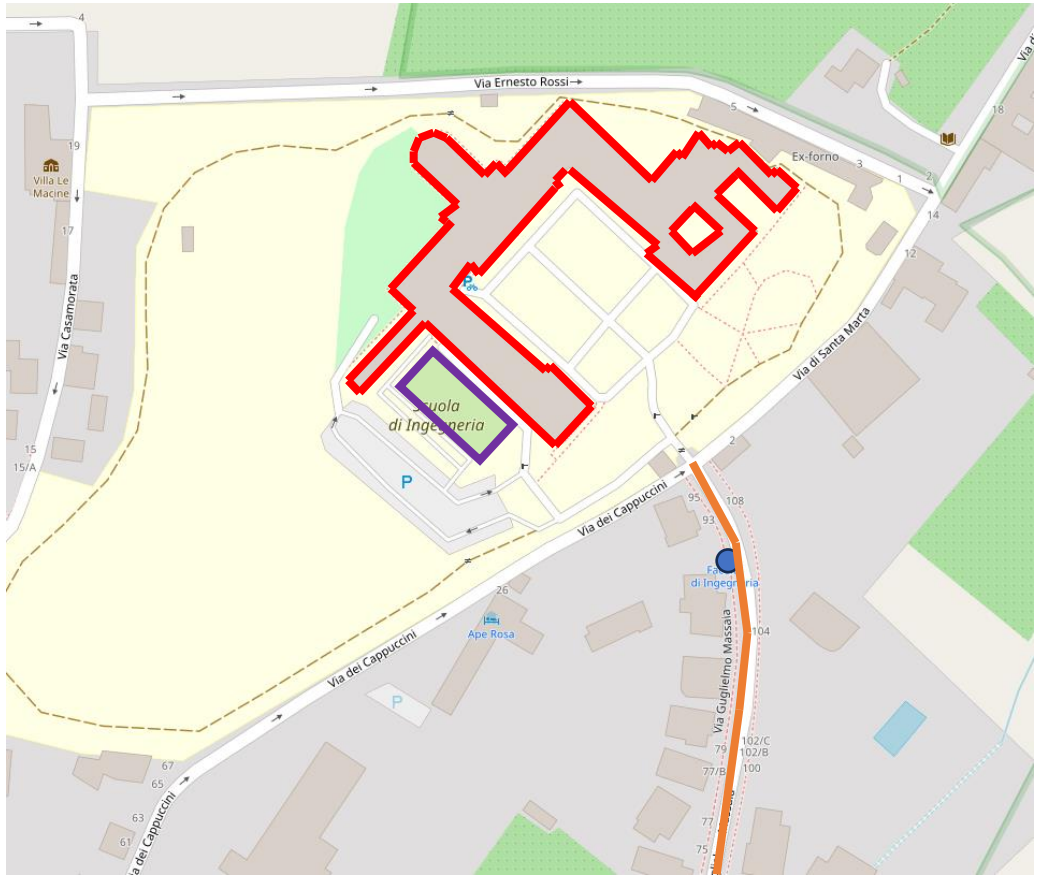
  - **…**



# GIS Data – Raster

- GIS data are used to represent and describe the infrastructures
  - **Ground maps**

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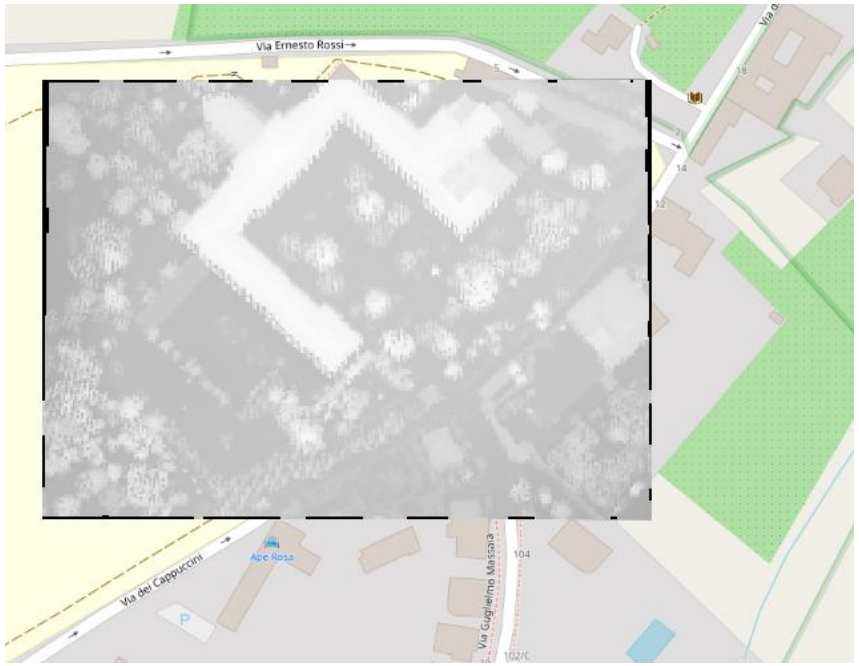
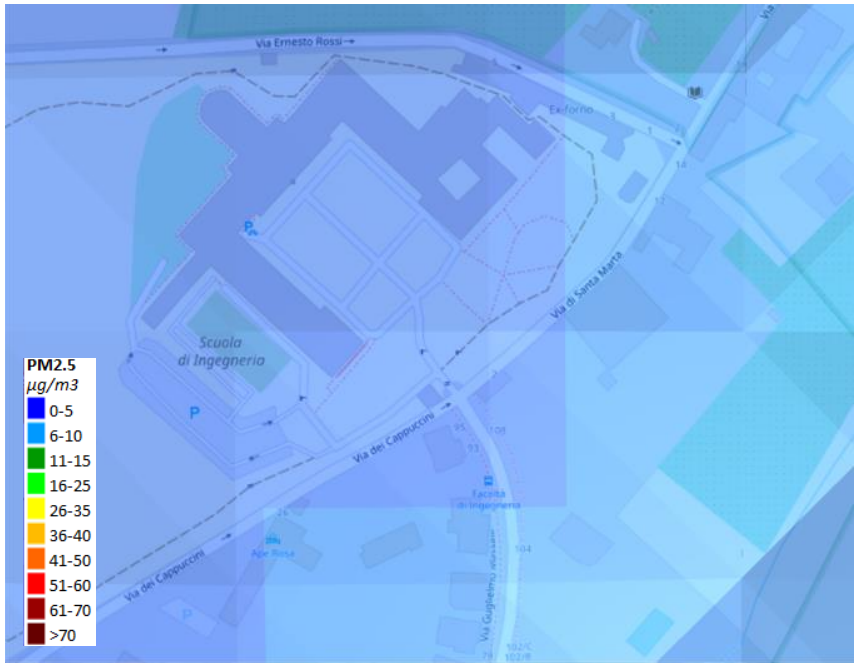
- GIS data are used to represent and describe the infrastructures
  - **Ground maps**, of different kinds
  - **Aerial/satellite photos (orthomaps)**
  - **Elevation maps**



# GIS Data – Raster

- GIS data are used to represent and describe the infrastructures
  - **Ground maps**, of different kinds
  - **Aerial/satellite photos (orthomaps)**
  - **Elevation maps**
  - **Heatmaps**



# GIS Data – OSM

- GIS data can be retrieved from different services
- OpenStreetMap (https://www.openstreetmap.org/) is one of the most complete and updated source

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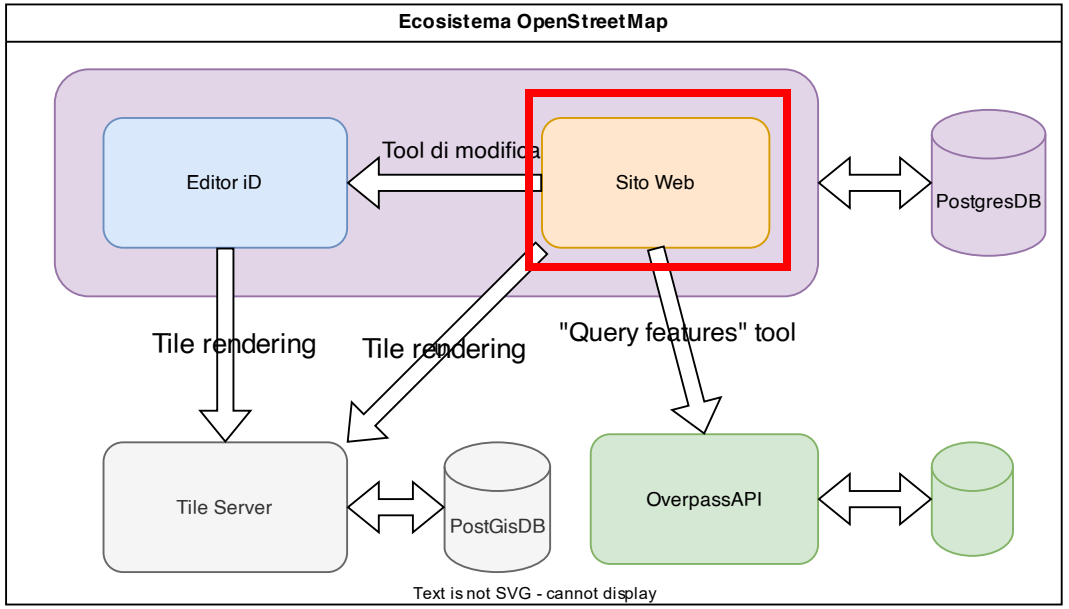

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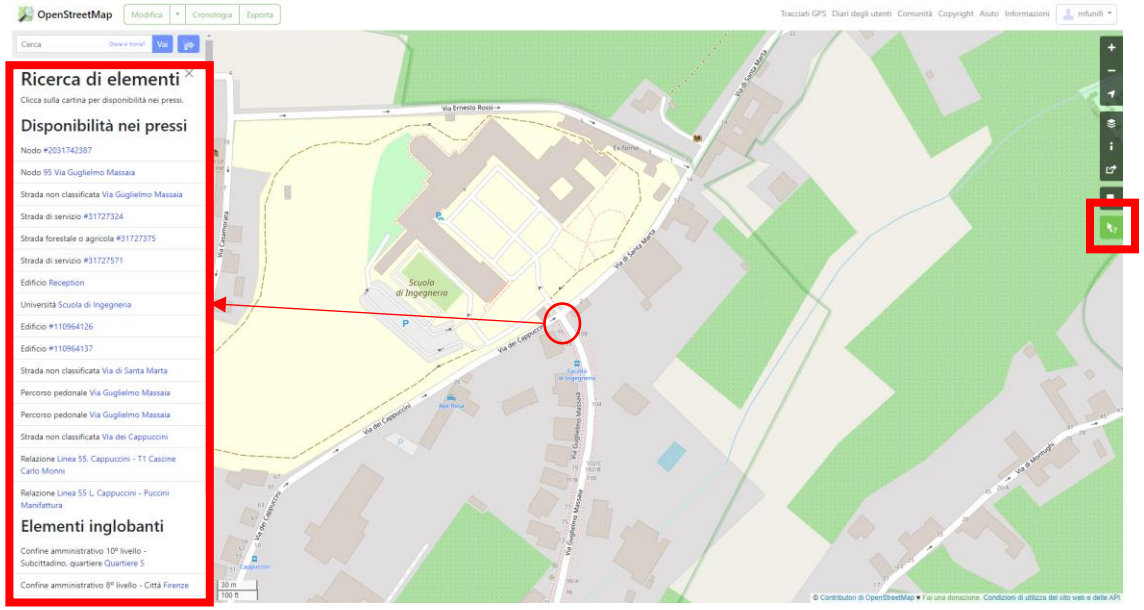


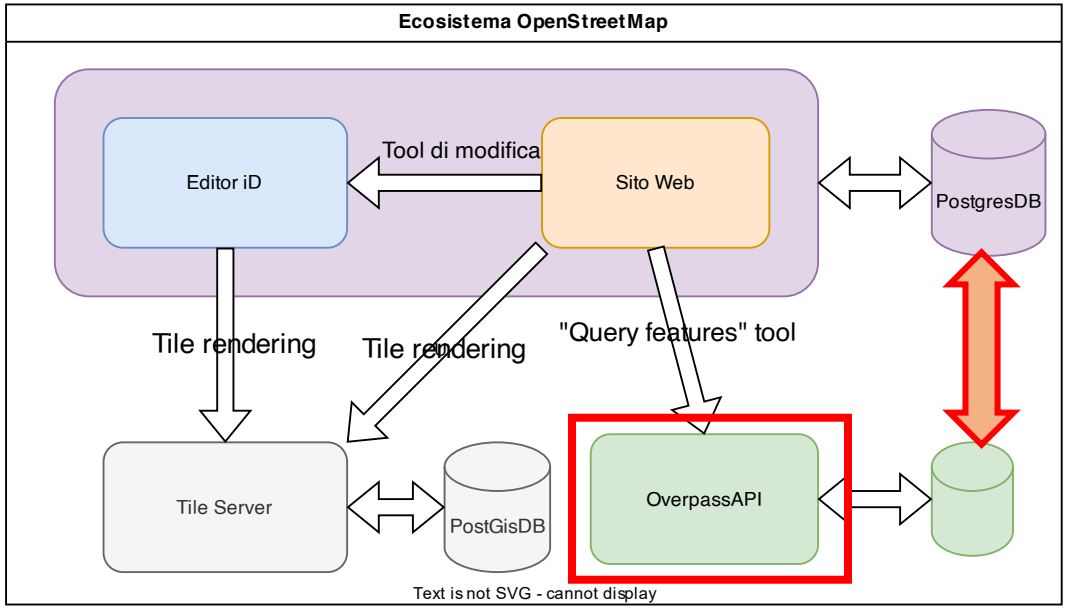

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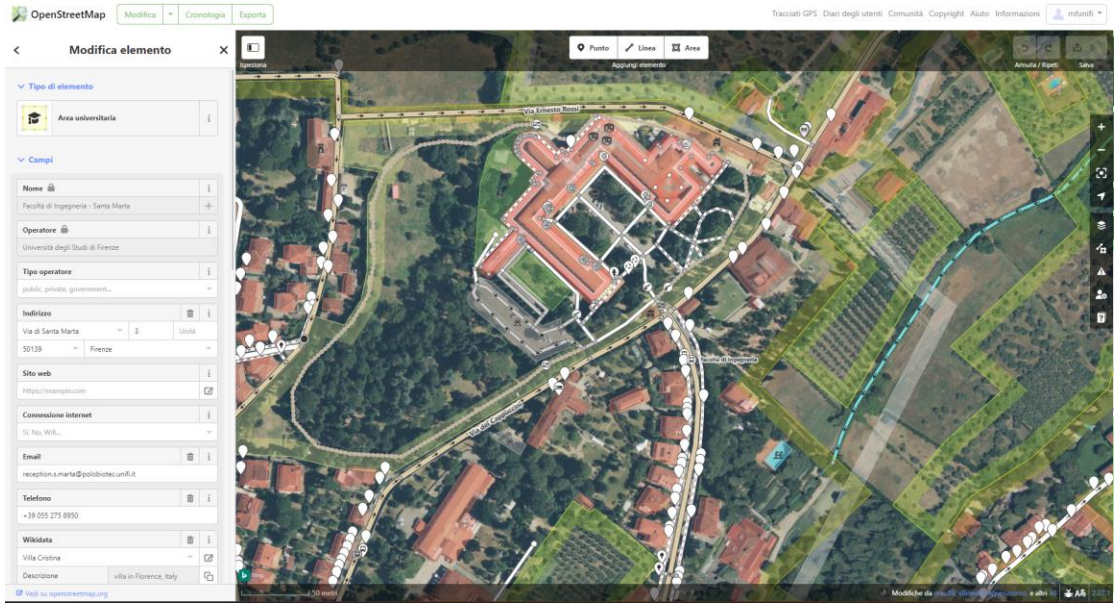


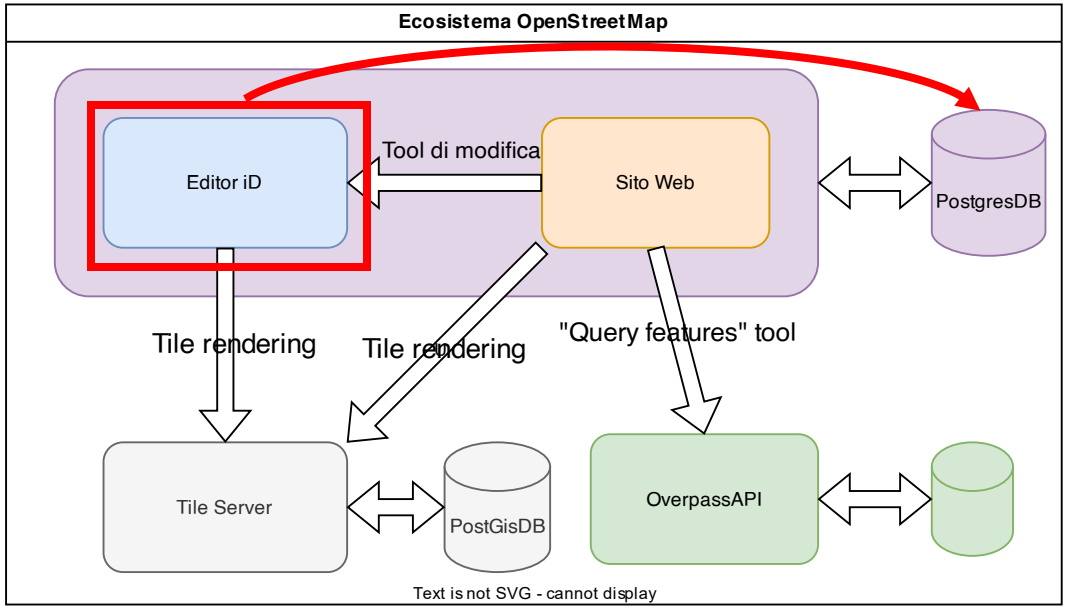

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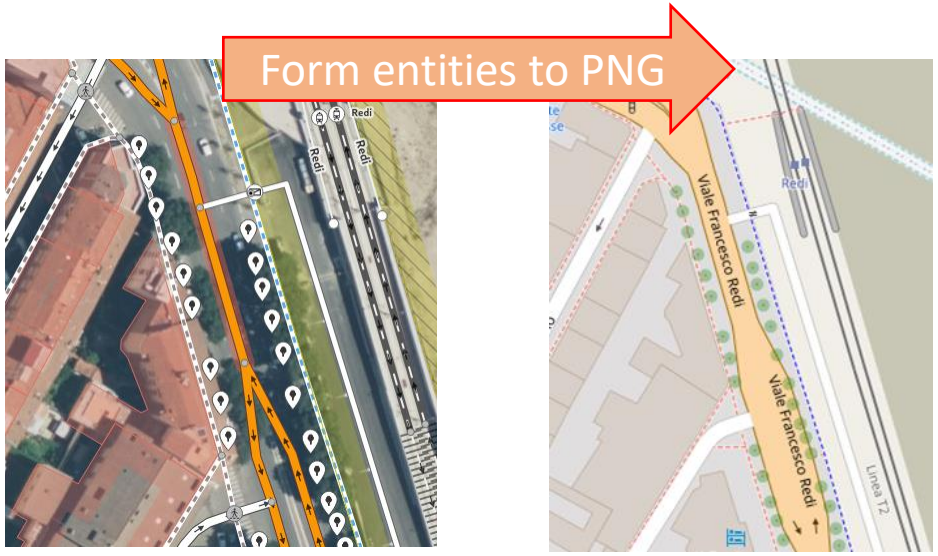


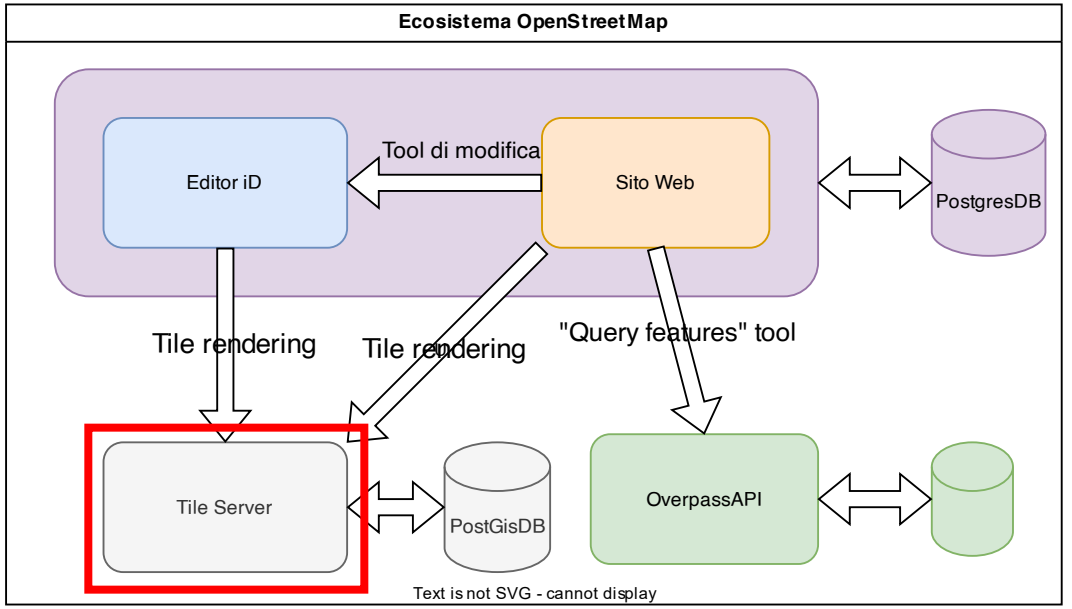

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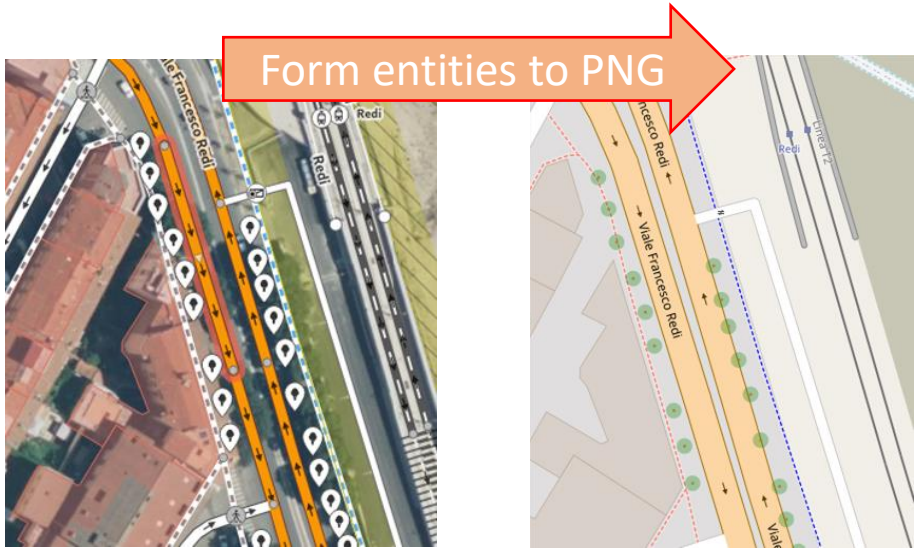
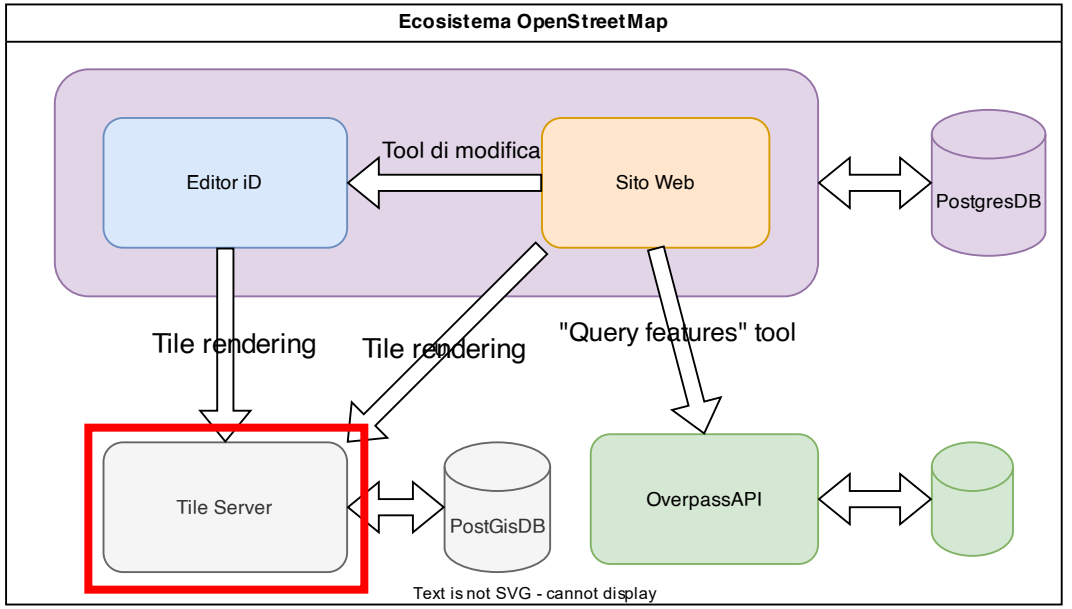
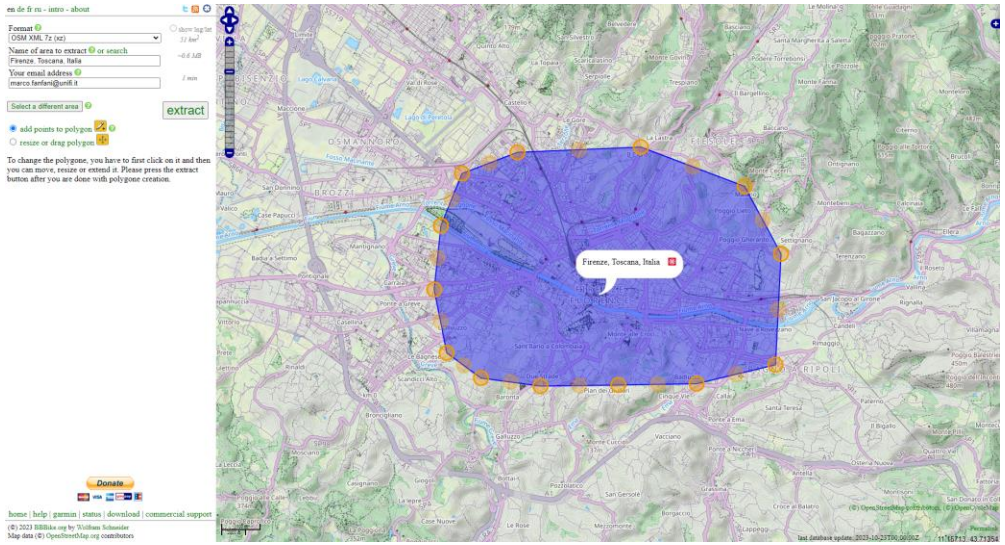


# GIS Data – OSM

- GIS data can be retrieved from different services
- OpenStreetMap (https://www.openstreetmap.org/) is one of the most complete and updated source
- Data from OSM DB can be exported using web services:
  - Geofabrik (https://download.geofabrik.de/)
  - HOT Export Tool (https://export.hotosm.org/)
  - BBBike (https://download.bbbike.org/osm/)



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  - Nodes

```xml
<node id="1533919" lat="43.7958032" lon="11.2447127" version="1">
    <tag k="crossing" v="zebra"/>
    <tag k="crossing:island" v="no"/>
    <tag k="crossing:markings" v="yes"/>
    <tag k="highway" v="crossing"/>
    <tag k="tactile_paving" v="no"/>
</node>
```

# GIS Data – Vector formats

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- The preferred format is the XML OSM standard. It includes descriptions of
  - Nodes
  - Ways

```
<node id="1533919" lat="43.7958032" lon="11.2447127" version="1">
    <tag k="crossing" v="zebra"/>
    <tag k="crossing:island" v="no"/>
    <tag k="crossing:markings" v="yes"/>
    <tag k="highway" v="crossing"/>
    <tag k="tactile_paving" v="no"/>
</node>
```

```
<way id="111566019" version="1">
    <nd ref="266934805"/>
    <nd ref="8256676004"/>
    <nd ref="2473224"/>
    <tag k="cycleway" v="track"/>
    <tag k="highway" v="primary"/>
    <tag k="lanes" v="3"/>
    <tag k="name" v="Viale Giacomo Matteotti"/>
    <tag k="oneway" v="yes"/>
    <tag k="surface" v="asphalt"/>
</way>
```

# GIS Data – Vector formats

- OSM data can be obtained in different formats
- The preferred format is the XML OSM standard. It includes descriptions of
  - Nodes
  - Ways
  - Relations

```
<node id="1533919" lat="43.7958032" lon="11.24
    <tag k="crossing" v="zebra"/>
    <tag k="crossing:island" v="no"/>
    <tag k="crossing:markings" v="yes"/>
    <tag k="highway" v="crossing"/>
    <tag k="tactile_paving" v="no"/>
</node>
```

```
<way id="111566019" version="1">
    <nd ref="266934805"/>
    <nd ref="8256676004"/>
    <nd ref="2473224"/>
    <tag k="cycleway" v="track"/>
    <tag k="highway" v="primary"/>
    <tag k="lanes" v="3"/>
    <tag k="name" v="Viale Giacomo Matteotti"/>
    <tag k="oneway" v="yes"/>
    <tag k="surface" v="asphalt"/>
</way>
```

```
<relation id="9128948" version="1">
    <member type="way" ref="28618378" role="outer"/>
    <member type="way" ref="656322769" role="inner"/>
    <tag k="addr:city" v="Firenze"/>
    <tag k="addr:housename" v="Santa Marta"/>
    <tag k="addr:housenumber" v="3"/>
    <tag k="addr:postcode" v="50139"/>
    <tag k="addr:street" v="Via di Santa Marta"/>
    <tag k="amenity" v="university"/>
    <tag k="building" v="university"/>
    <tag k="building:levels" v="3"/>
    <tag k="building:levels:underground" v="1"/>
    <tag k="email" v="reception.s.marta@polobiotec.unifi.it"/>
    <tag k="name" v="Facoltà di Ingegneria - Santa Marta"/>
    <tag k="old_name" v="Villa Cristina"/>
    <tag k="operator" v="Università degli Studi di Firenze"/>
    <tag k="phone" v="+39 055 275 8950"/>
    <tag k="phone_1" v="+39 055 275 8951"/>
    <tag k="roof:levels" v="0"/>
    <tag k="type" v="multipolygon"/>
    <tag k="wikidata" v="Q4011923"/>
    <tag k="wikipedia" v="it:Villa Cristina"/>
</relation>
```

# GIS Data – Vector formats

- Alternatively, OSM data can be downloaded as GeoJSON files


```
{
    "type": "Feature",
    "properties": {
        "osm_id": "9128948",
        "osm_type": "relation",
        "building": "university",
        "name": "Facoltà di Ingegneria - Santa Marta",
        "type": "multipolygon",
    },
    "geometry": {
        "type": "MultiPolygon",
        "coordinates": [
            [
                [
                    [
                        11.252543706842182,
                        43.798166701044707
                    ],
                    [
                        11.252441106842232,
                        43.798236701044694
                    ],
                    [
                        11.252745706842136,
                        43.79847220104464 6
                    ],
                    [
                        11.252709606842153,
                        43.79849500104465
                    ],
                    [
                        11.252774806842131,
                        43.798546501044655
                    ],
                    [
                        11.25257860684223,
                        43.798678101044651
                    ],
                    [
                        11.252561106842244,
                        43.79869930104465
                    ],
```

# GIS Data – Vector formats

- Alternatively, OSM data can be downloaded as GeoJSON files
- GeoJSON augment the standard JSON format with **geographical features**


```
{
    "type": "Feature",
    "properties": {
        "osm_id": "9128948",
        "osm_type": "relation",
        "building": "university",
        "name": "Facoltà di Ingegneria - Santa Marta",
        "type": "multipolygon",
    },
    "geometry": {
        "type": "MultiPolygon",
        "coordinates": [
            [
                [
                    [
                        11.252543706842182,
                        43.798166701044707
                    ],
                    [
                        11.252441106842232,
                        43.798236701044694
                    ],
                    [
                        11.252745706842136,
                        43.798472201044646
                    ],
                    [
                        11.252709606842153,
                        43.79849500104465
                    ],
                    [
                        11.252774806842131,
                        43.798546501044655
                    ],
                    [
                        11.25257860684223,
                        43.798678101044651
                    ],
                    [
                        11.252561106842244,
                        43.79869930104465
                    ],
```

# GIS Data – Sources

- GeoJSON can define several geometric structure

```
"geometry": {
  "type": "Point",
  "coordinates": [102.0, 0.5]
}
```

```
"geometry": {
  "type": "LineString",
  "coordinates": [
    [102.0, 0.0],
    [103.0, 1.0],
    [104.0, 0.0],
    [105.0, 1.0]
  ]
}
```

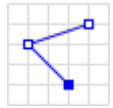
```
"geometry": {
  "type": "Polygon",
  "coordinates": [
    [
      [100.0, 0.0],
      [101.0, 0.0],
      [101.0, 1.0],
      [100.0, 1.0],
      [100.0, 0.0]
    ]
  ]
}
```

# GIS Data – Vector formats

- GeoJSON can define several geometric structure

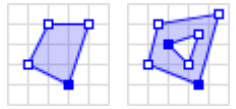


```
"geometry": {
  "type": "Point",
  "coordinates": [102.0, 0.5]
}
```

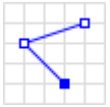
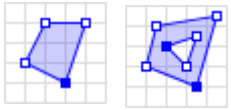
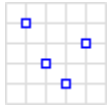
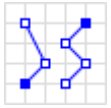
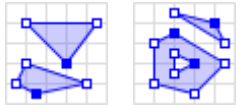
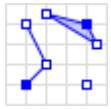


```
"geometry": {
  "type": "LineString",
  "coordinates": [
    [102.0, 0.0],
    [103.0, 1.0],
    [104.0, 0.0],
    [105.0, 1.0]
  ]
}
```

```
"geometry": {
  "type": "Polygon",
  "coordinates": [
    [
      [100.0, 0.0],
      [101.0, 0.0],
      [101.0, 1.0],
      [100.0, 1.0],
      [100.0, 0.0]
    ]
  ]
}
```



# GIS Data – Vector formats

- GeoJSON can define several geometric structure
  - **Point** 
  - **Linestring** 
  - **Polygon** 
  - **Multipoint** 
  - **MultiLinestring** 
  - **Multipolygon** 
  - **GeometryCollection** 

# GIS Data – Vector formats

- GeoJSON use the **EPGS:4326 – WGS84** coordinate reference system (CRS), defining the coordinate of point in **latitude** and **longitude**

- When using different CRS, this information must be specified

```
"crs": {
  "type": "name",
  "properties": {
    "name": "urn:ogc:def:crs:EPSG::3003"
  }
},
```

# GIS Data – Vector formats

- OSM data can be retrieved also as **Esri Shapefile format**
  - Developed and regulated by Esri as a *mostly open* specification for data interoperability
  - It can represent the entities already seen (points, lines, polygons, …)
  - It is composed by several mandatory and optional files
    - *.shp* — shape format;
    - *.shx* — shape index format;
    - *.dbf* — attribute format, columnar attributes for each shape;
    - *.prj* — projection description

# GIS Data – Sources

- OSM data can be retrieved directly from the PostgreSQL DB
- This relational DB is composed by tables representing
  - Nodes (i.e., points)
  - Ways (i.e., lines and polygons)
  - Relations (i.e., multilines and multipolygons)
- OSM can be deployed on-premise, see https://github.com/openstreetmap/openstreetmap-website

# Is good to know…

- Another format to represent geometric spatial objects is the Well-Known Text (WKT) format.
- Similarly to GeoJSON, WKT can encode spatial entities like

| | |
|---|---|
| **Point** | POINT(1 2) |
| **LineString** | LINESTRING(1.5 2.45, 3.21 4) |
| **Polygon** | POLYGON((1 2,1 4,3 4,3 2,1 2))<br>POLYGON((0.5 0.5,5 0,5 5,0 5,0.5 0.5), (1.5 1,4 3,4 1,1.5 1)) |
| **MultiPoint** | MULTIPOINT(0 0,1 1) |
| **MultilineString** | MULTILINESTRING((0 0,–1 –2,–3 –4),(2 3,3 4,6 7)) |
| **MultiPolygon** | MULTIPOLYGON(((0 1,3 0,4 3,0 4,0 1)), ((3 4,6 3,5 5,3 4)), ((0 0,–1 –2,–3 –2,–2 –1,0 0))) |
| **GeometryCollection** | GEOMETRYCOLLECTION(POINT(5 8), LINESTRING(–1 3,1 4)) |

# GIS Data – Raster formats

- Raster data, i.e., images, requires different formats
- Most common formats include
  - PNG
  - GeoTIFF
  - Esri grid ASCII (ASC)

# GIS Data – Raster formats

- Portable Network Graphics (PNG) is a raster-graphics file format that supports lossless data compression
- PNG is often the best raster format for maps, since the lossless compression keeps text and line work legible by preventing the compression artifacts (unlike JPEG)
- PNG can handle transparency (useful to indicate no-data values)
- PNG is widely used in many applications, in particular for web applications
- However, **PNG does not embed geographic information!**

# GIS Data – Raster formats

- Maps represented as PNG are usually provided by GeoServers
- A GeoServer implements the OpenGIS Web Map Service (WMS) interface standard over HTTP/HTTPS

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**Example REST call**:

https://wmsserver.snap4city.org/geoserver/Snap4City/wms?service=WMS&request=GetMap&layers=dtm_orografico_SuperRes_epgs4326_RGB&format=image%2Fpng&transparent=true&width=256&height=256&bbox=11.24725341796875,43.76911045236617,11.25,43.77109381775649

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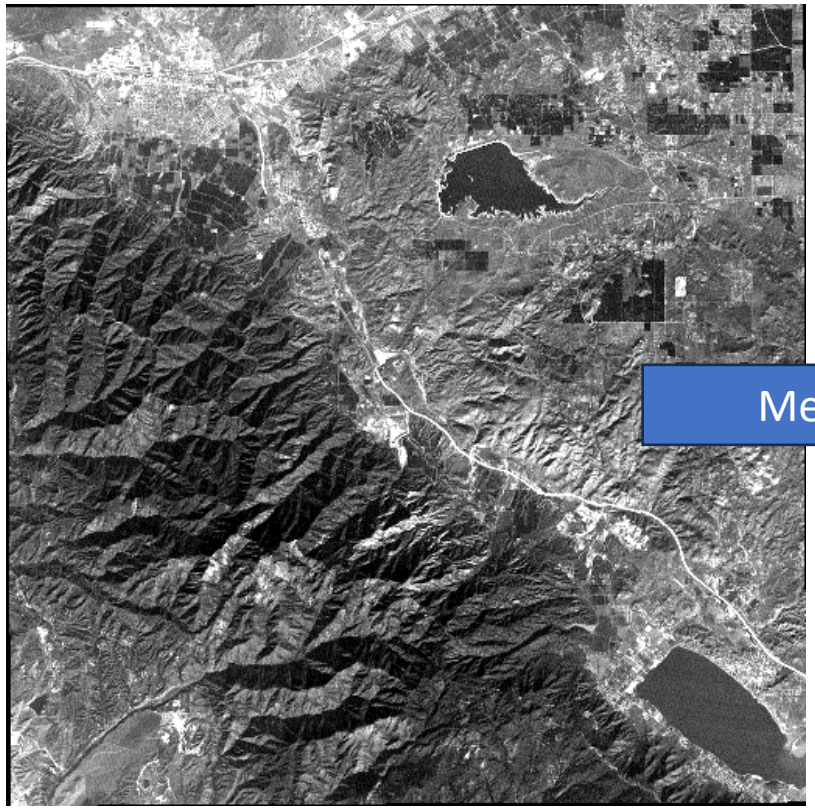
- In practice, PNG tiles are indexed with geo-coordinates and the client requests the PNG for a specific geographic bounding box

# GIS Data – Raster formats

- GeoTIFF is a public domain metadata standard which allows **georeferencing information** to be embedded into a TIFF file.



Metadata

```
Driver: GTiff/GeoTIFF
Files: cea.tif
Size is 514, 515
Coordinate System is:
PROJCRS[
  ...
]
Data axis to CRS axis mapping: 1,2
Origin = (-28493.166784412522247,4255884.543802191503346)
Pixel Size = (60.022136983193739,-60.022136983193739)
Metadata:
  AREA_OR_POINT=Area
Image Structure Metadata:
  INTERLEAVE=BAND
Corner Coordinates:
Upper Left  (  -28493.167, 4255884.544) (117d38'27.05"W, 33d56'37.74"N)
Lower Left  (  -28493.167, 4224973.143) (117d38'27.05"W, 33d39'53.81"N)
Upper Right (    2358.212, 4255884.544) (117d18'28.38"W, 33d56'37.74"N)
Lower Right (    2358.212, 4224973.143) (117d18'28.38"W, 33d39'53.81"N)
Center      (  -13067.478, 4240428.844) (117d28'27.71"W, 33d48'15.38"N)
Band 1 Block=514x15 Type=Byte, ColorInterp=Gray
```

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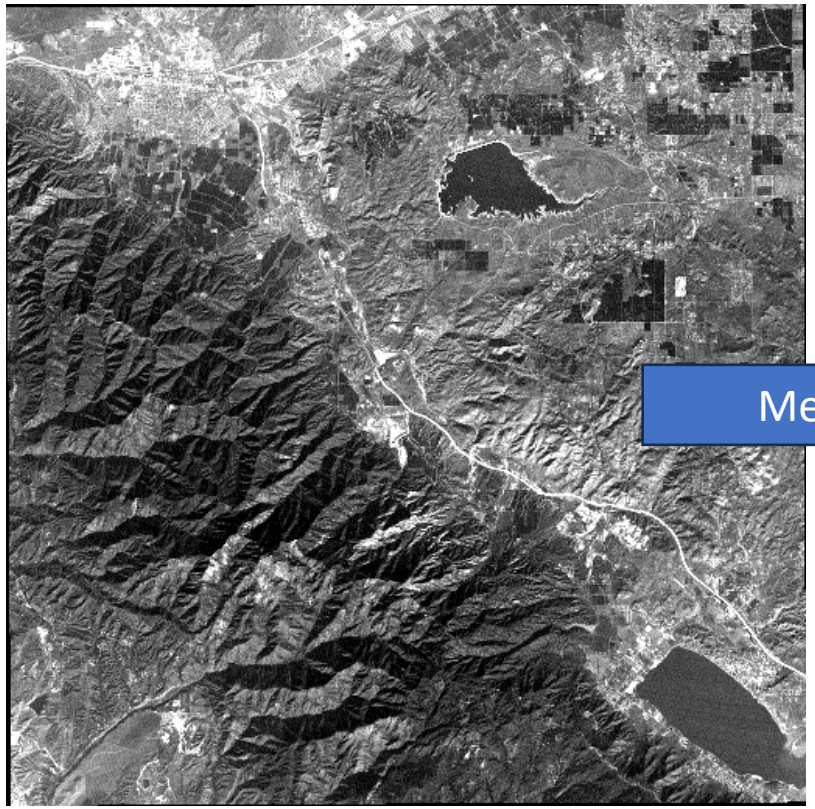

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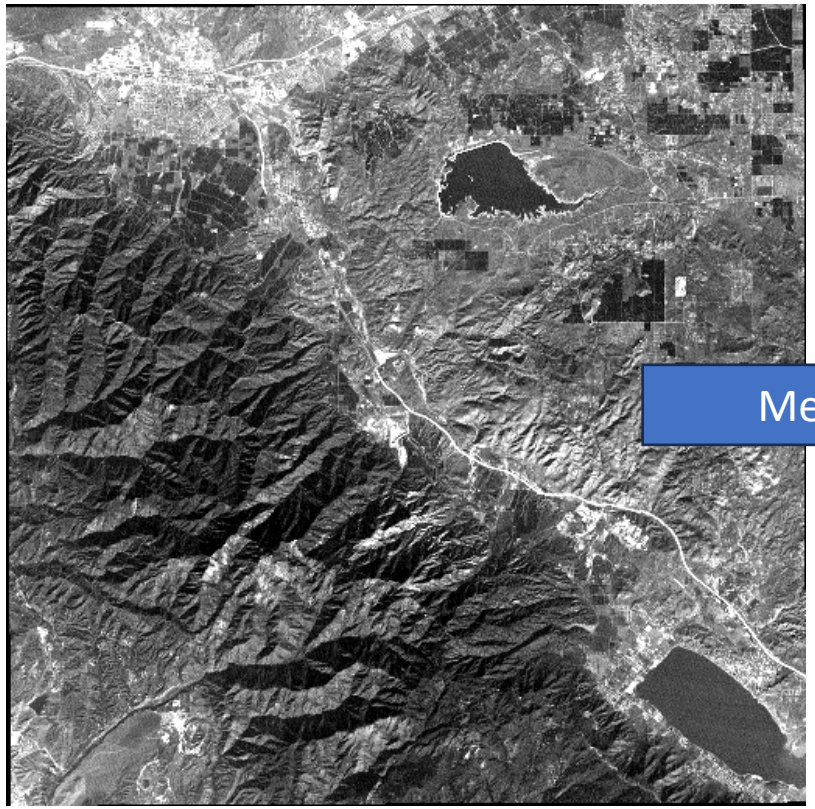

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- ASC is composed by two main part
  - Header with metadata

```
NCOLS 1640
NROWS 1240
XLLCENTER 1675980.500
YLLCENTER 4846780.500
CELLSIZE 1
NODATA_VALUE -9999.000
```

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  - Cell values

```
NCOLS 1640
NROWS 1240
XLLCENTER 1675980.500
YLLCENTER 4846780.500
CELLSIZE 1
NODATA_VALUE -9999.000
 41.236 41.226 41.226 41.226 41.256 41.216 41.206 41.156 …
 41.226 41.176 41.176 41.176 41.196 41.206 41.226 41.227 …
 41.287 41.307 41.287 41.257 41.287 41.307 41.317 41.317 …
 41.307 41.397 41.367 41.397 41.407 41.427 41.487 41.467 …
 41.447 48.407 51.757 52.207 47.947 49.867 46.577 46.197 …
 …
```

# GIS Data – Raster formats

- Esri grid ASCII (ASC) is a text format to represent matrix data with geographic information
- ASC is composed by two main part
  - Header with metadata
  - Cell values
- Note that, there are not CRS information!

```
NCOLS 1640
NROWS 1240
XLLCENTER 1675980.500
YLLCENTER 4846780.500
CELLSIZE 1
NODATA_VALUE -9999.000
 41.236 41.226 41.226 41.226 41.256 41.216 41.206 41.156 …
 41.226 41.176 41.176 41.176 41.196 41.206 41.226 41.227 …
 41.287 41.307 41.287 41.257 41.287 41.307 41.317 41.317 …
 41.307 41.397 41.367 41.397 41.407 41.427 41.487 41.467 …
 41.447 48.407 51.757 52.207 47.947 49.867 46.577 46.197 …
 …
```

# Mobility offer

- The mobility offer includes all the available public mobility services offered by public or private companies
  - Bus
  - Tram
  - Train
  - Ferry
  - Bike sharing
  - Car sharing
  - Scooter sharing
  - Taxi
  - Car hailing (e.g., Uber, Lyft)

# Mobility offer – Public transport

- For the public transports (bus, tram, etc.) a mobility offer must include
  - **Routes**, that are the trajectories covered with indication of the stops
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- This and other information are distributed from the transport operator using standards like **GTFS/GTFS-RT** and **NeTEx/SIRI**

# Mobility offer – GTFS Schedule (static)

- The **General Transit Feed Specification (GTFS)** is an Open Standard used to distribute information about transit systems
- It is composed by a list of CVS text files archived in a zip file
- The text file list includes:
  - *agency.txt*: info on the transit operator
  - *stops.txt*: stop list
  - *ruotes.txt*: route list
  - *trips.txt*: trip list for each route
  - *stop_times.txt*: arrival and departure times for each stop and each trip
  - *calendar.txt / calendar_dates.txt*: working days and exceptions
  - *shapes.txt*: lat/long coordinate to draw the routes on a map
  - *fare_attributes.txt*: prices of the service
  - …

# Mobility offer – GTFS Schedule (static)

## routes.txt

**route_id,agency_id,route_short_name,route_long_name,route_type,route_color,route_text_color**
"2182839646","303","T1.3","Servizio Tramvia Firenze - Linea T1.3","0","D86018","000000“
"3209345033","303","T2","Servizio Tramvia Firenze - Linea T2","0","D86018","000000"

## trips.txt

**route_id,service_id,trip_id,trip_headsign,trip_short_name,direction_id,shape_id**
"2182839646","4527_593642","4527_549189","Careggi - Ospedale","","0","2182839646"
"2182839646","4527_593642","4527_549190","Villa Costanza","","1","978952710"
"2182839646","4527_593642","4527_549191","Careggi - Ospedale","","0","3583783680"
"2182839646","4527_593642","4527_549192","Villa Costanza","","1","978952710"
"2182839646","4527_593642","4527_549193","Careggi - Ospedale","","0","3583783680"
"2182839646","4527_593642","4527_549194","Villa Costanza","","1","978952710"

## stops.txt

**stop_id,stop_name,stop_lat,stop_lon,stop_code**
"FM9004_103","De Andre","43.7547865043581","11.1790362683518","FM9004“
"FM9005_103","Resistenza","43.7579847316209","11.1822112945389","FM9005“
"FM9006_103","Resistenza","43.7580441494077","11.1822068713052","FM9006“
…
"FM9035_103","Vittorio Emanuele Ii","43.7958712112307","11.2415139153139","FM9035“
"FM9036_103","Morgagni-Universita","43.7995953955465","11.2439861801234","FM9036“
"FM9037_103","Careggi - Ospedale","43.8033027414408","11.2465976104274","FM9037"

## stop_times.txt

**trip_id,arrival_time,departure_time,stop_id,stop_sequence,shape_dist_traveled**
"4527_549189","05:29:00","05:29:00","FM9004_103","1","0"
"4527_549189","05:30:00","05:30:00","FM9006_103","2",".44279"
"4527_549189","05:32:00","05:32:00","FM9008_103","3","1.04775"
"4527_549189","05:34:00","05:34:00","FM9010_103","4","1.93364"
"4527_549189","05:36:00","05:36:00","FM9012_103","5","2.96611"
"4527_549189","05:37:00","05:37:00","FM9014_103","6","3.46874"
"4527_549189","05:38:00","05:38:00","FM9016_103","7","4.00089"
"4527_549189","05:40:00","05:40:00","FM9018_103","8","4.34465"
"4527_549189","05:41:00","05:41:00","FM9020_103","9","4.66609“
"4527_549189","05:42:00","05:42:00","FM9022_103","10","4.98182“
"4527_549189","05:43:00","05:43:00","FM9024_103","11","5.41694“
"4527_549189","05:45:00","05:45:00","FM9026_103","12","6.08557“
"4527_549189","05:49:00","05:49:00","FM9027_103","13","6.92863“
"4527_549189","05:51:00","05:51:00","FM9028_103","14","7.3331“
"4527_549189","05:54:00","05:54:00","FM9029_103","15","7.84536“
"4527_549189","05:56:00","05:56:00","FM9030_103","16","8.339“
"4527_549189","05:57:00","05:57:00","FM9031_103","17","8.61417“
"4527_549189","05:59:00","05:59:00","FM9032_103","18","8.9197“
"4527_549189","06:00:00","06:00:00","FM9033_103","19","9.29738“
"4527_549189","06:02:00","06:02:00","FM9034_103","20","9.66363“
"4527_549189","06:04:00","06:04:00","FM9035_103","21","10.00552“
"4527_549189","06:06:00","06:06:00","FM9036_103","22","10.53703“
"4527_549189","06:08:00","06:08:00","FM9037_103","23","11.03527"

# Mobility offer – GTFS Schedule (static)

## routes.txt

```
route_id,agency_id,route_short_name,route_long_name,route_type,route_color,route_text_color
"2182839646","303","T1.3","Servizio Tramvia Firenze - Linea T1.3","0","D86018","000000“
"3209345033","303","T2","Servizio Tramvia Firenze - Linea T2","0","D86018","000000"
```

## trips.txt

```
route_id,service_id,trip_id,trip_headsign,trip_short_name,direction_id,shape_id
"2182839646","4527_593642","4527_549189","Careggi - Ospedale","","0","218283964"
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"2182839646","4527_593642","4527_549194","Villa Costanza","","1","978952710"
```

## stops.txt

```
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"4527_549189","05:42:00","05:42:00","FM9022_103","10","4.98182“
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"4527_549189","06:06:00","06:06:00","FM9036_103","22","10.53703“
"4527_549189","06:08:00","06:08:00","FM9037_103","23","11.03527"
```

# Mobility offer – GTFS-RT (RealTime)

- The **GTFS-RT** is a feed specification that allows public transportation agencies to provide real-time updates about their fleet
- Provide three types of real-time updates to users:
  - Trip updates - delays, cancellations, changed routes
  - Service alerts - stop moved, unforeseen events affecting a station, route or the entire network
  - Vehicle positions - information about the vehicles including location and congestion level
- Feeds are served via HTTP as binary files based on Protocol Buffers

# Mobility offer – NeTEx

- The **Network Timetable Exchange** standard is intended to be a general-purpose XML format designed for the exchange of transport data
- NeTEx is the first standard that also covers **multimodal fares**
- NeTEx includes
  - Schedules
  - Stops
  - Routes
  - Service days
  - Fares

# Mobility offer – NeTEx

- NeTEx is described in four parts
  - Part 1: Public transport **network topology** exchange format
  - Part 2: Public transport **scheduled timetables** exchange format
  - Part 3: Public transport **fares** exchange format
  - Part 4: Passenger Information European Profile

- Part 5 is under development and will focus on car sharing, cycle sharing, carpooling, car/cycle rental

- More info:
  - https://netex-cen.eu/
  - https://github.com/entur/profile-examples

# Mobility offer – SIRI

- The **Service Interface for Real time Information (SIRI)** allows pairs of server computers to exchange structured real-time information about transport services
- SIRI complements NeTEx for **real-time data exchange**
- Messages consist of XML documents, whose tags and content are exactly specified by the SIRI XML Schemas
- SIRI allow both **synchronous request/response** and **asynchronous subscribe/publish** protocols

# Mobility offer – NeTEx & SIRI

- Both NeTEx and SIRI shared a common conceptual model provided by **Transmodel** (http://www.transmodel-cen.eu/), that is an abstract model of common public transport concepts and data structures

- More info:
  - https://netex-cen.eu/
  - https://www.siri-cen.eu/
  - https://github.com/entur/profile-examples

# Mobility offer – Sharing

- In case of sharing mobility offers, static data are less relevant since there are not fixed routes or scheduled trips
- Real-time data on vehicle position and their availability are more important
- The most advanced standards covering sharing mobility are the **General Bikeshare Feed Specification** (GBFS) and the **Mobility Data Specification** (MDS)

# Mobility offer – GBFS & MDS

- GBFS is intended to provide real-time data to the final user
- MDS is designed to exchange data between the mobility operator and the public administration, including real-time and historical data
- Their adoption is still limited, in particular in Italy
- When widely deployed they can offer
  - A clear status of the shared mobility offer
  - Data to estimate the mobility patterns of the users

# Mobility offer – GBFS

- The **General Bikeshare Feed Specification** (GBFS) is based on a series of JSON
  - *gbfs.json* – an index with links to the other files
  - *vehicle_types.json* – list types of available vehicles
  - *station_information.json* – list of all stations, their capacities and locations
  - *station_status.json* – available vehicles and docks at each station
  - *vehicle_status.json* – describes all vehicles that are not currently in active rental
  - …

# Mobility offer – GBFS

## gbfs.json


```
{
  "last_updated": 1698165756,
  "ttl": 0,
  "version": "2.2",
  "data": {
    "en": {
      "feeds": [
        {
          "name": "gbfs_versions",
          "url": "https://gbfs.helbiz.com/v2.2/firenze/gbfs_versions.json"
        },
        {
          "name": "system_information",
          "url": "https://gbfs.helbiz.com/v2.2/firenze/system_information.json"
        },
        {
          "name": "vehicle_types",
          "url": "https://gbfs.helbiz.com/v2.2/firenze/vehicle_types.json"
        },
        {
          "name": "station_information",
          "url": "https://gbfs.helbiz.com/v2.2/firenze/station_information.json"
        },
        {
          "name": "free_bike_status",
          "url": "https://gbfs.helbiz.com/v2.2/firenze/free_bike_status.json"
        },
...
```


## *vehicle_status.json*


```
{
  "last_updated": 1698166031,
  "ttl": 0,
  "version": "2.2",
  "data": {
    "bikes": [
      {
        "bike_id": "X8CS5R",
        "lat": 43.788457,
        "lon": 11.271341,
        "is_reserved": false,
        "is_disabled": true,
        "vehicle_type_id": "moped",
        "rental_uris": {
          "android": "https://...
          "ios": "https://...
        },
        "last_reported": 1660338193,
        "current_range_meters": 13.5,
        "pricing_plan_id": "price_moped"
      },
...
```

Data 4 Mobility

# Sensor data

# Sensor data

- IoT/IoE sensors are exploited to acquire **real-time measurements and information** of the mobility environment

- Such sensors can provide different kind of data:
  - traffic vehicle density
  - number of passages though specific areas
  - number of vehicles in a parking
  - environmental information on whether, pressure, pollutant
  - …

# Sensor data

- Messages from IoT Sensors depend on the specific sensor setup
- Typically, text format as JSON or XML are used

# Sensor data

- **Data transmission** follows a client/server architecture, with push or pull modalities
- Most common **pull protocols** are
  - REST call over HTTP/HTTPS
  - FTP
- **Push protocols** (data-driven with subscriptions) are
  - WebSocket (WS)
  - Constrained Application Protocol (CoAP)
  - Message Queue Telemetry Transport (MQTT)
  - Advanced Message Queuing Protocol (AMQP)
  - FIWARE NGSI and NGSI-V2

# Sensor data

- **Camera sensors** are a more particular case: video transmission usually requires a continuous data flow
- Different **codec** and **video container** can be used (for example the H.264 codec with mp4 container)
- Several protocols are available, such as
  - HTTP Live Streaming (HLS)
  - Real-Time Messaging Protocol (RTMP)
  - Web Real-Time Communications (WebRTC)
  - Real-Time Streaming Protocol (RTSP)
  - Dynamic Adaptive Streaming over HTTP (MPEG-DASH)

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  - Real-Time Messaging Protocol (RTMP)
  - Web Real-Time Communications (WebRTC)
  - Real-Time Streaming Protocol (RTSP)
  - Dynamic Adaptive Streaming over HTTP (MPEG-DASH)
- More recently **cameras with processing units (CPU and GPU)** are available to elaborate the video feed on-the-edge and extracted information can be transmitted with text messages

# Sensor data

- Among the information provided from sensors, **traffic data** are very important for smart mobility application
- Not all the cities deployed enough sensors to capture traffic information, or you may not have access to the sensors' data
- Alternative solution are available
  - **Paid solutions**: companies like Waze or Here offer API to retrieve data feed, that can include information also on events such as road accidents
  - **Open data**: for some areas* traffic data are released freely. These data are sent with different formats. One of the possible format (in particular from European providers) is the **DATEX-II** standard.

* https://github.com/graphhopper/open-traffic-collection

# DATEX-II

- DATEX-II is a data exchange standard for exchanging traffic information
- DATEX-II contains
  - **Road and traffic related events** (called "Traffic elements"): abnormal traffic, accidents, public event, driving conditions, obstructions, …
  - **Operator actions**: network management, traffic control, roadworks, …
  - **Impacts**: information on lane availability and on delays
  - **Measured or elaborated data**: travel times, traffic speed, traffic status, weather measurements, …
  - **Messages displayed on Variable Message Signs** (VMS)
  - **Service information:** closed rest area, information about other transport means (e.g., delays on trains), ...
- Data is presented in **XML**

# IoT Actuators

- In smart mobility systems include also actuators, i.e., devices that can be used to implement **Adaptive Traffic Signal Control (ATSC)**, that are dynamic traffic management strategies

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  - **Smart traffic lights**

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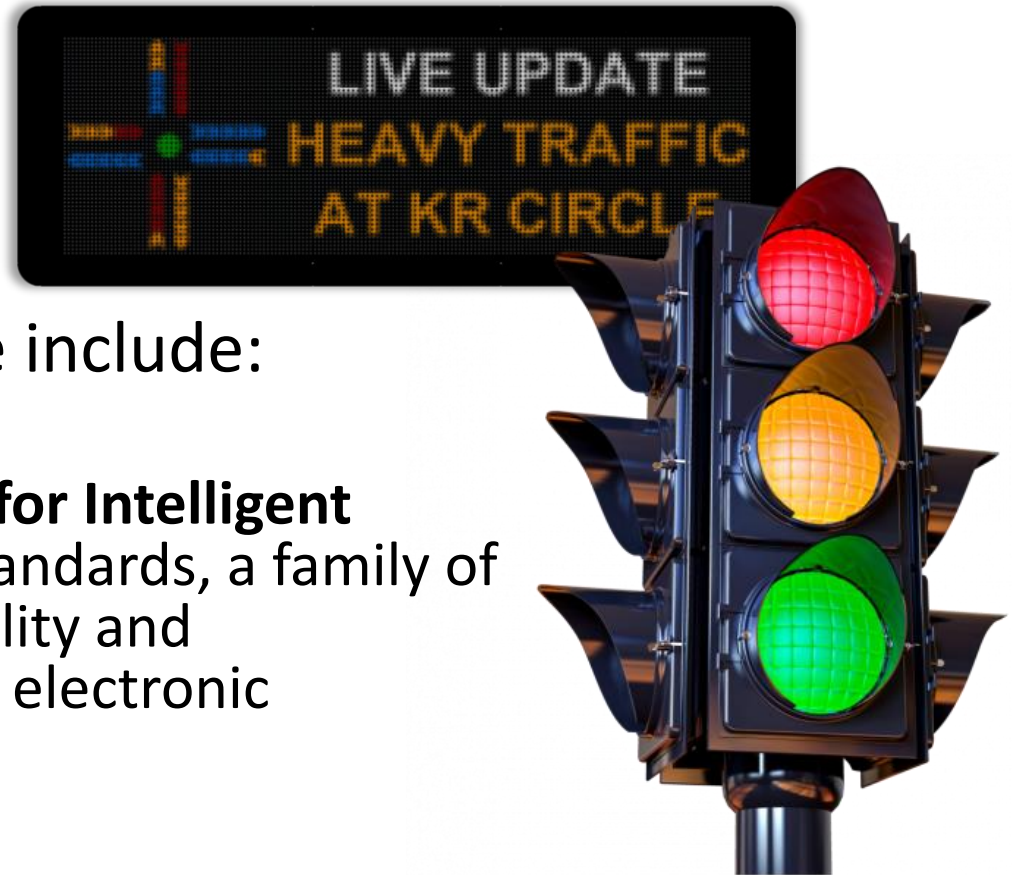
- Such devices include for example
  - **Variable Message Signs (VMSs)**
  - **Smart traffic lights**
- Standard and protocols used in this case include:
  - **DATEX-II**
  - **National Transportation Communications for Intelligent Transportation System Protocol (NTCIP)** standards, a family of standards designed for enable interoperability and interchangeability between computers and electronic traffic control equipment



Data 4 Mobility

# Vehicle & people data

# Vehicle and People data

- In this group we consider data produced directly from vehicles or persons
- These data are a relevant source to estimate the **demand of mobility**
- These are typically the most difficult data to acquire, mainly due to privacy issues

# Mobile devices

- Smartphones, tables, etc., can be used to observe the mobility pattern of the users
- A coarse information, useful for extra-urban travels, can be obtained from the **connection to cell towers** of telecommunication operators
- A finer representation can be obtained from geo-localization (i.e., GPS position) of **mobile apps** as for example routing and travel planning apps like Google Maps, Waze, Moovit, etc.

# Mobile devices

- Both data from telecommunication operators and app vendors are not released freely but **require to be purchased**
- Data are provided in an anonymized and aggregated modality
- Even if acquired in real-time, are released as **historical data**
- Data retrieval is done using vendors' APIs, without specific standard

# Vehicle data

- **On-Board Units** (OBUs) are an electronic devices installed in vehicles able to record traffic and driving data and connect to roadside and satellite systems to transmit and collect data for various applications

- These are the fundamental device to enable **vehicle-to-everything** (V2X, including V2V, V2I, V2P, V2N) communications and to develop CAV (Connected autonomous vehicle) and CCAM (Cooperative, connected and automated mobility)

- OBUs communication happen with dedicated protocol stacks, and data are exchanged in XML or JSON formats, or using specific standards

# Vehicle data

- **Abstract Syntax Notation 1 (ASN.1)** is a standard interface description language (IDL) for defining data structures that can be serialized and deserialized in a cross-platform way, more recently adopted for V2X communications
- **SENSORIS** is a global standardized interface to exchange information between in-vehicle sensors and a dedicated cloud, as well as between clouds. It enables real-time, cloud-based information services that support mobility and automated driving
- **Extended Vehicle (ExVe)** is a concept that allows external service providers to access vehicle data and functions via a standardized interface
- **Open Diagnostic Data Exchange (ODX)** is a standard that defines a common data format for exchanging diagnostic data between vehicle manufacturers, suppliers, and service providers

# Smartcard data

- **Smartcards** are a physical electronic authentication device used in mobility to access and pay public transport services

- Smartcards can be used as
  - Entry-only
  - Entry-exit

- Smartcard data acquired by mobility operators can be released using text formats like CSV, JSON, XML, or Keyhole Markup Language (KML) an XML notation used to represent geographic annotations

# Social media data

- **Social media** can also be used to acquire data on mobility
- Most of the posts contains check-in data including location information
- Web-scraping tools are available to extract data from social media and deliver them in JSON, CVS, HTML, Excel