Iso-edges for the Geovisualization of Consumptions

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Abstract: Data Visualization is emerging as a tool to understand and explore data in various ways. It enables us to interpret, synthesise, and present complex and vast amounts of information. We use Data Visualization to represent the evolution of consumptions in 729 hypermarkets and supermarkets of the biggest Portuguese retail company, for a time span of two years. We aim to apply an Information Visualization technique in order to study how, through Data Visualization, we can represent, synthesize, and interpret consumptions' data. The geospatial data enables us to represent the consumptions in the different municipal districts and to analyze how consumptions evolve over time. To present this data, we apply an isoline approach, introducing a new technique called iso-edges. We also implement an interface for the exploration and analysis of the data.

1 INTRODUCTION

The number of structures to collect and save data on retail companies is increasing, and thus the necessity to analyze and understand this data is of the utmost importance. Data Visualization can be an invaluable asset in this process. The representation of geospatial data with the goal of understanding how data evolves through time in specific regions is an important task for retail companies. This type of information may assist retail companies in, for instance, stock management, understanding seasonal variations, determining where to place new facilities, etc.

For this project, we have access to the dataset of 729 Portuguese supermarkets and hypermarkets of the SONAE chains, which covers the entire country. We used all transactions made on those supermarkets and hypermarkets from May 2012 to April 2014. Furthermore, we have access to the zip-codes of all clients of the SONAE chains, which gives us an estimate of the clients' geographic position, and to the locations of the main buildings of Portugal. This data about the consumptions was already explored through a calendar visualization which aided in the understanding of how the consumptions evolved in the different departments of the SONAE chains (Macas et al., 2015; Maçãs et al., 2015). We also used the geographical data of the consumptions to explore how the customers move from one supermarket to another (Polisciuc et al.,). The main goal for this project is to apply an Information Visualization technique to represent how consumptions are distributed throughout Portu-

gal and how this distribution evolves through time, thus highlighting the changes in the patterns of consumption in specific times of the year, such as Christmas. Additionally, it is a first step in the development of a visualization tool to assist decision making regarding the opening, or renewal, of facilities.

To represent the geographical variations of consumptions, and as an initial approach, we resort to contour lines, i.e. isolines, which delineate areas with similar values of consumption, thus identifying regions with different consumptions. Isolines depict consumptions that were not measured in those specific geographical points, but that were calculated in relation to the area of collection. The use of isolines allows us to identify, delimit and highlight geographic areas of high and low consumption values. When applying this technique to our data we realized that the isoline density was low, which impaired the readability of the visualization. As such we introduce a new approach to complement the isolines, iso-edges, increasing their density in order to promote the efficiency of the visualization.

The paper is structured as follows: in Section 2 and Section 3 we present a short overview of spatiotemporal visualizations and thematic maps, respectively; Section 4 describes the data, our approach for the geo-representation of consumptions using isolines and iso-edges, and the interface, which enables the user to explore the visualization; Finally, in Section 5, we draw some conclusions.

2 SPATIOTEMPORAL VISUALIZATIONS

Data representing time and space are found in a wide range of domains, and can be used to find and comprehend natural and social patterns, and to help make predictions. Spatiotemporal visualization techniques can efficiently organize and represent temporal geographic data sets, providing a global view of the activities, and thus revealing overall tendencies and movement patterns (Meirelles, 2013). The application of these visualization techniques carries some challenges such as their computational requirements, caused by the usually large data sets, and the need for a sound understanding of how information and knowledge can be extracted from the data, and transposed in the visualization (Zhong et al., 2012).

Traditionally, maps have been used as models for spatiotemporal datasets (Meirelles, 2013). Through the use of maps, the geospatial patterns and clusters are generally easier to identify. Zhong et al. (Zhong et al., 2012) groups the most important spatiotemporal visualization techniques in 5 different types: (1) Timestamps and Time Labels, which are series of events marked with date and time information. The time labels are specific graphic variables used in maps indicating changes. This type of visualization is static. Minards famous graphic of Napoleons Russian campaign is one example of this technique; (2) Baselines, which use arrows and lines to represent the changes in the data. This technique can apply animation methods to represent the progress. Natalia Andrienko and Gennady Andrienko (Adrienko and Adrienko, 2011) propose a method for spatial aggregation of movement data, which can be explored in an interactive visualization that creates legible flow maps; (3) Image Series, where timelines are used as the basis for mapping events over time, and the dataset is represented through series of images. Guo et al. (Guo et al., 2006) developed a tool called VIS-STAMP which aid in the exploration and understanding of spatiotemporal patterns. Their approach includes several visualizations within which one of geographic small multiple display; (4) Space-Time Cube, developed by Hägerstraand (Hägerstraand, 1970) is a three-dimensional diagram with time as the third spatial dimension. He explored this technique to show life histories of people and how people interact in space and time; and (5) Real-Time Rendering of Dynamic 3D Scenes, which uses real-time animated 3D rendering techniques. Weber et al. (Weber et al., 2009) creates an interactive simulation of 4D cities, which is based in 3D models of an urban environment and its evolution through time.

3 THEMATIC MAPS

Thematic maps appeared in the second half of the seventeenth century representing data in the natural sciences, and can be defined as the representation of attribute data on a base map. Thematic maps display qualitative or quantitative data. Their purpose is to reveal patterns and frequencies in the geography where they occur (Meirelles, 2013), to discover the geographical structure of the subject, and to relate its distribution on the map (Robinson, 1982).

The 1701 isoline map of magnetic fields by Edmond Halley is considered the first thematic map. These maps can be divided in: dot distribution maps (Fry, 2004); graduated symbol maps (Brewer and Campbell, 1998); choropleth maps (Brewer and Pickle, 2002); isometric and isopleth maps (Mellier et al., 1988); flow and network maps (Thorp, 2009); and area and distance cartograms (Meirelles, 2013).

The first isopleth maps depicting population densities were created by N. F. Ravn in 1857. The General Bathymetric Chart of the Oceans records from the International Hydrographic Organization is another isopleth example, which uses as a visual metaphor for coloring "the deeper or higher, the darker". It shows the great ocean trenches of the western Pacific and Japan Sea, and has numbered contours to improve accuracy of reading (Tufte, 1990). In 2006, Chris Lightfoot created a *Travel-time Map* that represents the time needed to travel from site A to site B (Lightfoot, 2006). The visualization is drawn on a base map where the color of each pixel depends on the time spent, having warm colors to indicate short journeys and cool colors for longer journeys.

For this project, we will only focus in the isopleth maps, more specifically, in the isolines. Isopleth maps are composed by a set of lines or areas that show the distribution of values that cannot be referenced to points. These lines, depict data that were not measured in those specific points, but were calculated in relation to the area of collections. The calculated centroid of each area is considered the data point for the line construction (Meirelles, 2013). Some examples of this technique can be seen in maps that represent the mean temperatures or the average precipitation levels. In 2013, the Department of Energy & Climate Change of England created an isopleth map that shows the actual heat demand from buildings across England (DECC, 2013). With this map developers and planners can perceive which areas are suitable for the development of local heat networks. Isoline maps, are isopleths where there is no shading. Edmond Halleys 1701 map of magnetic lines is considered the first map to make use of lines of equal value to encode

data. Nowadays, the use of isolines to represent population data is less popular, and the majority of isometric and isopleth maps, shows natural phenomenas, such as climate and geology.

4 GEO-REPRESENTATION OF CONSUMPTIONS

We propose the application of the isoline technique as a method to visualize and explore the evolution of consumptions in the different municipal districts of Portugal through time. We also propose a complementary method, which we designate as iso-edges, to increase the density of information presented in the map, improving readability.

In this project, the isolines are projected on the Portuguese map along with the representation of the main buildings (retrieved from the Open Street Maps[1]) and the zip codes of costumers. This data provides a visual reference to the viewer, highlighting on the map the main residential conglomerates and buildings[2]. These locations are represented in the map with small, black circles of equal size so they do not overpower the visualization but, at the same time, are visible and can be compared with the consumption data. For this project, and since we wanted to analyse the differences between the different months, we calculated the average consumption of every month from the dataset.

To differentiate the areas with different consumptions we draw a set of lines to separate them: isolines. Each one of these lines, is representative of one consumption value and separates the areas with more and less consumptions than the lines' value. With this Information Visualization technique we are able to see the geographic map behind and to analyze the differences in consumptions.

To generate the isolines, first we had to create a triangulation between the centroids of all municipal districts of Portugal. We used the Delaunay Triangulation algorithm to do so (Lee and Schachter, 1980). Ideally, to avoid cluttering and promote readability, the isolines should have a similar distance among them, as in the work of Bruno Jobard (Jobard and Lefer, 1997). Considering that we want our isolines to be evenly distributed, the isolines' values cannot be

predefined. As such, we defined a minimum distance and represented only the isolines that have that minimum distance among them. With this first approach, the resulting isolines were too sparse, which translated into a small amount of information, difficulting the reading of the data. To give more insight, we decided to complement the isolines. As such, in addition to the previously drawn isolines, we also draw isolines which are not closed—iso-edges. These iso-edges, are calculated in the same way as the isolines, but, if the isoline has segments which are too close from the previous drawn isolines, those edges are eliminated until the isoline is drawable. This technique resulted in a wide number of iso-edges, which completed the visualization and gave more insight about the data, specially in cluttered areas created by municipal districts which are too close to each other.

This section is divided in three sub-sections. In the first, we describe the dataset and explain how we aggregated the data. In the second sub-section, we describe how we generated the isolines and iso-edges, and present some results. In the last sub-section we present the interface which enables the user to explore the visualization.

4.1 Data

The consumptions data is retrieved from 729 Portuguese supermarkets and hypermarkets of the SONAE chains, which covers the entire country. The clients from these chains tend to use their client cards when shopping, to accumulate discounts and other benefits. Currently, the number of active cards is above 6 million, which can be considered an impressive number, specially if we take into consideration that the Portuguese population is below 11 million, and that the cards are issued by "household" and shared by the entire family. For this project we used all the transactions made on those supermarkets and hypermarkets from May 2012 to April 2014. Each transaction corresponds to one product bought and it has properties such as price, date, place, and time of purchase. Each product is placed in the product hierarchy of the company, which has 6 levels and corresponds to a type of the product. For this work, we aggregate all the purchases independently of the type of product. Since the goal of the project is to give an overview of the consumptions differences among the months of our dataset, we also calculated the average consumption value for every month, depending on the municipal district where the purchases occurred. The shapes of Portugal and its municipal districts were both retrieved from the Open Street Maps.

Our data, has some inherit characteristics: first,

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[1] https://www.openstreetmap.org

[2] It is important to notice that the areas where people live and the areas where people shop are not necessarily the same. In certain cases areas with low population density correspond to business centers which are highly populated throughout the day. As such it is necessary to convey both types of information.

the consumption volumes are not related to each other, meaning, municipal districts close to each other can have different consumption volumes, what causes the consumption distribution to be irregular; and second, the distance between municipal district centers is not the same, some districts are close to each other and others far apart. These two characteristics are, in some way, related: in general, the nearer from the coast the municipal district is, the higher the consumption value is and the closest the districts are from each other; and the nearer to the interior of Portugal the municipal district is, the lower the consumption value is and the farthest the districts are from each other. Furthermore, the places where the consumptions are higher, occur mostly in the same areas, such as, Lisbon, Porto and Faro. These characteristics are deeply linked with the demographics of Portugal.

4.2 Isolines and Iso-edges

To visualize the consumption differences between the municipal districts of Portugal we implement an isoline technique which delimits the areas with different consumption values. One isoline represents one consumption value. To generate them, we have to define the values that they are going to represent. Given the inherent characteristics of our data, and the goal of having the isolines evenly distributed along the Portuguese map, we cannot divide the space of consumption values in equal ranges, as our range of consumption values are not linearly distributed by the municipal districts. Furthermore, in our consumption data there are more municipal districts with low consumptions then with high consumptions, so if we divide the range of consumption values in a linear way, the isolines would be very irregular, some too close to each other, others too far apart (Figure 1).

To attain a more uniform and informative distribution of isolines over the map, we defined their values using an iterative process. First, we find the higher consumption value of all months, so that it is possible to compare the differences among the different months, and use this value, iso_{max} as reference for an isoline. The remaining isolines are obtained by decreasing values of consumptions with a sampling step of $step$, in other words, the ith isoline corresponds to a consumption value of $iso_{max} - i \times step$. The higher the $step$ is, the fewer isolines are calculated, resulting in a map with less detail, since the range of consumption values is divided in fewer parts. In order to have as much isolines as possible without compromising legibility, we used a $step$ of 100, so small differences in the consumptions are discarded. Once the isolines' values are calculated, the drawing algorithm deter-
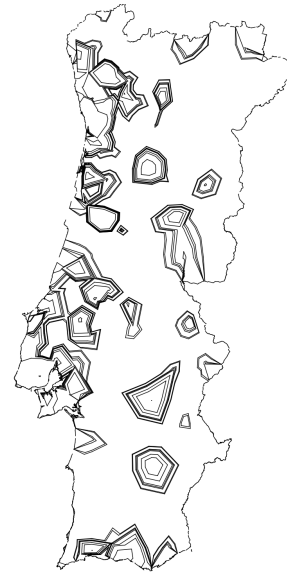

Figure 1: Isolines generated with a linear division of the consumption values.

mines which isolines are drawn. We start by drawing the isoline corresponding to iso_{max} and proceed by iteratively decreasing the consumption values; An isoline is drawn if, and only if, all of its points are, at least, at a minimum predefined distance, min_{dist}, of the isolines that were already drawn. The isolines which are too close to those that were already drawn are discarded. The values for the constants $step$ and min_{dist} are empirically determined.

Before computing the isolines, it is necessary to create a triangulation between the municipal districts centroids. These centroids are pre-calculated for each municipal district shape through the centroid of the polygon (Bourke, 1988). Afterwards, we implement the Delaunay Triangulation (Lee and Schachter, 1980) for these centroids, and we get an array of triangles that link the closest municipal district centers. Note that our triangulation does not connect the centroids of the municipal districts that are in the edges of Portugal and have more than one municipal district centroid in the middle (Figure 2) (Ahlen, 2010). The connection of all the centroids would create isolines which are out of the area of Portugal and that do not represent the data.

For every month, each centroid has a value corresponding to the consumption in that municipal district. To find the points that compose the isoline corresponding to a given consumption value, we search pairs of vertices of the triangulation whose associated consumption values define an interval comprising the value of the isoline. To position the isoline point along the vertex defined by these two points, we interpolate linearly between the the vertices' values.

Figure 2: Triangulation of the municipal districts of Portugal. Note that there are no connections out of the Portugal's Shape.
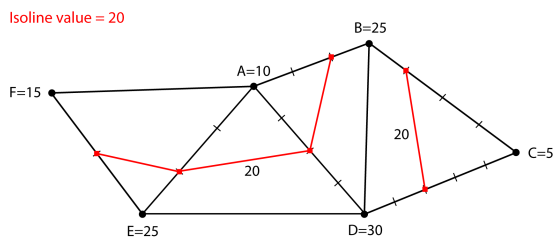

Figure 3: Six centroids [A..F] and corresponding consumption values. The points of the isoline corresponding to a consumption value of 20 are determined through interpolation between the extremes of each edge.

Figure 3 illustrates this process.

Once the points of the isoline are determined, the isoline is defined by connecting the two points of each triangle belonging to the isoline path[3], generating an iso-edge. We save each iso-edge in a hash map that has as key the consumption value of the isoline and as value an array of the edges. This way, we easily separate the iso-edges of different values.

Once all the iso-edges are calculated, we group the edges that belong to the same isoline and see if the isolines have a predefined minimum distance from each other. To generate an isoline, and since an iso-edge is represented by two points, we just need to join the iso-edges that have one point in common.

We generate all isolines for every isoline value and

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[3]If the triangle belongs to the isoline path, then it will always be intercepted in exactly two points, except when all the vertices of the triangle have the exact value of the isoline. In that case the isoline matches the shape of the triangle
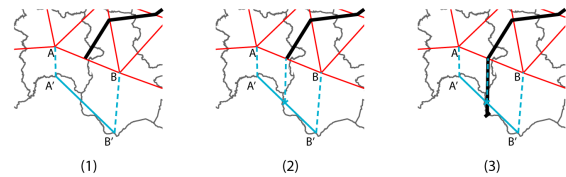

Figure 4: Schematic of the isoline closing technique. 1) Projection and connection of the Municipal District centroids; 2) Connection of the end of the isoline and it's projection; 3) closing the isoline.

save them. At each iteration through the isoline's values, we need to determine which isolines are to be drawn. To do so, and to make this process faster, we defined a radius, so the algorithm only searches for isolines whose centroid is close to the current isoline's centroid. For each point of the closer isolines, we compare the distance among the points of the current isoline. If the distance between two points is smaller than the minimum distance, we do not draw the current isoline and repeat the process for the next isoline. It is important to note that we start our algorithm with the isoline with higher consumptions, so no isoline intersects. With this method we are able to create a relatively uniform distribution for the isolines.

Next, since the triangulation does not use the edges of the Portuguese map, it is necessary to connect the isoline's endings which are placed near the outline of Portugal. We decided to: project the centroid of the municipal district by placing it in the middle of the coast line; map the isoline value into an imaginary line that connects the projected centroid of the two municipal districts; generate a line that connects that point to the end of the isoline; and draw it until it reaches the outline of Portugal. This way, there is no isoline with unclosed endings (Figure 4).

The final step for the creation of the isolines is the rounding of the isolines' corners and the coloring. For the rounding of the isoline's corners we applied a method described in (Polisciuc et al., 2015). With this method we were able to smooth the corners and to give a more organic aesthetics to the visualization. With all isolines set, it is necessary to distinguish the different consumption values that they represent. Since our data has substantial differences in the number of isolines with high and low consumptions, a linear color palette, that goes from one color to the other to represent the range of values between the lower and higher consumptions, would not differentiate enough the low values and would create detail in the high values, which is not desired. Therefore, we need to create an algorithm to generate a color palette that gives more detail in the low values and less detail in the high values. First, we calculated all the isolines which are drawn in each month of the two

Figure 5: Differences of the visualization with iso-edges (left) and without (right). One can perceive that in the left side of Portugal, specially in the center and upper part, the iso-edges generate more density, thus creating more insight about the consumptions.

Figure 6: Visualization of the consumptions in December 2012 (left) and January 2013 (right). Between these two months, the average consumption is similar, having higher differences in the center of Portugal, higher consumptions in December than in January.
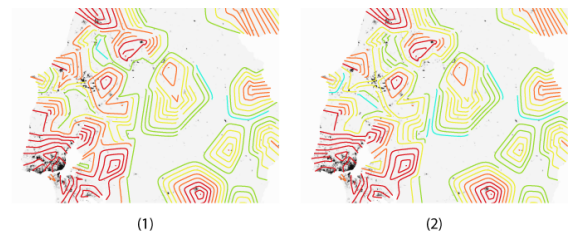

Figure 7: Visualization of the consumptions in February 2013 (1) and February 2014 (2). Small differences in the generated isolines and iso-edges. Higher consumptions in February 2013 in the west coast of Portugal.

Figure 8: Visualization of the consumptions in October 2012 (1) and October 2013 (2). One can perceive the opening of a new store in October 2013 through the appearance of new isolines.

years of data, and group them by consumption value. Note that, having calculated the color palette for every month enables us to use the same color palette, and thus enables us to compare the different months and the evolution of consumptions over time. To define the color palette we divided our consumption values in equal sized bins (quantile) to group the consumption values in different ranges. With this method, we have more colors to distinguish the isolines with low consumptions, since there are more isolines in those ranges, and less detail in higher consumptions. Our color palette goes from the cold colors, for the low consumptions, to the warm colors, for the high consumptions.

Since some centers of the municipal districts are too close to each other, and the isolines are restricted to a minimum distance among them, we get few isolines in some areas of Portugal. This is translated in a lack of information about the consumptions, which does not fulfill our objectives. To generate a complete visualization of the consumptions we propose a new method—iso-edges. This method, creates more density in our visualizations promoting readability. We used the isolines that were not drawn in the previous approach. Implementing a similar algorithm, every time that an isoline cannot be drawn, we save it into an array. When all the drawable isolines are generated, we start again with every non-drawable isoline. Then, to each point of the isoline we see if it is too close, or not, to the points of the other isolines. Here, instead of not drawing the isoline, if one or more points are too

close, we cut the isoline in edges, so that the drawable edges have, at least, a minimum distance from the other isolines already drawn. Figure 5 highlights the differences between including or not the iso-edges.

In Figure 6 we can see the results of our approach. With the use of the color palette we can better distinguish the areas with different consumptions. In Fig-
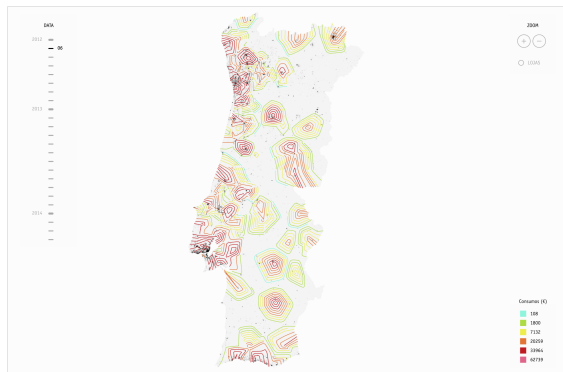
Figure 9: Isolines interface.

ure 7, we can perceive that the consumptions were higher in 2013 than in 2014 in the region of Lisbon. It is possible to see that our isolines do not have significant changes as time passes. They are almost in the same locations only with different colors. This is due to the fact that the triangulation is the same and the places where the consumptions occur also stay the same. The only exception to this, is the opening of a new store in October of 2013 in the district of Sines. In the visualization (Figure 8), it is possible to find a new set of isolines in the south of Portugal (2).

4.3 Interface

To facilitate the interaction and exploration of the visualization, we developed a intuitive interface which allows the user to explore the map and to change the displayed time period (Figure 9). To change the month, the user has a slider on the right side of the interface. This slider allows the user to choose between the different months simply by clicking on the intended month. The user can also interact with the map by zooming, using the buttons in the right upper corner or by using the scroll of the mouse. The zoom has different levels in which the isolines and iso-edges are updated. As the user zooms in, more isolines and iso-edges appear creating a more detailed map of the consumptions in the zoomed area (Figure 10). The user can also drag the map and explore different areas of Portugal.

In order to have a more extensive understanding of the consumptions, it is also possible to see the location of the stores where the consumptions occurred. To do that, the user has to click in the upper right corner, in the "lojas" (stores) toggle. Finally, to help the user to read the values, a caption with the color palette of the isolines is displayed in the right bottom corner.

5 CONCLUSION

Through Data Visualization we are able to explore, comprehend and synthesize big and complex datasets. With access to the geo-localization of the hypermarkets we represented the evolution of consumptions in Portugal in the 729 hypermarkets and supermarkets of the biggest Portuguese retail company, SONAE. We applied an isoline technique to differentiate the areas with different consumptions. An isoline is a line which represents a value that is calculated through the consumption value in the municipal districts. Our first approach was considered unsatisfactory since, due to the dataset characteristics and the demographics of Portugal, the resulting visualization conveyed little information regarding the areas of Portugal with highest population densities and consumptions. As such, we introduced a new technique, iso-edges, which can be defined as unclosed isolines. This technique overcomes the problem by providing additional visual information to these regions, which are, arguably, the most important ones from a facility allocation standpoint. With this technique, we are able to analyze the differences in consumption among the municipal districts, to analyze the areas which are not covered by the SONAE's hypermarkets, and to highlight areas of low consumptions and high populations, which can be promising locations for opening new stores. Furthermore, we implemented an interface to enable the user to easily explore the visualization. Through this interface the user can access different zoom levels which give to the visualization of different levels of complexity.

Future work will focus on providing, through visualization, a tool to further support decisions concerning the opening of new facilities. To this end we will take into account the number of inhabitants per region, their estimated income, the percentage of active and inactive costumers, the proximity to existing surfaces and their capacity.

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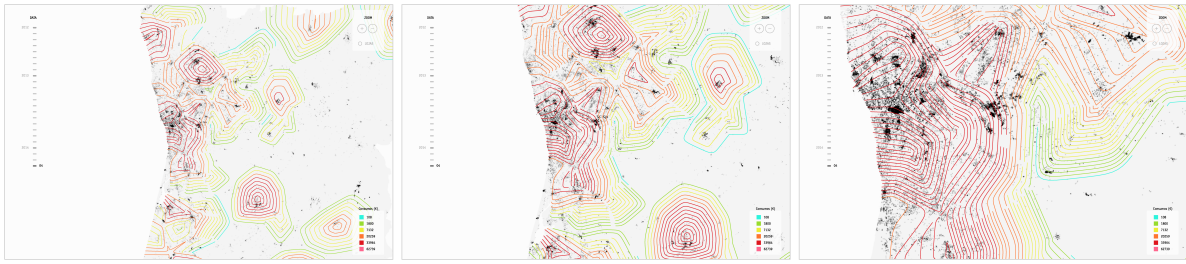
Figure 10: Different zoom levels.

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