

Identifying natural cities based on nighttime imagery

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This tutorial shows in a step by step fashion how natural cities can be generated from night time imagery. Based on the available data cities are delineated by selecting the light which is the brightest, which indicates that a city is present at that position. Along the way the concept of natural cities is explained and a possible interpretation of the end result is given. This tutorial is based on the method conceived by Jiang (2018) and developed further by de Rijke et al. (2020).

Introduction

When we move from point A to point B, there are certain rules we must adhere to. We cannot teleport to our destination, we have to move through doorways as we cannot walk through walls. Our most efficient paths to our destination are also predetermined. Locations of building, roads, bridges, stairs, etc. shape the path we are most likely to take. The structure we have built in the past shapes our movement in the present (Lynch, 1960). Natural cities is a concept which, based on present structure, delineates city borders. The concept of a city is not strict, but fuzzy. Is a settlement a city when it reaches a certain size, a certain population, a certain wealth level, or a combination of those. By delineating the city based on its physical structure, or derivatives of that, we obtain the natural city.

In this tutorial the natural cities are going to be determined based on nighttime imagery. This is data collected by a satellite flying above and around the earth taking pictures of the earth surface at night. Due to lighting in cities at night, for example along streets and in industrial areas, concentrations of light are measured at city locations. Because the satellite measures how much light is being emitted from places we are able to separate areas with a relatively high intensity in light from areas with a low intensity of light (or none at all). In this case cities will be located at areas of high intensity, while rural areas are located in areas of low intensity. Thus separating the urban areas (natural cities) from the rural countryside.


Data gathering and preparations


This tutorial is written for use with ArcGIS software (<https://desktop.arcgis.com/en/arcmap/>) but only basic GIS (Geographic Information Systems) operations are used and therefore could be done with other GIS software like QGIS (<https://qgis.org/en/site/>) as well. For the calculation of head/tail breaks you can use an excel file calculator (<https://github.com/ChrisdeRijke/HeadTailBreaksCalculator>), you will need the two columns version for working with rasterdata (which is the nighttime imagery) and the one column version for working with one dimensional lists (which is used in the interpretation of the generated natural cities).


The input data used for this tutorial will be composite nighttime imagery from the Earth Observation Group who maintains the current generated nighttime VIIRS (Visual and InfraRed Imaging Suite). The data can be found at: <https://eogdata.mines.edu/products/vnl/>. For this tutorial the data which is used is a snippet of the Europe tile (60W75N). Optimally when natural cities are generated you would want to do this based on information about the entire world – therefore the entire nighttime dataset. However while this is technically possible, for this tutorial the data used will be lighter for easier and faster computation. This tutorial uses the year composite nighttime data from 2016, version 1, VIIRS Cloud Mask – Outlier removed – Nighttime Lights (vcm-orm-ntl_v1) dataset.

Delineating natural cities from nightlights

The natural cities will be based on the brightness of the lights detected at night. All lights with a value below a mean lightlevel will be considered to be rural or dark(er) areas while all lights with a higher value will be considered to be bright enough for it to be considered a city. When the whole world is used the optimal value can be found for all natural cities in the world by using the first mean of the head/tail breaks method, i.e. the average lightlevel observed splits rural from urban areas. However due to the selection of a smaller area the first mean of the head/tail breaks method is not sufficient, and the second mean instead will be used.

1. Download and open the nighttime imagery *.tif* dataset in ArcGIS (*Add data -> SVDNB_..._vcm-orm-ntl_v1_avgrad.tif*)
2. Transform the dataset to integer format for easier calculation of head/tail breaks. Find the tool *Int (Spatial Analyst or 3D Analyst)* and run it with the nighttime dataset as *input dataset* and save the new integer nighttime dataset in a retrievable place.
3. Open the *attribute table* of the **Integer Nighttime .tif** by *right-clicking* it in the *Table of Contents* and selecting *Open Attribute Table (Or Ctrl-Left-Doubleclick)*. Then export the table to an excel file by exporting the table to a *.csv* (*table options*  -> *export*) or by selecting all table entries and copying them to the clipboard (*table options -> Select All -> Right-click*

the square before a row  -> *copy selected*) and then pasting them in excel.

4. Use the head/tail breaks calculator for two columns and input the *Count* column in column A and the *Value* column in column B.
5. Due to the relatively small and densely inhabited study area the first mean selects too much rural areas still. Therefore the second mean is selected as a delineator for the natural cities. *Reclassify (3D Analyst or Spatial Analyst)* the **Nighttime.tif** into two classes so that 0 contains all rural areas (value<=9,8) and 1 contains all cities (value >9,8).
6. Use the *Raster to Polygon(Conversion)* tool to create the final natural cities shapefile. Checkmark *"Simplify Polygons"* and Uncheck *"Create Multipart Features"*.
7. Select all polygons with the value "Gridcode" = 1. Go to *Selection -> Select by attributes*. Select the polygon layer generated in the previous step as *layer*. As *Method* select *Create a new selection* and finally in the empty white space below *SELECT * FROM ...* fill in: *"gridcode" = 1* and click *OK*.
8. Export this selection by *right-clicking* the layer from the previous step in the *Table of Contents* and selecting *Data -> Export Data*. Export the *Selected features* and select a name and place for the exported layer to be saved by clicking . You have now generated the natural cities based on nighttime imagery.


	A	B	C	D	E
1	Count	Value	<--- Insert Here		
2	4671662	0		Head/tail breaks 1.0	
3	300507	1		# rows	Mean
4	142585	2		5602608	1.160881325
5	89558	3		630439	9.839898864
6	62748	4		179082	24.39514859
7	46762	5		55406	45.32319604
8	36214	6		16880	83.28388626
9	29243	7		3281	186.1853094
10	24130	8		851	396.2690952
11	20117	9		259	690.7683398
12	16984	10		63	1274.111111
13	14561	11		10	3636.5

Interpreting natural cities

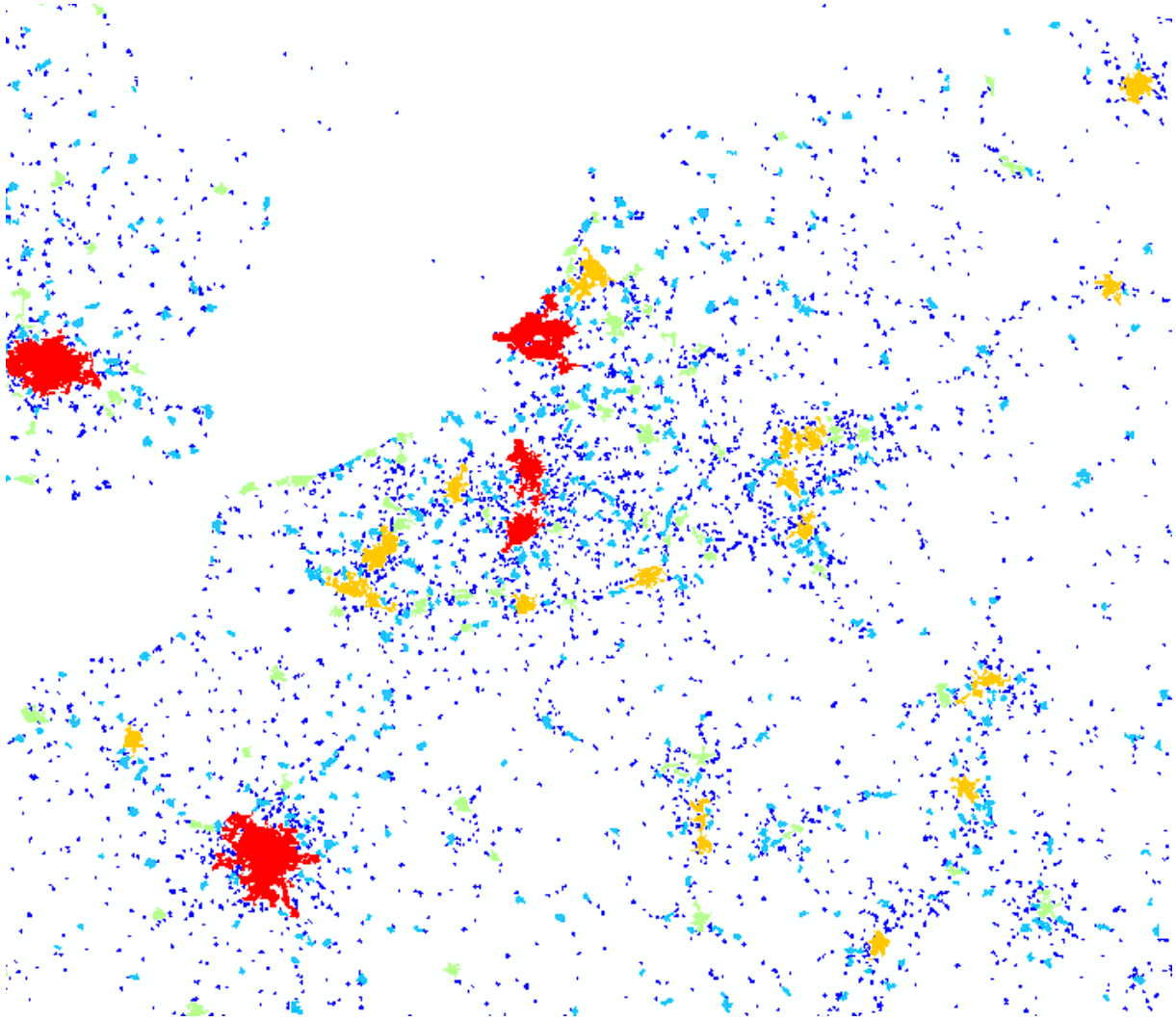
The natural cities which you have generated delineate city borders based on light radiation. This means that especially industrial areas and large infrastructure like harbors and airfields are comparatively

overrepresented. At night residential areas produce limited amounts of light radiation, while the aforementioned areas usually are active 24/7, meaning a lot more lighting is needed. Another consequence of using light radiation is that light diffuses over a distance and from a distance it merges together as well. This means that the generated city borders are smoothed out and separate cities close to each other can be observed as one big city. Other methods of generating natural cities therefore may be preferable for more detailed city delineation, however the method described in this tutorial is computational very quick and easy to understand.

The generated natural cities can be analysed further than just their positioning, namely they can be compared to each other. By calculating the area of each natural city and then running the different sizes of natural city through the head/tail breaks calculator (or calculating head/tail breaks manually).

1. First *Project(Data Management)* the final natural cities shapefile generated in the previous section to a *Projected Coordinate System* (WGS84 = Geographic Coordinate System). One such *Projected Coordinate System* suitable for the area of Europe is EPSG:3035 (ETRS89 LAEA Europe) (<https://epsg.io/3035>). In the *Project* tool select the shapefile generated in the last step of the last section as *Input dataset*. It should automatically select *GCS_WGS_1984* as *Input Coordinate System*. Give the new file a name and a place in *Output Dataset* and finally select *ETRS_1989_LAEA* as *Output Coordinate System* (Which you can find in *Projected Coordinate Systems -> Continental -> Europe*). After you have reprojected and added the layer to your *Table of Contents*, *Right-click* in the dataframe and select *Data Frame Properties*. Find the *Coordinate System* tab and select the *ETRS 1989 LAEA* as coordinate system to match your reprojected file.
2. Open the *Attribute Table* of the reprojected natural cities shapefile generated in the previous step. (How to open the attribute table is in step 3 of the previous section).
3. Click the *Table Options*  and select *Add field*. Name it *area* and as *Type* select *Double*. Now a new column should show up in the attribute table.
4. *Right-click* the *area* column and select *Calculate Geometry -> Area* (If this is disabled, make sure your layer and dataframe are in a projected coordinate system (See step 1)).
5. Transfer the *area* column to excel (See step 3 of the previous section) and calculate head/tail breaks on this column, input the whole area column in column A in the *HTcalculator* one column.
6. Using the calculated head/tail breaks the natural cities can be classified into different classes. Go to the *properties -> symbology* of the natural cities and select *Quantities -> Graduated Colors*, with *area* as value. Then click the *classify* button and manually select the correct number of classes and break *values*.

Not only do the amount of head/tail breaks indicate that the natural cities are for example long tailed, but also the visualization highlights where the largest natural cities are, and also how they are organized and supported by nearby natural cities.



Acknowledgement

This tutorial is made to explain the concept of natural cities in a basic and applicable manner and has been transferred into a step by step guide after discussions with Prof. Dr. Bin Jiang during our research into living structure. In an attempt to educate more people in the concept of living structure a set of tutorials was made indicating living structure across different scales. We would also like to thank the participants of the 2021 AGILE conference living structure workshop, as their comments have helped improve this exercise.

References

- Jiang B. (2018), A topological representation for taking cities as a coherent whole. *Geographical Analysis*, 50(3), 298-313.
- Lynch K. (1960), *The image of the City*, the MIT Press: Cambridge, Massachusetts
- de Rijke C. A., Macassa G., Sandberg M., and Jiang B. (2020). Living Structure as an Empirical Measurement of City Morphology. *ISPRS International Journal of Geo-Information*, 9(11), 677.