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Understanding City Dynamics through Spatio-temporal Visualization

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Abstract

Every time we visit a new city there is a huge effort made in understanding its dynamic, i.e. what are the relevant locations within that city in each time period, for there are large amounts of data to sift through. Although several attempts have been made to combine information from various sources, the majority focus on geographic data, lacking on time representation. In this paper we describe and evaluate three representation approaches for spatio-temporal data, to understand which is better to convey the dynamics of a city at a glance. We devised 2D and 3D visualizations to understand their adequacy to our objectives. Based on the results from the evaluation with users we noticed that they preferred the 2D visualization of the data, but on the other hand there was no significant difference to the 3D representation.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Methodology and Techniques]: Interaction techniques—H.5.2 [User Interfaces]: Evaluation/methodology—

1. Introduction

With the latest advances in technology we can now record not only the time but also the exact place where the data was collected, leading to a high amount of temporal- and geo-tagged data. However, it is still very difficult to perceive the dynamics of a city just by combining this information. Our goal was to devise a visualization for this type of data able to convey in a simple, effortless and effective way the dynamics of a city, *i.e* what are the places with a higher affluence in the morning, at night, on Mondays, in April, etc.

The concept of combining time and space into a single representation was first approached by Torsten Hagërstrand [Hä70] in the early seventies. More recently there have been several approaches using 2D and 3D representations. Andrienko et al. [AAB*09] and Kisilevich et al. [KKK*10] developed 2D solutions using density and flow maps, which lack the representation of the time dimension and were prone to visual clutter. Kapler and Wright [KW05] created an approach based on the Space-Time Cube metaphor, which tried to improve the perception of movements, events and relationships as they change over time within a spatial context. This also suffer from visual clutter. Thakur and Hanson [TH10] proposed a new method where disks of variable diameter (according to normalized data values), are stacked along a vertical temporal axis, enabling the display and exploration of patterns both in space and time. There are also approaches for real time dynamics that capture and analyse digital bits of human activity, as if the city was a complex near real time system [RKR08]. These solutions overlay real-time collected data on maps of a city to capture urban dynamics as they occur [KSDLR11]. Although, several attempts have been made to show the dynamics of a city, the majority just focus on the geographical factor, some suffer from visual clutter, others are difficult to understand by the common user and finally few of them provide a good overview of the city dynamics at a glance.

In this paper we present three approaches for the representation of spatio-temporal data, describe their evaluation with users and the achieved results.

2. Techniques for Spatio-Temporal Visualization

To achieve our goal of providing a simple and easy way for users to understand the dynamics of a city at a glance without extra interaction, we developed three visual representations of the data, inspired by the solutions studied in the related work. We tried to explore different approaches for the visualization, by going from a pure 3D representation to a pure 2D visualization with an hybrid one in the middle.

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In our work, we assume that the spatio-temporal data to be displayed could be obtained from any source (photos, tweets, foursquare, etc.), given that it contains the time, date and the geographical coordinates where it was collected.

2.1. Dot Clouds

This technique is based on the Space-Time Cube concept and combines notions like the depiction of every event in their correct time and space and the "instant of focus" [KW05]. However, instead of making a 3D representation of the cube, we used two 2D regions. One to depict the temporal part of the data (timeline) and the other to represent the spatial information (map). Data is depicted as points both in the map (position where it was collected) and in the timeline. Here, points are horizontally aligned with their spatial position and vertically positioned according to their time. However, while all the points are available in the timeline, only those belonging to the selected time intervals will be represented in the map, respecting the "instant of focus" idea. This way, we provide users with a mechanism to explore the different periods of time and we avoid the visual cluttering in the map.

To help users identify the correspondence between the point in the map and the point in the timeline, our technique draws a guideline connecting the two points whenever the user hovers one of the points. Figure 1 illustrates the visual representation of this technique.

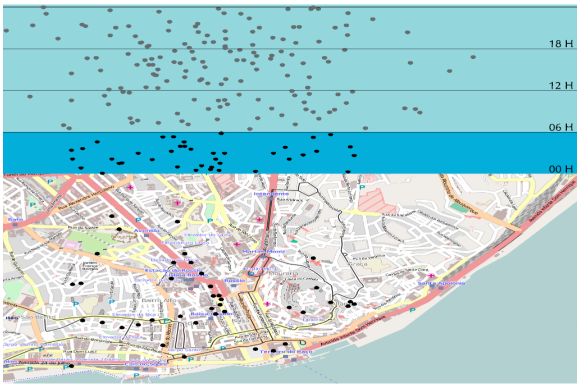

Figure 1: ***Dot Clouds*** *visualization, showing in the map the places with activity during the time interval from 0:00am to 6:00am*

2.2. Coloured Cylinders

In this solution we placed 3D markers on the map to represent the data associated to that place. The marker is a cylinder composed by four layers, each one corresponding to a time interval, as illustrated in Figure 2. By placing the markers in their specific location and by depicting all the correspondent data in the cylinder's layers we wanted to provide an overview of the city dynamics in a single representation.

To better recognize the various intervals we coloured them with distinct colours, not only from themselves but also from the map colours. To take advantage of the spatial memory of users, we draw all the cylinders with a constant height and their layers with the same size and always in the same position within the cylinder. When an interval does not have values, we draw that part of the cylinder with a neutral colour.

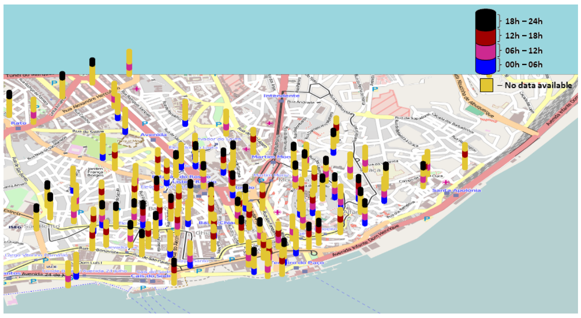

Figure 2: ***Coloured Cylinders*** *visualization, for the time intervals of a day.*

2.3. Coloured Pies

The last visualization is purely 2D, representing the timeline through circles divided in four (equal) intervals, similarly to what we did for Coloured Cylinders. The position of the time intervals inside the circle was decided using the clock metaphor, because it is more familiar to the users. Time intervals containing data are coloured, while the others are transparent, as shown in Figure 3. As in the previous visualization, Colour Pies allows users to get a quick overview of the city dynamics without any needed interaction.

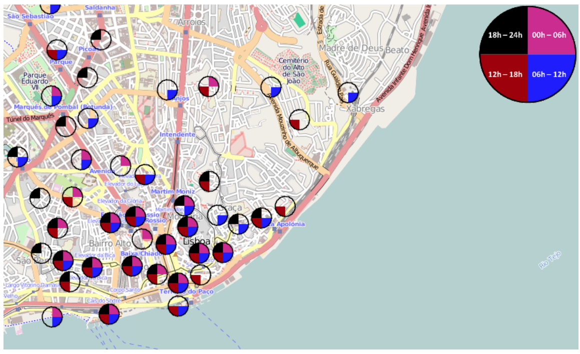

Figure 3: ***Coloured Pies*** *visualization, for the time intervals of a day.*

2.4. Time Intervals

Since sifting through the data is a hard task, we provide three timelines to aid the users while analysing the city dynamics, namely Day, Week and Year. All of them are available in the

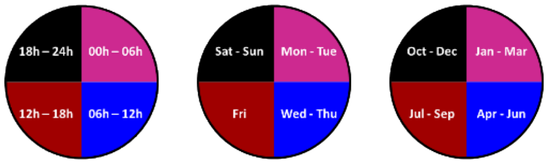

Figure 4: *The four intervals for each of the three timelines, Day (left), Week (center) and Year (right).*

three visualizations and were divided into four intervals, as illustrated in Figure 4 (for the Coloured Pies case).

2.5. Visual Cluttering

To minimize the problem of visual cluttering we applied a 3D hierarchical clustering algorithm to organize the spatio-temporal data into a cluster tree, before being consumed by the visualization techniques. Each level of the tree has a direct correspondence to the level of zoom in the map. This way, when we zoom out or in, the data points are merged or separated, respectively, as illustrated in Figures 3 and 5. The center of the clusters are used as the spatio-temporal points to represent.

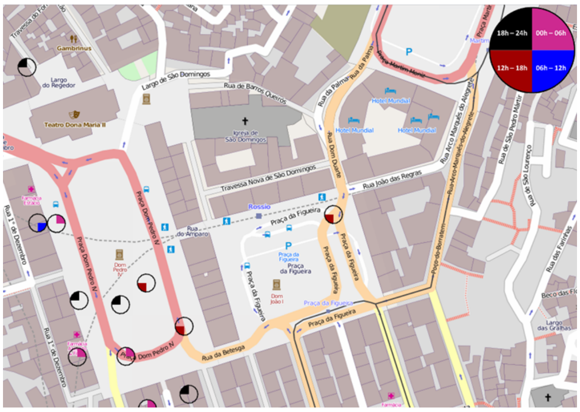

Figure 5: *Detailed view (zoom in) showing more data points.*

3. Evaluation

After developing the three visualization techniques, we performed an experimental evaluation with users to assess their effectiveness and easiness in conveying the dynamics of a city. We recruited 10 users ranging from 18 to 30 years old, 7 males and 3 females, with six of them living in the metropolitan area of the city used during the tests and without any knowledge on visualization techniques. Since all users tested the three solutions, we alternated the testing sequence to avoid the learning effect. We started the evaluation by providing a brief explanation about the concept of spatio-temporal data and of the objectives of our work and then we introduced the three visualizations. Users were not allowed to experiment the solutions before performing the requested tasks. During the execution of the tasks, we used the think aloud protocol to perceive their learning patterns and their difficulties. After executing the set of tasks, we asked them to complete a satisfaction questionnaire.

We used 5,000 photos with temporal and geographical information, collected from Flickr. The tasks were the same for the three visualizations to ensure a correct comparison. We asked users to perform seven tasks: the first three required limited interaction and focused on the identification of patterns and affluence of people in certain regions and/or time periods, and also on the understanding of the timeline. The second set of tasks focused on finding the time periods in which given locations had more/less affluence. The seventh and final task was divided in two parts, first a personal question to understand whether the users had the same perception of the real dynamics of a given location, and then they were asked to verify in the visualization if the results shown corresponded to what they expected.

All users performed the required tasks without much effort and with few errors in their answers. Figure 6, summarizes the average ratings for four questions of the satisfaction questionnaire. Question 1 was related to the easiness on understanding the time interval of the most visited locations, question 2 measured the easiness on understanding the points-of-interest given a time interval, question 3 evaluated the suitability of the available timelines (day, week, year), and finally question 4 was related with the representation of the points, regarding colour and shape.

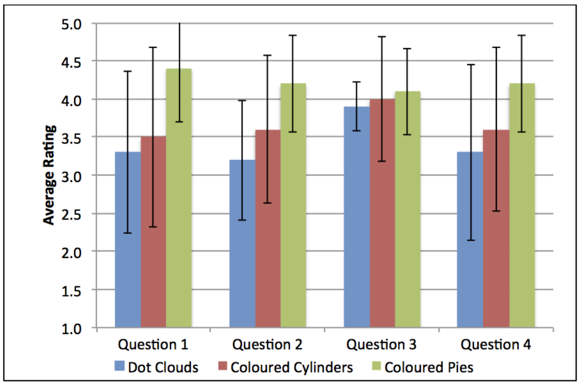

Figure 6: *Average rating of the three visualizations by question, with the correspondent standard deviation.*

As we can see, the Coloured Pies was rated higher in all questions, while on the other hand Dot Clouds was the worst rated. The majority of the users were more comfortable using Coloured Pies to understand the locations and time intervals with more affluence. Question 3 had a more consistent result because it concerns the timelines, which are the same on all visualizations. Additionally, the four users that do not

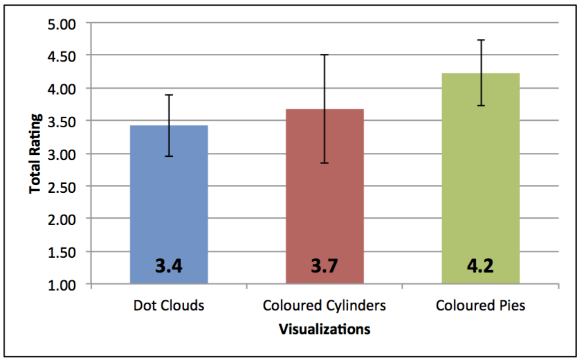

Figure 7: *Average score for each visualization, and the correspondent standard deviation.*

reside in the metropolitan area of the city, had no problems in understanding its dynamics and its most visited places, which shows that any of these visualizations are able to convey the dynamics of a city.

To get a better notion of the classification for each visualization, we combined the ratings from the various questions in a single value. The final scores are depicted in Figure 7. As we can see Coloured Pies has the best score ($M = 4.2, SD = 0.5$), while Coloured Cylinders is shortly behind ($M = 3.7, SD = 0.8$) and Dot Clouds is the last ($M = 3.4, SD = 0.5$). Although, the differences between the three visualizations are small a pairwise t-test shows that the average rating of the Coloured Pies is significantly bigger than Dot Clouds rating with a value of $p < 0.05$. On the other hand a pairwise t-test between Coloured Pies and Colour Cylinders did not reveal any significant difference in the ratings, with a value of $p < 0.28$. In fact, given the observed standard deviation, we can say that these two visualizations had almost the same rating, which can somehow be explained by their similarity. However, in the satisfaction questionnaire all users selected Coloured Pies as the best of the three visualizations to represent spatio-temporal data.

These experimental results allowed us to achieve some conclusions. The first is that the users feel more comfortable using products similar to those they are familiar with. Since the majority of them had already used online map services, they prefer a 2D representation. This was a little bit against what we were expecting, since the majority of the related works use a 3D representation to depict spatio-temporal data.

The identification of the most visited locations and time intervals was easy to understand, by almost every user, when performing the required tasks on our solutions. The biggest problem was with Dot Clouds, but when verbally questioned, the users replied that with the evolution of the tasks it became easier to understand the representation.

Finally, although we took some care on the selection of the colours for each time interval, we did not take into account colour blindness, making the execution of the tasks harder for one of the users suffering from this problem.

4. Conclusions

We presented in this paper three approaches for the visual representation of spatio-temporal data. One was in 3D, another in 2D and a third one using two projections of a 3D cube. Our goal was to understand which one conveyed more effectively the dynamic of a city, based on a set of spatio-temporal data.

Experimental results from an evaluation with users revealed that the Coloured Pies was the visualization preferred by the users, not only when we asked it directly, but also from the partial ratings that they performed along the satisfaction questionnaire. Moreover, users considered that it was easier to understand the dynamics of the city and its most visited places, using the Coloured Pies.

Our next steps will be to perform a deeper study to see whether 3D is not really a valid option to display spatio-temporal data, since there was no significant difference for the 2D visualization.

Acknowledgments

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References

[AAB*09] ANDRIENKO G., ANDRIENKO N., BAK P., KISILEVICH S., KEIM D.: Analysis of community-contributed space- and time-referenced data (example of panoramio photos). In *Proc. of the Int. Conf. on Advances in Geographic Information Systems (GIS'09)* (2009), ACM, pp. 540–541. 1

[Hä70] HÄGERSTRAND T.: What about people in regional science? *Papers in Regional Science 24*, 1 (1970), 6–21. 1

[KKK*10] KISILEVICH S., KRSTAJIC M., KEIM D., ANDRIENKO N., ANDRIENKO G.: Event-based analysis of people's activities and behavior using flickr and panoramio geotagged photo collections. In *Proc. of the Int. Conf. on Information Visualisation (IV'10)* (2010), IEEE, pp. 289–296. 1

[KSDLR11] KLOECKL K., SENN O., DI LORENZO G., RATTI C.: Live singapore!-an urban platform for real-time data to program the city. In *Computers in Urban Planning and Urban Management (CUPUM'11)* (2011). 1

[KW05] KAPLER T., WRIGHT W.: Geotime information visualization. *Information Visualization 4*, 2 (2005), 136–146. 1, 2

[RKR08] ROJAS F. M., KLOECKL K., RATTI C.: Dynamic city: Investigations into the sensing, analysis, and application of real-time, location-based data. In *Proc. of Harvard GSD Critical Digital Conference* (2008). 1

[TH10] THAKUR S., HANSON A. J.: A 3d visualization of multiple time series on maps. In *Proc. of the Int. Conf. on Information Visualization (IV'10)* (2010), IEEE, pp. 336–343. 1