Semantic Cities - Studying the Mental Maps of Urban Centers

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Abstract

Finding a population's mental map has seen increased interest in fields like psychology and urban planning. However, it represents a hard process to go through, often requiring long face-to-face interviews and producing results impossible to quantify. To address this difficulty, we introduce "Semantic Cities, a complete framework to create and deploy a mental maps survey and to analyze its results. To achieve this, we first uncovered the interactions necessary to make the data gathered by a digital survey on this topic as reliable and effective as the data from a personal interview. Then, we created a simple way to specify such a survey, and easily generate the respective interface from that specification. Finally, we established another standard, this time to describe the data that each respondent produces, and made a flexible and powerful tool to analyze it, and export the results. In order to test its effectiveness, we put our framework to test by applying it to a case study about the city of Lisbon, trying to find the different mental maps associated with it.
Keywords: mental maps, framework, survey interface design, space perception, geographic information system

1. Introduction

A **mental map** is a subjective representation of a city or area, emphasizing familiar and meaningful landmarks, paths, and locations, and thus closely related to one's daily habits. For example, a bus drivers mental map would be quite detailed in terms of paths, while a childs would be mainly built around home and school, and the way in-between. [10, 9]

Since differences in mental maps of a population can be traced to particular, personal aspects on each person, it's possible to select individuals into groups, where a specific city image is generally shared between members. One can even find, for most cities, a general consensus on the overall image, or collective mental map, among the whole population.[10] All of this together, offers great advantages in discovering the mental maps of a target population.

We see mental maps being widely used for psychological studies, trying to decode emotions and thoughts through insights on how people feel, or see, their everyday environment. [7] Its for city development and planning, though, where they show great practical use, as studies of mental maps help gather multiple viewpoints of the city, display traditional knowledge, and reveal hidden spatial preferences and cultural meanings. [4, 13]

Currently, most projects usually adopt the "sketching method" to uncover mental maps, consisting on asking the participant to draw from memory the target area's map, while others turn to coloring or marking maps, in order to, for example, know how a person feels in relation to the different areas of the city. These two approaches, while the most accurate and data-rich, make it difficult to both gather and analyze a large number of individuals mental maps, which is the most important feature for surveys in areas like urban planning. More recently, some studies got around this problem by starting to directly use digital technology to gather and treat mental maps. However, either the tools aren't open for everyone, or not flexible enough for satisfying every researchers needs, and thus results in not existing a *de facto* tool to simply create and analyze a mental maps study, whichever the city or population.

We propose to solve this problem with our own solution: **Semantic Cities**. A complete framework that offers the due digital tools to easily create and publish a proper survey, and to analyze its results. The goal is to simplify the process of gathering and analyzing mental maps. With an appropriate number of participations, a researcher should be able to quickly identify collective mental maps, by filtering and manipulating the data as freely as possible.

We see the customization of the survey as one of the most crucial element of this framework, right after its effectiveness. Therefore, the easy adaptability of the study to any place or population, regardless of scale, is put first in our implementation.

In order to reach such output, the first step we took was to study the most effective set of tools and functions with which we can find a population's mental map on a non-interpersonal manner, as is our approach.

After that, we defined a virtual representation, or notation, for the data to present on the survey. That way, functionality could be more independent from the data, and it would be possible for our framework to generate a survey just by "reading" such data. In other words, we can separate the *how* from the *what*.

The next step was creating the two different interfaces: one for answering the survey, and another for analyzing the results. Special attention was give to the first interface's usability, in order to guarantee the greatest number of complete and valid participations.

At last, we evaluated the overall framework, where we validated the usefulness and effectiveness of the implemented tools by analyzing the results from our own created survey.

The main goal of this project can then be stated as: **"Create a set of digital tools that, together, provide a complete and customizable framework for finding a population's mental maps towards any area"**

With this, come secondary goals to specifically achieve during the making of our project. The first is to **create a website, to host the online survey**, which in turn implies the need to **identify the necessary features to find a participant's mental map**. Then, we should offer the researcher the possibility to create his own survey by **creating a way to simply specify and create a survey**, allowing the creator to **pick whichever features, and arrange them in any order, as needed**. Finally, we must **build an application for analyzing the results of the published survey**, which in turn requires us to **find all the possible ways to filter and manipulate the data from the survey participations**.

As previously mentioned, the success of our project depends on the validity of the data gathered by the survey. In order to test this, we decided to run a test case, creating our own survey to find the different mental maps for Lisbon's neighborhoods. Therefore producing a separate objective: **"Find the different mental maps of Lisbon's neighborhoods"**

It also comes with its own share of smaller, secondary objectives. The most trivial, is **the use of the results to validate both the features and interface of the survey**. And, of course, we should also use the case study to run a study ourselves, and thus draw our own conclusions on **how one's mental map is influenced by his daily-life, residence, and other personal aspects**.

2. Related work

Related work was separated into three different groups: Environmental Psychology, Subjective Data Gathering, and Data Driven Approaches.

2.1. Environmental Psychology

To discover the best way to gather meaningful data, and the best way to approach it, we needed to find the different influences on a person's mental map.

"How Immigrant Children Experience and Picture Their Neighborhoods" [7] shows that there's a clear relation between a person's space perception and her feelings, experiences, and conditions. And emphasizes the usefulness of mental maps to show those relations. "Psychological Maps of Paris" [11] also explores people's subjective view, and relates it with some of their personal characteristics - ranging from their living area to their income level. Thus, the work identifies some patterns that reveal some of the psychology behind a person's construction of her mental map, including the influence of the city characteristics themselves.

"Mental Maps of San Francisco" [1], on the other hand focuses on how the city itself influences the space perception of its population. Different elements can act as "barriers" and "corridors", and they show how well designed a city is. The fewer the first and the more of the second, the better for the population relation with the city. Furthermore, its also shown that perceptions on borders and orientation seem to be more related to the city's history and geography.

Regarding the association of certain ideas with spaces, "Different Perceptions of a Place Brand" [14] analyzes how those ideas change within different lifestyles and experiences. Furthermore, it shows how someone strange to a certain space has his own preconceived thoughts about it, which can be applied to a case like a neighborhood's resident ideas towards another neighborhood, something of interest for our work. Although it doesn't directly explores mental maps, this work proves that, even without such technique, it is possible to understand a population's perception around a given area, helping us design the framework's tools.

Finally, "Investigating suburban environment by means of mental maps" [3] again proves how important each city's landmarks are for the existence of a shared, well-formed spatial image among the population. The authors end this work on a note that mental maps can easily show a population depicts a municipality, but that it's still very difficult to compare them, and thus form conclusions.

From this set of works, we are prompted to include in our project the due features to enable the exploration of: relations between a person's background, and her space perception; and relations between the city's design and history, and the overall population space perception.

2.2. Subjective Data Gathering

This type of projects are focused on **collecting subjective views of space**. Some approaches explore the differences between mental images of space with the help automated tools, such as an online questionnaire. Projects that follow that path are what interest us the most, helping us understand how to take on the challenge of comparing highly variable, mostly qualitative, subjective data in an automated way.

"Boston's Crowdsourced Neighbourhood Boundaries"[1] presents the approach of drawing Boston neighborhoods' boundaries in a web-app to find the mental maps around them. This approach is shared with "Mental maps applied to the coast environment" [8], that asks participants to draw by hand the boundaries of the coastline on a map, then duly scanning and compiling the results to find the agreement between the drawings.

"Psychological Maps of London" [12] uses a gamified process, showing London's streets images to participants and asking them to guess where they are from. It then generated a duly distorted map of the city of London, where each region of the city is bigger depending on the amount of right answers in it.

Following a more classic approach, "Drawing the city of Chicago" [2] asks people to sketch on a paper their mental map of Chicago. However, it adds the step of asking them to identify the different neighborhoods of the city on a blank map also asking which of them they most most fear, and which are they most familiarized with. This added step shows a great way of gathering more insightful data with quantifiable data.

By considering each of these approaches, we reached the conclusion that the drawing of boundaries as a mental maps uncovering method was the most insightful of them, as it allowed "tangible" observations of mental maps on top of a map.

2.3. Data Driven Approaches

This type of works usually focus on the gathering of massive amounts of objective, as in non-subjective, data (e.g: points in space). Conclusions are then left to whatever patterns emerge from those clusters.

"Twitter Languages in London"[2], "Where The Tourists Really Flock"[3], and "Cities Pulse via Foursquare Check-ins"[4] concentrate on mapping on maps the positions of different events, building a great overview of distribution of people or habits across the area of a city. They target the language in which tweets were made, the profile of a photo's author, either tourist or resident, or even the check-ins in location based systems such as Foursquare. These show how powerful simple objective data can be, and how much of each city it can describe. Thus, it propels us to also care for objective data, for the insights it can hold.

"Livehoods"[5] and "Livecities"[6] take the previous approaches one step further, by trying to identify neighborhoods, or areas, only based on Foursquare check-ins. "Livehoods" was based on the geographic proximity between venues which people checked-in, and the social proximity between those venues, this latter increasing with the amount of users in common who checked-in between them. By clustering venues into groups, it identified more real areas than some official boundaries, according to a set of opinions from the residents of the targeted city.

"Livecities" combined that same clustering technique with user profiling from openly available information on the internet, thus not only distinguishing different areas, but also different social activities and groups associated with each area.

From these projects we understood how important it is to allow our survey to gather some spatially-objective information on the respondents, like their favorite venues, places of work, or most meaningful public places.

3. Semantic Cities

Bellow we describe the implementation of our framework, and the resulting components.

3.1. Survey interactions

Based on the works described in Section 2, we were able to identify the different interactions that were crucial to the effectiveness of any Semantic Cities survey. These were:

- **A questionnaire** - Should cover all relevant background information than can be retrieved by simple questions with quantifiable answers, such as numbers, options chosen on multiple-choice questions, and dates.

[1] Last visited on 22.06.2016 at http://bostonography.com/2013/neighborhoods-as-seen-by-the-people/

[2] Last visited on 12.10.2016 at http://twitter.mappinglondon.co.uk and http://www.visualcomplexity.com/vc/project.cfm?id=777

[3] Last visited on 03.10.2016 at http://flowingdata.com/2010/06/08/where-the-tourists-really-flock/

[4] Last visited on 10.10.2016 at http://vimeo.com/foursquarehq/videos

- **Spatial Habits and Important Places** - Where participants could point on a map places important in their day-to-day living, in order to better absorb participants spatial behavior. Well made, this objective information can backup many subjective data given under drawn boundaries.

- **Drawing Boundaries** - Where participants are asked to draw what they think to be the boundaries of some target area. Through this data, respondents are showing what space they associate with a name, and thus exposing their mental map.

Confronted with this, we decided to implement a survey system that works on a step-by-step-basis. As such, a **Semantic Cities survey is characterized by being composed of a series of steps, or phases, and where each of them implements one of the following interactions**:

- **"Survey Information"** for simple briefing or debriefing steps, where there's no interaction other than provide information to a participant

- **"Questionnaire"** for a phase with questions to answer directly, similar to common online forms

- **"Point a Place"** for a phase where participants are asked to point to one single place on the map, by dropping a marker on that position

- **"Point Multiple Places"** for a phase where participants are asked to point to one or more places on the map, by dropping a marker on each of those positions

- **"Draw Area"** for a phase where participants are asked to draw boundaries of a specific area, as a polygon on top of the map

- **"Draw Multiple Areas"** for a phase where participants can choose to draw the boundaries of one or more areas among a list of them

3.2. Data Objects

Joining the previously described model together with the need of a JSON specification for the survey, we arrived at two different conclusions. One, that a survey can be described as an array with one object per phase. Two, that each phase object, on that array, must have a property, `type`, that is used to describe the different interactions there present.

We identified six different interactions, specified at the beginning of this section, and thus created six different types of phases, each with its own `type` value. These are: `survey-information`, `questionnaire`, `point-a-place`, `point-multiple-places`, `draw-area`, and `draw-multiple-areas`.

Every survey phase necessarily has the `type` property in common in their JSON specification, see 1(a), but each type of phase has their own specific properties, that we address further down.

```
[
    { //phase number 0
        "type" : "phaseType",
        //phase-specific properties...
    },
    { //phase number 1
        "type" : "somePhaseType",
        //phase-specific properties...
    },
    //other phase
]
```

(a) Survey's JSON general structure

```
[
    {
        //input on phase number 0
    },
    {
        //input on phase number 1
    }
]
```

(b) General structure of the JSON for the input on the survey

Figure 1: General structures for both data objects.

As previously mentioned, in addition to a JSON specification for describing a survey, we also needed to create a standardized JSON representing a participant's input on the survey. For this, we followed a similar approach as we did for the survey specification, breaking it into one object per phase, each representing the input on the phase with same index on the array, as you can see when comparing Figure 1(a) with 1(b).

Phases of type `survey-information` are simple briefing or debriefing steps in the survey. As so, one of the only needs of its corresponding specification object is a property for the title and the body, specified respectively by properties `title` and `description`.

They can include a `followup` property to describe the inclusion of a input field asking for the participant's email.

Phases of `questionnaire` type are among the most complex to specify, for the arbitrary number of questions the designer can include in them. In order to support this feature of having any number of questions in each questionnaire phase, the JSON for a `questionnaire` type of phase must necessarily contain a `questions` property. It is described by an array, and each element is an object representing a question.

The specification for each question follows a common structure, starting with the `questionBody` property, the question to ask, and an `answer` object, containing the properties of the answer to give. Since the answer to a question can be given under very different forms, we figure it would be better to characterized each one by a `typeOfAnswer` property. Answers types range from:

- `number-input` for answering with a number
- `time-input` for answering with a time period, such as “10 years”
- `month-input` for answering with an approximate date, with only month and year, such as “03.1984”
- `choose-multiple` for answering with multiple items (check boxes) among a list of items
- `choose-one` for answering with only one item among a list of items
- `select-dropdown` for answering with a selected item among a dropdown with a list of items

Phases of type `point-a-place`, and `point-multiple-places` share the same properties on their JSON specification.

In addition to the a `title` and `description` elements, there is the addition of a `instructions` field. We decided to include those in all phases with map interaction because of the many hidden features these kind of interactions can have, like how to remove a marker.

There are also the properties `markerRadius` and `markerDetails`. They serve the purpose of offering special configuration to the markers that users will place on the map. While the second serves purely the goal of customization, the first is based on the fact that, depending on the case, its important to guarantee a certain accuracy, or lack of it, to the places pointed on the map.

Finally, there's also the requirement of including the `mapView` property. This is an important attribute for all the phases with map interactions, as it details the needed parameters to properly initialize the map. In it, it contains two more objects, `view` and `tiles`. The `view` property regards the view over the map, such as where to center it and how zoomed in it will be loaded. `tiles` on the other hand, focuses on the tile layer of the map, or in other words, the looks of the map, such as the inclusion of roads and terrain.

Phase of type `draw-area` share an identical specification to the phases with marker placement interactions, described above. The only difference relies on the marker configuration that, for these phases, doesn't exist.

Phases of type `draw-multiple-areas` differ from a group of sequential `draw-area` phases because, here, the respondent can choose only some of the many areas to draw, not going through a much bigger number of phases which areas he doesn't know how to draw.

Nevertheless, as participants select one of the areas to draw, we figured it made sense to lead them into a `draw-area` phase for the selected area. As such, the best way we found to do this was to provide, in the `draw-multiple-areas` specification, a `subPhases` property. As the name indicates, this attribute is an array where each element represents a `draw-area` phase to which participants will navigate to, going back to the `draw-multiple-areas` parent phase when they finish their drawings.

3.3. Data Gathering Tool

As we've mentioned before, our framework has two main programs: a data gathering tool, and a data analysis tool. Here we will describe in detail the first of those, and will dive into the overall code structure, the main algorithms, the different elements of its interface, and the decisions we had to take to implement the application.

We already described how a Semantic Cities survey consists of a series of phases, each with its own interaction and configuration. Faced with this situation, we needed to make our code as flexible as the survey specification, and decided to implement a simple but effective pattern of a state machine, where there's a state for each phase that loads both its interface and its functionality.

“Questionnaire” State: A questionnaire has a variable number of questions, and each question has one of several ways to be answered. Therefore, we had to shape our code to be able to render each question differently, depending on its specification, much like we did with the whole survey and its phases' types. The interface, however, is similar to what most of us are familiar with from online forms.

States with Map Interactions: While there is one state for each type of interaction, states that cover interactions with maps share a lot of similarities, mainly in their interface. They all share a map covering most of the screen, and a sidebar, that contains textual information and instructions about the actions available over the map.

“Points” States: When in these states the available interaction with the map consists on clicking the map to place a marker on that position.

“Drawings” States: When in these states the interaction with the map consists on clicking and dragging the mouse to draw free-form shapes on the map. The shapes are then processed into polygons with a limited number of vertices. There is also the possibility to delete or edit those polygons with a dedicated interaction controller on the sidebar.

3.4. Data Analysis Tool

The data analysis tool consists in three different parts: the dashboard, the analysis screen, and the report screen.

The dashboard is the initial state of the Data Analysis Tool. Researchers reach it immediately as they load the tool, and are presented with an overview of the different phases of the survey being analyzed. There, they can choose which phases to load into analysis, being possible to select several phases at the same time, as long as they have compatible data types.

The analysis screen is where most of the analysis to the results is made. Here, researchers see how respondents drew their areas, where they placed their markers, or what were their answers. It's also in this screen where it is possible to filter participations, depending on data given in other phases, and to configure the results, offering the possibility to more easily uncover patterns. Thus, in this screen, users can filter, process, style, and save the results.

Results for questionnaire phases are displayed under a list of chart-bars containing the distribution of all the answer. It is possible to configure the values represented by each bar, and the number of bars each graph has.

The results for phases with points data are presented as a color coded hexagonal grid over the map, thus representing the distribution of the placed markers. Each hexagon represents the amount of participants that placed markers in that area.

The results for phases with drawn polygons are presented similarly, also resorting to an hexagonal grid. However, here, each hexagon shows the intersection of drawings in that area, thus displaying the agreement of the participants over the limits of a target area.

For both those results, we allow a series of configurations, mostly related to the hexagonal grid. It is possible to change the hexagons' size, the levels and limits of the color scale, and the color associated with each level of that scale.

It's also here that the researchers can capture each set of results into a snapshot, and later download it as an image.

The filtering system is a powerful feature on the analysis screen, and allows the application of conditions over the data under analysis. Each filter targets the results of a phase, and selects only the participations that are valid under its configured condition.

When changing the participations through a filter, the analysis screen updates the results being displayed to reflect the new set of participations under analysis.

It is possible to combine filters under "AND" and "OR" logic, allowing powerful exploration of results.

The report screen offers an overview over every snapshot taken, allowing the due actions over each of them. From this screen is also possible to load an interface where researchers can calculate several measurements, for each participation. These consist of: the agreement between a drawing and a given area, and the distance between points and that area. It allows the researcher to export that data under a CSV file to further analyze correlations on a proper program.

4. Case Study: Mental Maps of Lisbon

The framework framework was applied to the city of Lisbon, Portugal, in order to find the different mental maps of its neighborhoods.

We designed a survey that started by asking questions that profiled the participants according to their personal background and relation with Lisbon. Then, we targeted objective spatial information by adding two steps where participants pointed places that were part of their daily lives. Next, there were two phases of boundaries drawing, one for the official area of Lisbon, and another for the area of the city with which participants feel familiar to. Finally, we asked participants to draw their perception of the limits on several neighborhoods of Lisbon.

The survey was published on relevant Facebook groups, and also on Reddit. However, most participations came from our college's Facebook group, where we could more easily convince people to take the survey. There were 183 participations, mostly from college students that live in Lisbon.

The results provided many insights. We discovered what areas of Lisbon are more meaningful to most people, where we identified a clear "central Lisbon" and an isolated Parque das Naes.

It was also possible to know how people living in Lisbon perceive the borders of the city, compared with people that cross those borders everyday to work in the city. We discovered that the second group had in general a much better notion of those borders. We also identified a relation between the drawn boundaries and the different high speed roads in Lisbon, corroborating previous work in this area.

Regarding the neighborhood limits, we were able to observe the influence of subway stations and open spaces on the mental map of the population. Furthermore, by resorting to the filtering feature of the framework, it was also possible to understand how the perception of each neighborhood varies with each person's background, such as age or occupation.

5. Evaluation

Due to the extension of our work, it wasn't possible to execute enough user tests to gather statistically relevant data on the usability of our different applications. Instead, we opted for formative tests, which focused on finding problems and errors on the interface. These, together with the results from the case study, validate our framework in terms of effectiveness and efficiency.

The 6 tests made to the survey tool revealed problems with the drawing interaction. Whenever users made a mistake while drawing, they wouldn't know what to do, and eventually they would feel frustrated with the interface. The case study reveals this tendency, as results shown that most participants quit during phases with drawing interactions.

The 5 tests made to the analysis tool revealed problems with the filtering system. Users wouldn't understand the filter logic and thus wouldn't know how to combine them correctly. Regardless, the application was able to present very complex interactions in an overall efficient manner. Furthermore, the wide variability of conclusions reached when making the case study point for an effective and powerful tool.

6. Conclusions

This project presents a new method for studying the mental maps of a population. By gathering all the different insights, it is clear that we were able to provide a very flexible tool, that allowed the efficiency of digital approaches, and was able to maintain the effectiveness of the classic methods.

Thus, it is possible to say that we achieved our main goal of **creating a set of digital tools that, together, provide a customizable framework for finding a population's mental maps towards any area**, while also fulfilling the secondary objective of **finding the different mental maps of Lisbon**.

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