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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Satellites Characterization

Clustering using orbital characteristics

Intro

Two Parts:

- Orbit Clustering:
  - Relevant Orbit Metric
  - Graph Representation
  - Phase Clustering
- Satellites Launch Sites Clustering
  - Baycurtis Distance Between Features
  - Subgraphs Extraction
  - Lauch Site Classification

Data Extraction

- From SpaceTrack.org
  - TLE File
  - Satellites in orbit info
  - Satellites statistics by country

- From CelesTrak.com
  - SatCat info

SpaceTrack.org:

TLE File

```
- 0 VANGUARD 2
- 1     11U 59001A   17329.92226964 +.00000367 +00000-0 +19707-3 0  9992
- 2     11 032.8697 323.5388 1468703 016.5820 347.7999 11.85506786164031
```

	OBJECT_NAME	Longitude [°]	Latitude [°]	Elevation [km]
0	VANGUARD 1	-63.01315328238157	-26.65173623575367	950.1053125
1	VANGUARD 2	33.607191075144456	-32.25819456312109	2825.77825
2	VANGUARD R/B	158.90670062542114	1.4622271746404283	746.4226875
3	VANGUARD R/B	-117.00344908625789	12.395302654786787	2056.953375
4	VANGUARD 3	-14.979412519707317	-30.811335100669776	3271.14

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SpaceTrack.org:

Satellites in orbit info

	OBJECT_ID	OBJECT_NAME	NORAD_CAT_ID	COUNTRY	PERIOD	INCLINATION	APOGEE	PERIGEE	LAUNCH
0	2017-075D	CZ-2C R/B	43031	PRC	95.19	35.21	599.0	457.0	2017-11-24
1	2017-075C	YAOGAN-30 F	43030	PRC	96.62	35.00	604.0	590.0	2017-11-24
2	2017-075B	YAOGAN-30 E	43029	PRC	96.62	35.00	604.0	590.0	2017-11-24
3	2017-075A	YAOGAN-30 D	43028	PRC	96.62	35.00	603.0	590.0	2017-11-24
4	1998-067NL	OSIRIS-3U	43027	US	92.59	51.64	405.0	398.0	1998-11-20

Satellites statistics by country

	COUNTRY	SPADOC_CD	ORBITAL_TBA	ORBITAL_PAYLOAD_COUNT
0	ARAB SATELLITE COMMUNICATIONS ORGANIZATION	AB	0	13
1	ASIASAT CORP	AC	0	8
2	ALGERIA	ALG	0	5
3	ARGENTINA	ARGN	0	17
4	AUSTRIA	ASRA	0	3

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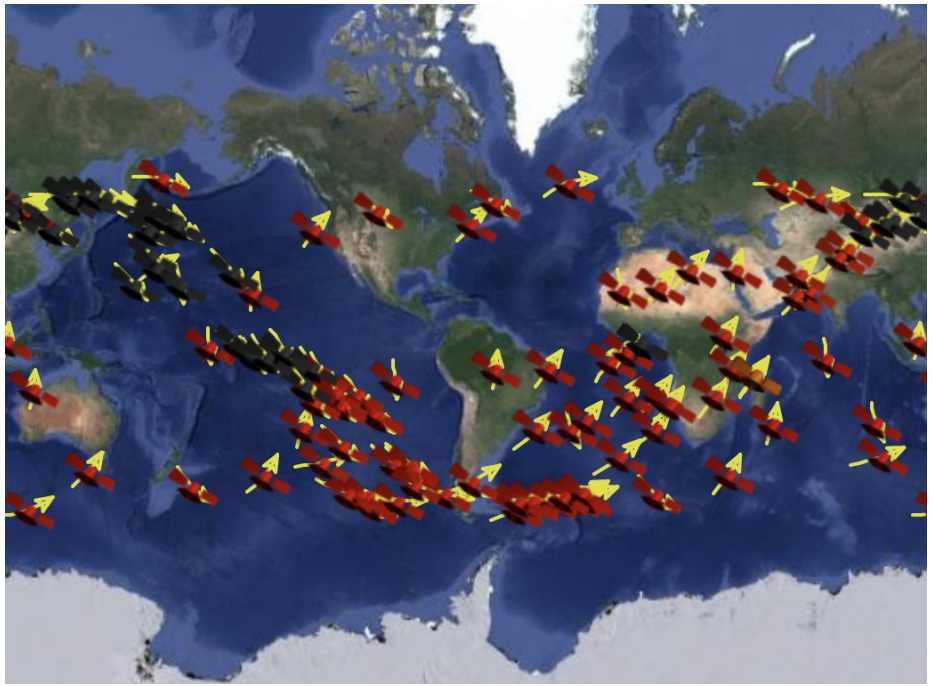
CelesTrack.com:

SatCat info

NORAD	apogee	decay_date	inclination	launch_date	launch_nbr	launch_piece	launch_site	launch_year	multiple_name_flag	name	operational_status
1	938.0	1957-12-01	65.1	1957-10-04	1	A	TYMSC	1957	False	SL-1 R/B	Decayed
2	945.0	1958-01-03	65.0	1957-10-04	1	B	TYMSC	1957	False	SPUTNIK 1	Decayed
3	1659.0	1958-04-14	65.3	1957-11-03	2	A	TYMSC	1957	False	SPUTNIK 2	Decayed
4	215.0	1970-03-31	33.2	1958-02-01	1	A	AFETR	1958	False	EXPLORER 1	Decayed
5	3834.0		34.3	1958-03-17	2	B	AFETR	1958	False	VANGUARD 1	Unknown

Data Exploitation

Origin of the idea



https://in-the-sky.org/satmap_worldmap.php

Data Exploitation

Merged Data

- The actual data to be used
- Contains all the data to perform the sampled orbit representation

Merged Data:

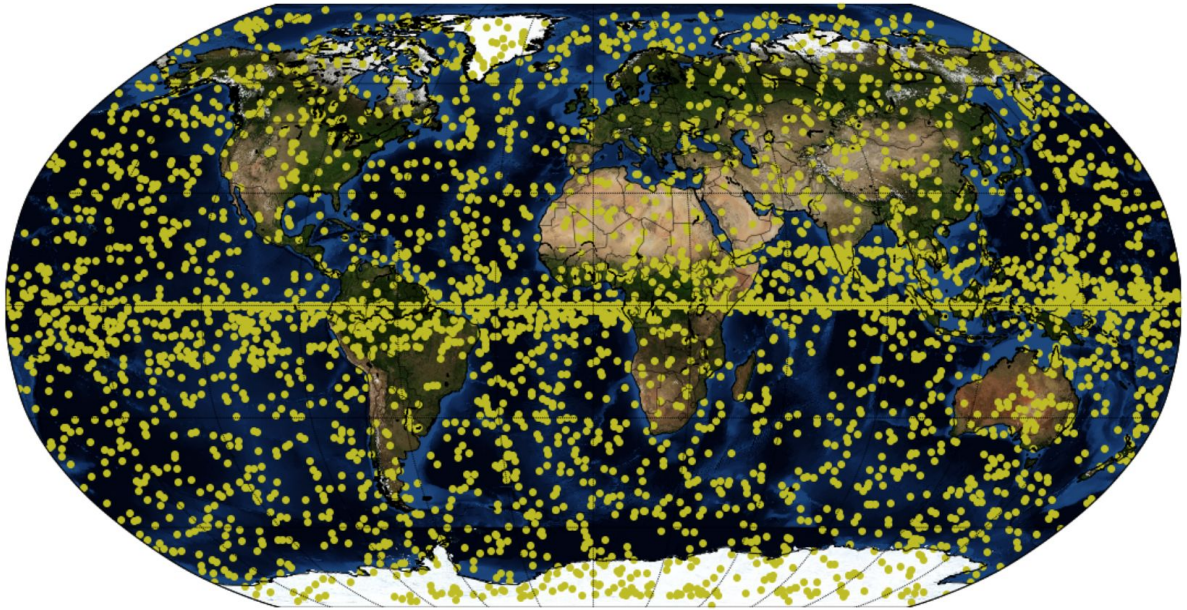
	OBJECT_NAME	Longitude [°]	Latitude [°]	PERIOD
0	VANGUARD 1	-63.01315328238157	-26.65173623575367	132.75
1	VANGUARD 2	33.607191075144456	-32.25819456312109	121.47
2	VANGUARD R/B	158.90670062542114	1.4622271746404283	137.32
3	VANGUARD 3	-14.979412519707317	-30.811335100669776	124.62
4	EXPLORER 7	165.9903034740197	9.845133707399345	96.36

Data Exploitation

Raw Data

- All the satellites
- Unprocessed data

Need to process the data to recognise different orbits



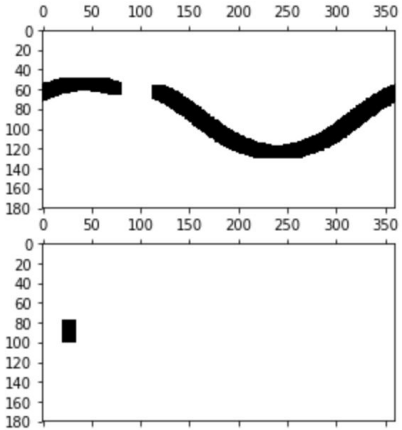
Data Exploitation

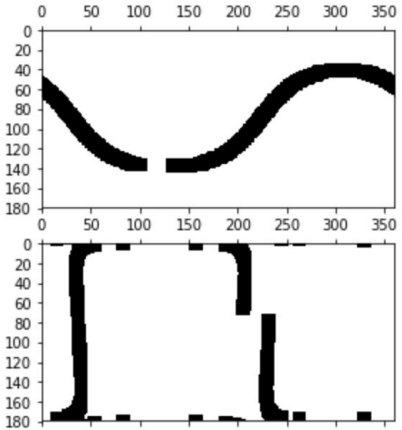
Grid Explanation

- Sampling of the period
- Computation done with PyEphem
- Resulting binary map

What about the metric ?

- Simple sum
- Allowed to compute the adjacency





Data Exploitation

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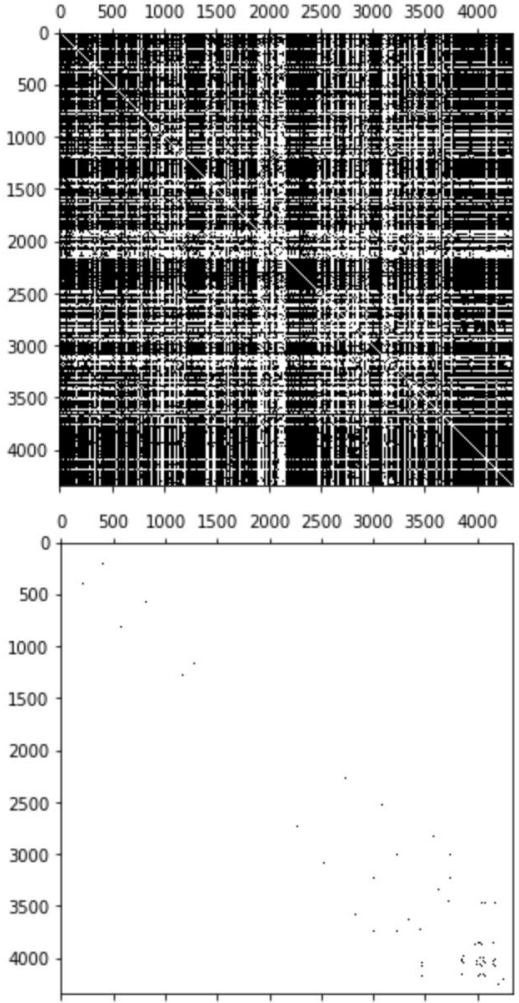


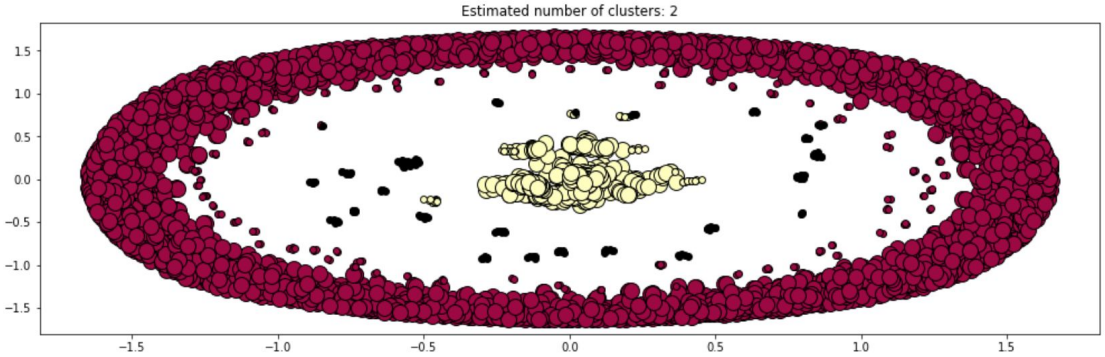
Data Exploitation

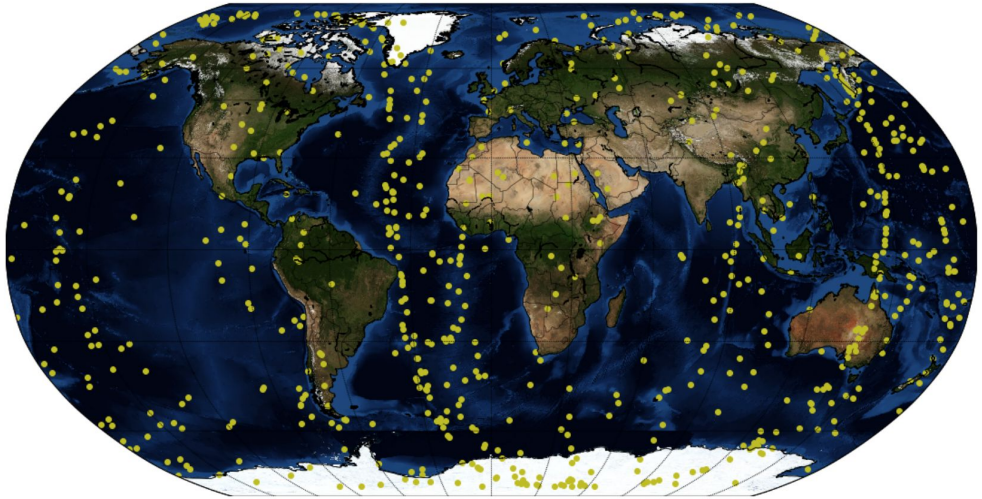
First Processing

- Need to cluster the different groups

How did we do that ?

- DBSCAN algorithm
  - Nearest neighbors
- Allowed to isolate the central cluster





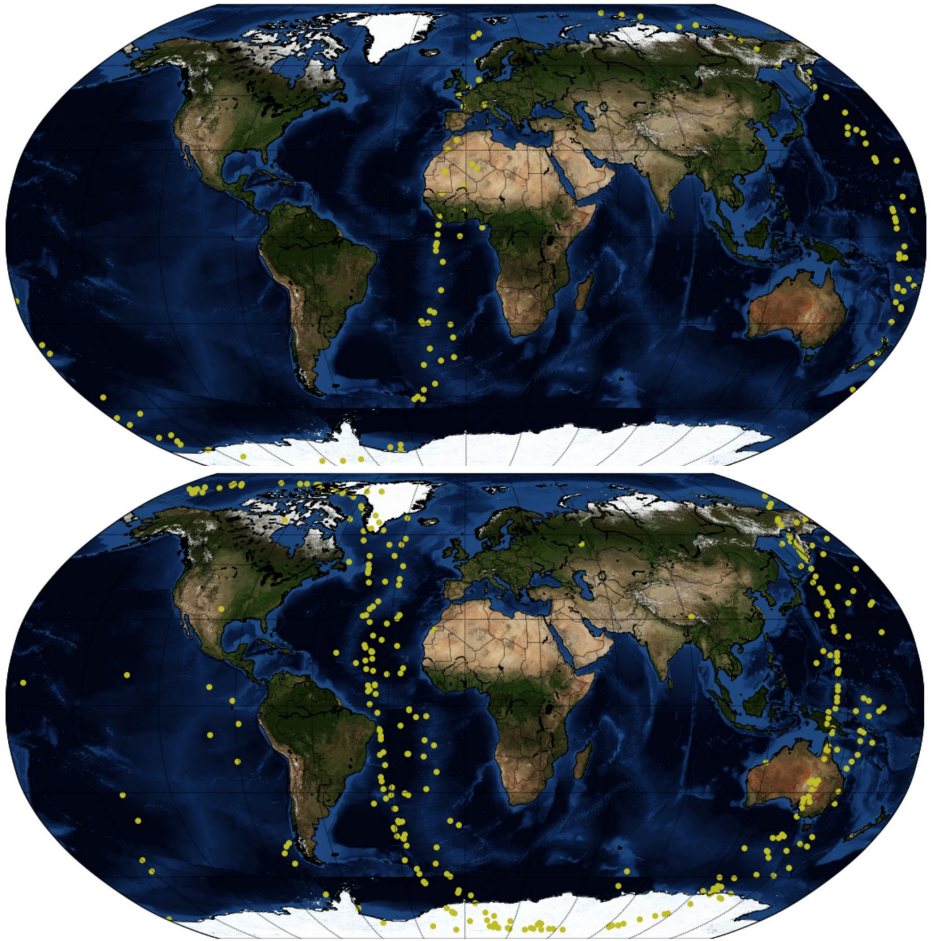
Data Exploitation

Second Processing

Results were acceptable but could be better

- Processed a 2nd DBSCAN
- Isolate the different phases successfully

What about the Geostationary from the raw data ?



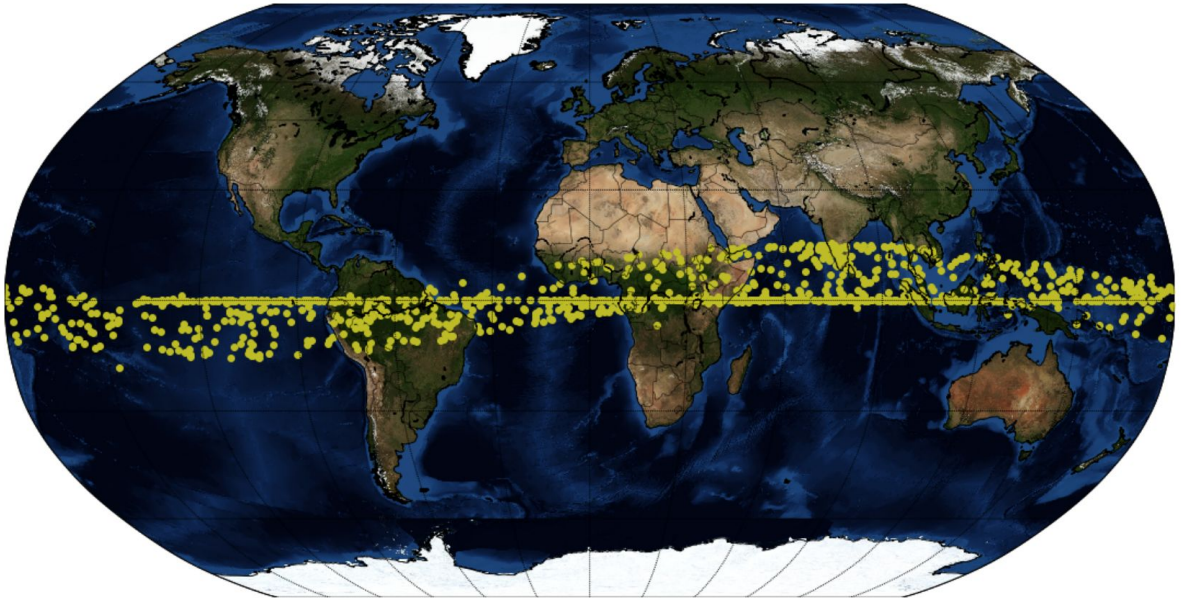
Data Exploitation

Exception to our metric

- Geostationary, Geosynchronous

Graph processing not needed

- Simple threshold
- Isolate both orbits



From orbits to launch sites

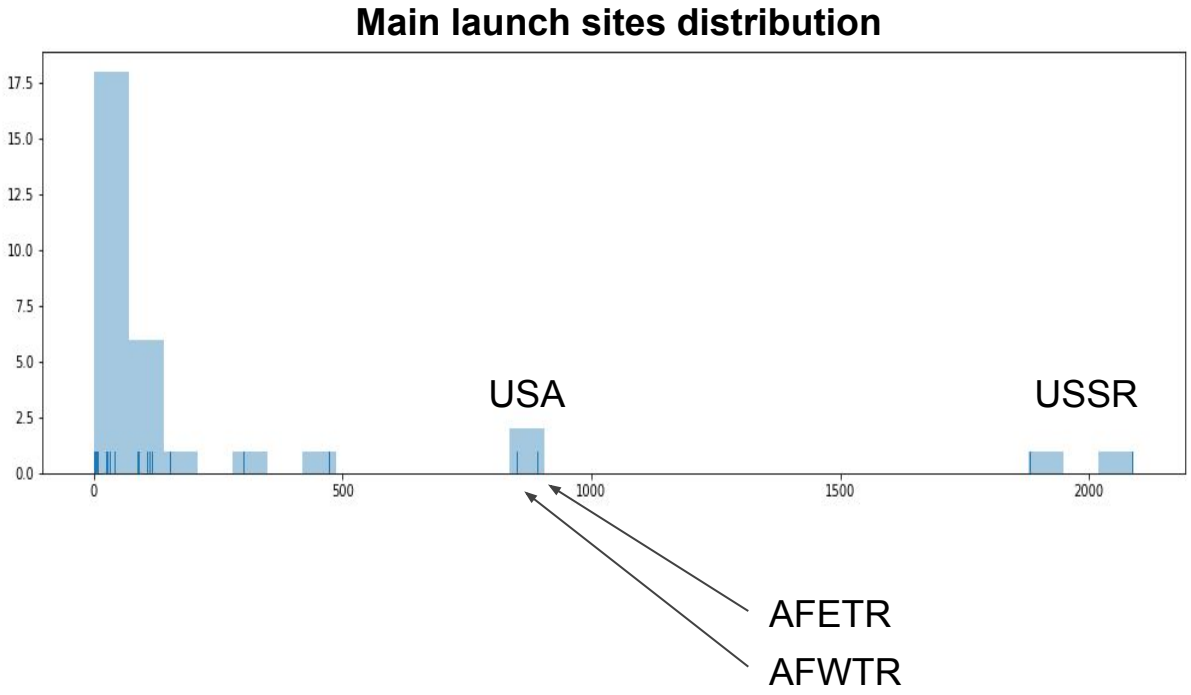
- Able to cluster different satellite orbits

Raised a question :

- Is there a preferential launching site to send a Satellite to a given orbit ?
- Is it possible to assess if there is an optimal launch site for a given wanted orbit ?

Launch site importance

- Two critical actors in space missions: the USSR and the USA
- USA: Two main launch sites
  - Air Force Eastern Test Range, Florida
  - Air Force Western Test Range, California
- **Main Idea:**
  - On two sides of a large country
  - What is the effect on launched satellites?



Features and weight function

- **Feature dataframe**
  - **Numerical and categorical**
  - **Normalized**
- Distance metric
  - Bray-Curtis
- Weight Matrix
  - Sparcified
  - 0 if < epsilon (1e-8)

Features

NORAD	apogee	inclination	launch_year	orbital_period	perigee	radar_cross_section	operational_status	source
4	215.0	33.2	1958	88.5	183.0	0.000	0	1
5	3834.0	34.3	1958	132.8	650.0	0.122	1	1
6	1739.0	33.5	1958	103.6	117.0	0.000	0	1
9	585.0	50.3	1958	92.8	239.0	0.000	0	1
10	1187.0	32.3	1958	98.2	159.0	0.000	0	1

Normalized Features

NORAD	apogee	inclination	launch_year	orbital_period	perigee	radar_cross_section	operational_status	source
4	-0.390693	-0.766486	-1.44112	-0.192732	-0.501090	-0.171139	-0.943187	-0.312776
5	-0.285957	-0.734247	-1.44112	-0.176636	-0.473941	-0.168288	-0.147073	-0.312776
6	-0.346588	-0.757693	-1.44112	-0.187246	-0.504927	-0.171139	-0.943187	-0.312776
9	-0.379985	-0.265311	-1.44112	-0.191170	-0.497834	-0.171139	-0.943187	-0.312776
10	-0.362563	-0.792864	-1.44112	-0.189208	-0.502485	-0.171139	-0.943187	-0.312776

Features and weight function

- Created a feature dataframe
  - Numerical and categorical
  - Normalized
- **Distance metric**
  - **Bray-Curtis**
- Weight Matrix
  - Sparcified
  - 0 if < epsilon (1e-8)

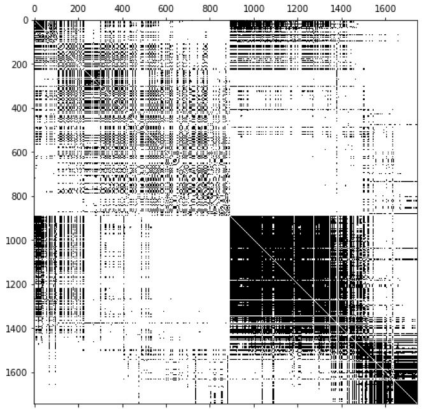
Distance: Bray-Curtis Dissimilarity

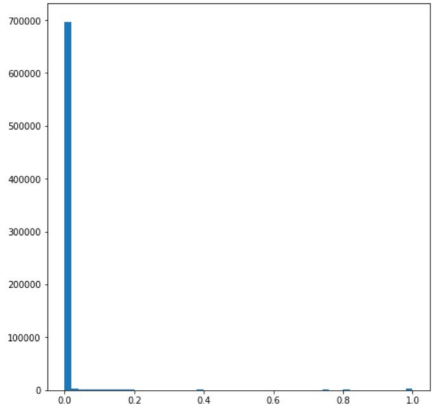
$$d = \frac{\sum |u_i - v_i|}{\sum |u_i + v_i|}$$

Features and weight function

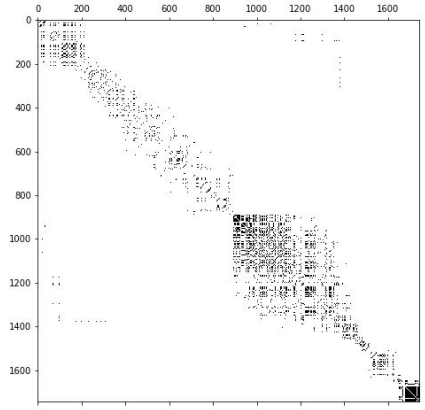
- Created a feature dataframe
  - Numerical and categorical
  - Normalized
- Distance metric
  - Bray-Curtis
- **Weight Matrix**
  - **Sparcified**
  - **0 if < epsilon (1e-8)**

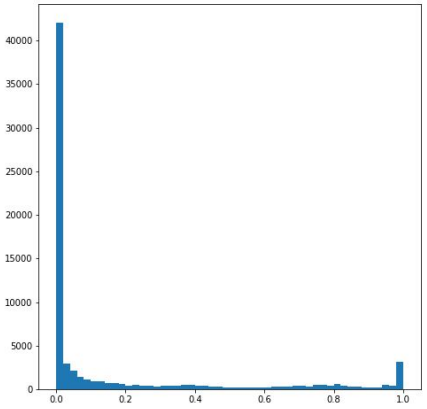
Initial Weight Matrix





Sparse Weight Matrix

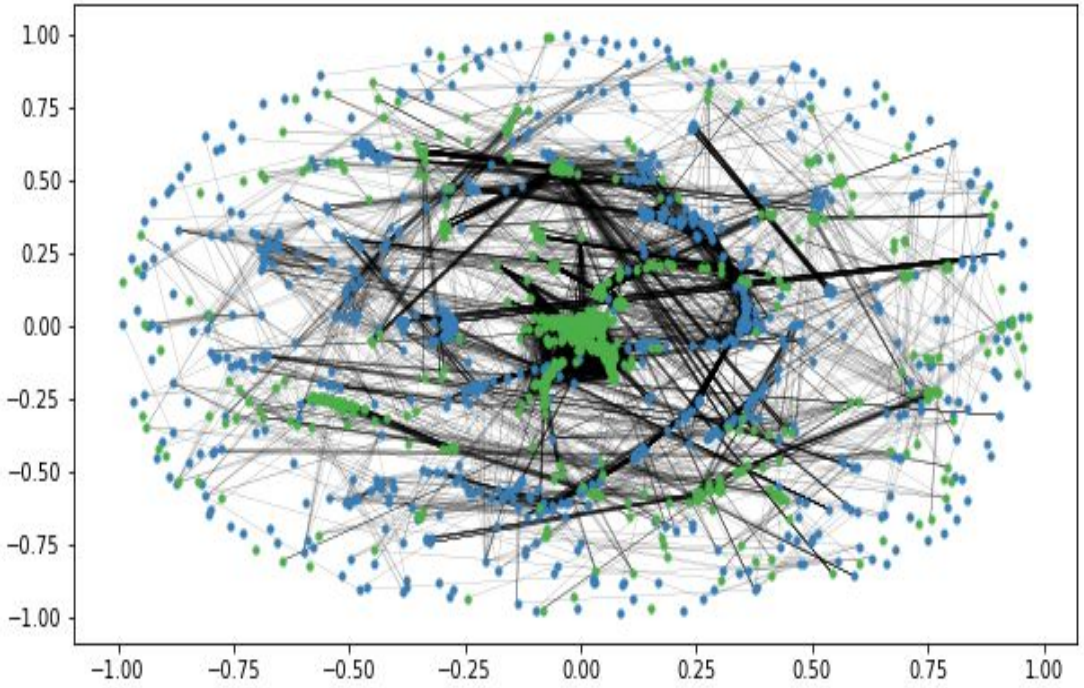




Graph processing

- **Base graph**
- Connected graph extraction
- Clique processing

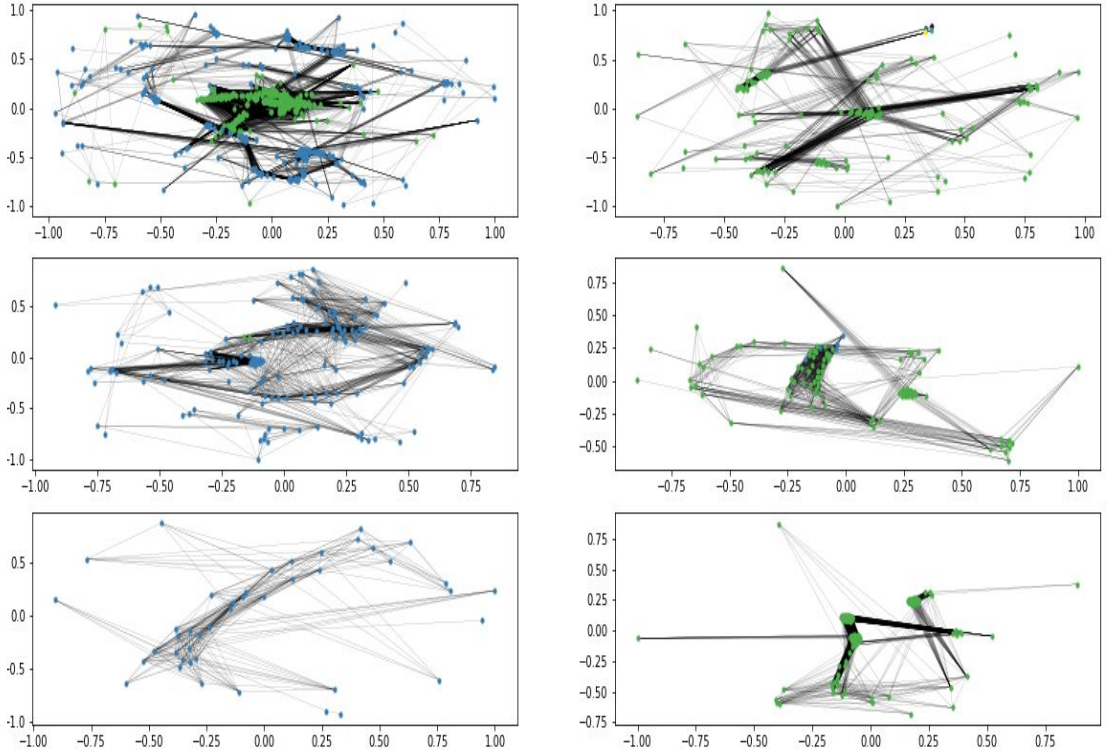
Base Graph



Graph processing

- Base graph
- **Connected graph extraction**
- Clique processing

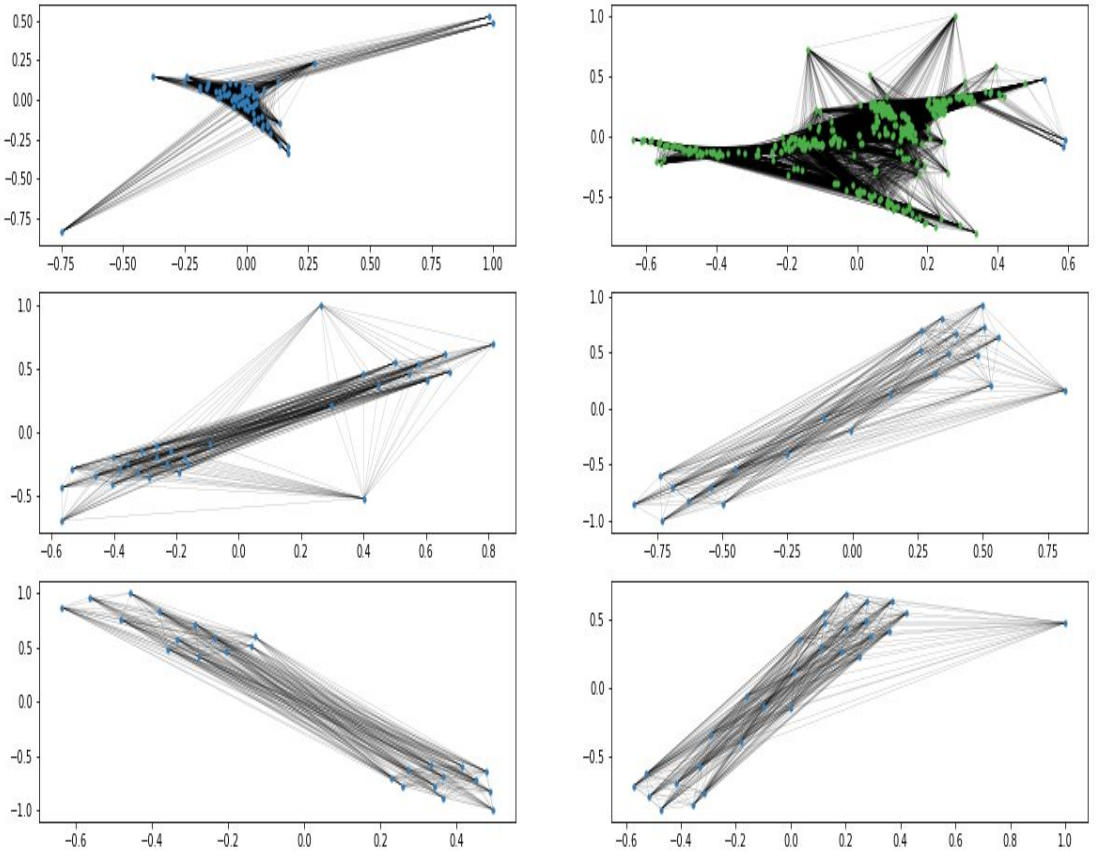
Connected Graphs



Graph processing

- Base graph
- Connected graph extraction
- **Clique processing**

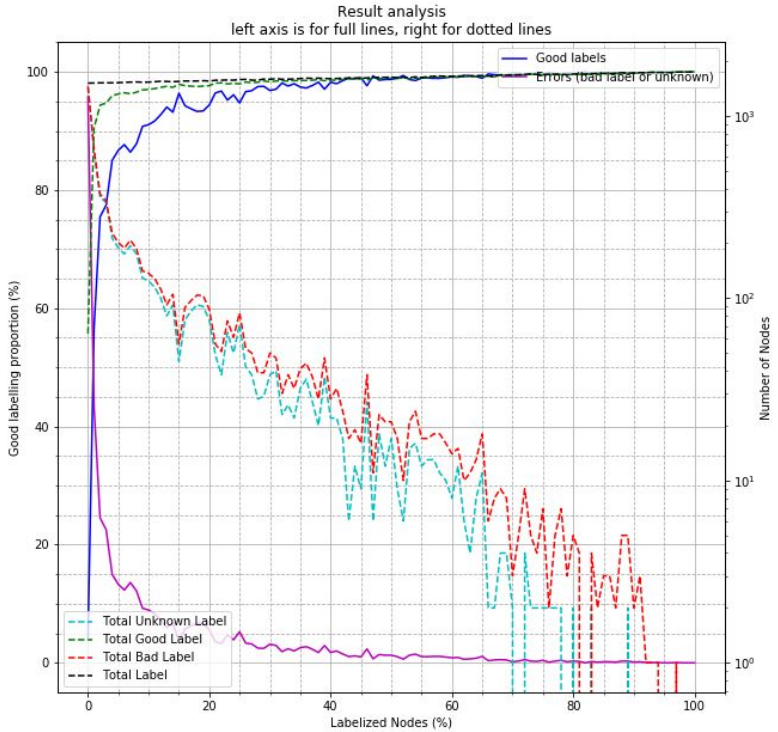
After Clique Processing



Labelling

- Labelled A Fraction of satellites
- One label per subgraph
  - Statistical metric
- Analysed for many fractions of labelized nodes

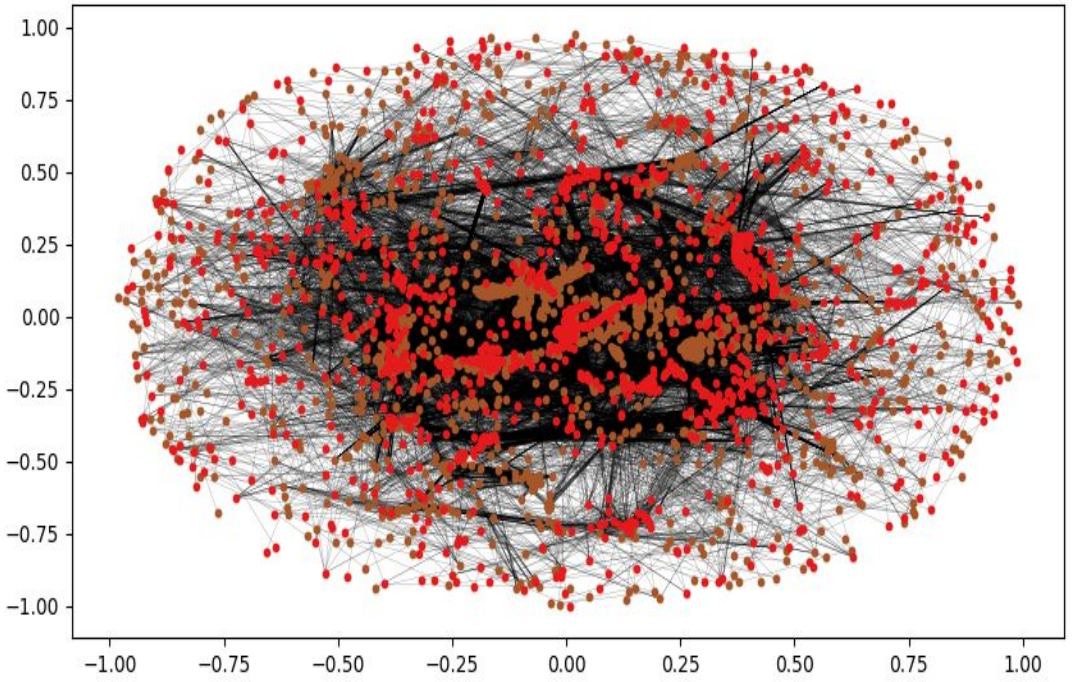
After Clique Processing (USA)



Bonus: USSR

- **Same analysis**
- Different launch site locations

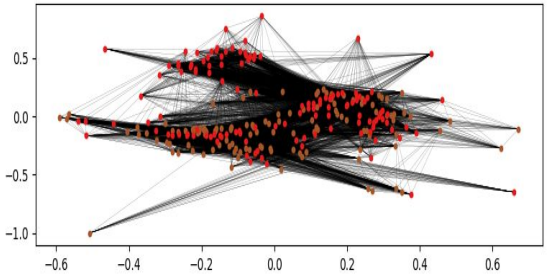
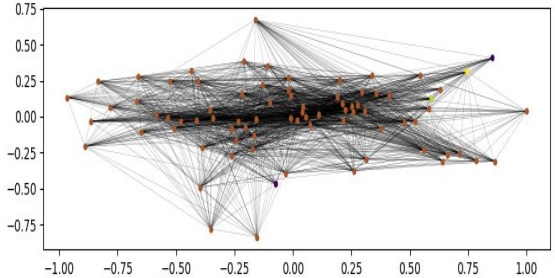
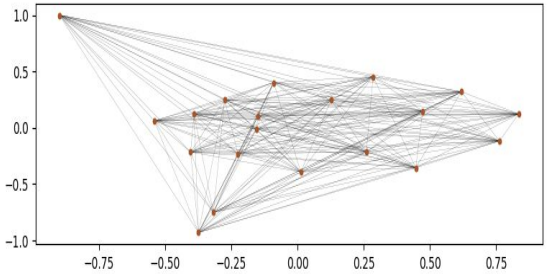
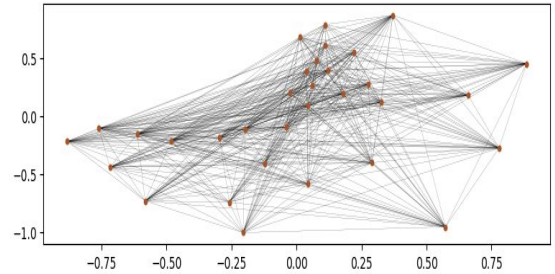
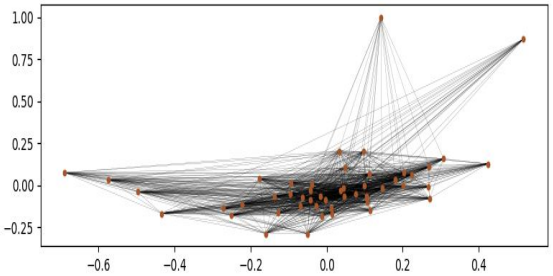
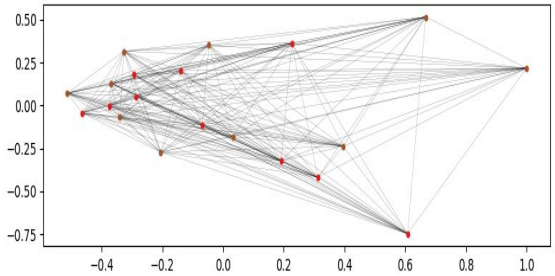
Base graph for USSR



Bonus: USSR

- Same analysis
- Different launch site locations

Subgraphs for USSR

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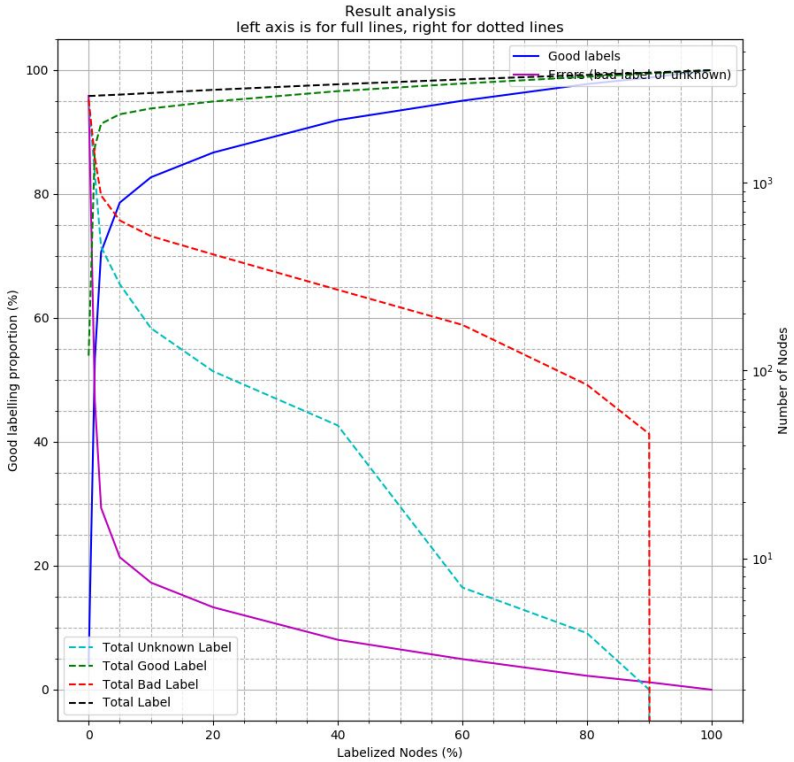
Labeling results for USSR



Conclusion

- Analysed satellites informations of two different databases
- Extracted information
  - Similarities of orbits
  - Clustering by launch sites
- Further work : **TLE to Launch Site**

Any Questions?