Multi-temporal Flow Maps
Looking Back to Look Forward

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1 STAGE OF THE RESEARCH

A flow map is a thematic map that is been used to emphasize the spatial pattern of one or more geographic attributes. Although most flow maps are still drawn by hand, a few algorithms exist to automatically generate this kind of thematic maps.

The flow magnitude is represented as the width of each line, and the sum of all flow line branches should add up to the width of the flow line (Dent, 1990). Usually the traces depicted by lines do not correspond to the real route. In many instances the flow magnitude is not placed over the map, so the reader must judge relative amounts visually, without the legend (Dent, 1990).

At present we proposed a novel algorithm for the automatic generation of flow maps, which is theoretically grounded on physics' laws to describe the motion and force of attraction or repulsion between points. Properties associated to these laws are then used to merge different flows, as well as for the improvement of the maps' visual quality (see Figure 1f). Finally, we evaluate our work by generating a set of flow maps and we make a comparison with flow maps produced by existing algorithms.

1.1 Outline of Objectives

The graphical representation of numbers started in 1750 – 1800 with the invention of time-series, scatter plots, multivariate displays. Geographic maps were used in the seventeenth century combining cartographic and statistical elements. (Tufte and Graves-Morris, 1983). Nowadays with the advent of calculators some innovations open new possibilities described in the following section.

1.2 The Use of the 3D

We have the ability to create more information-rich, and dynamic visualization processes using 3D (Spence and Press, 2000). Usually when there is the need to represent spatio-temporal data, the time dimension is simply associated to the z axis and this is a limit. A smart use of this dimension can open big opportunities to novel visualization techniques.

1.3 The Possibility to Interact

Interaction techniques allow the data analyst to directly interact with the visualizations and dynamically change the visualizations according to the exploration objectives. Besides, they also make it possible to relate and combine multiple independent visualizations (Spence and Press, 2000). A single static view can rarely give the whole detailed information of the data being analysed. With the appropriate interactive exploration techniques allow the user to analyse the data in every detail for example providing support for multiple tasks in a single visualization tool.

1.4 The Use of Animations

In a visualization, animation might help a viewer work through the logic behind an idea by showing the intermediate steps and transitions, or show how data collected over time changes. Animation can be a powerful technique when used appropriately, but it can be very bad when used poorly. Some animations can enhance the visual appeal of the visualization being presented, but may make exploration of the dataset more difficult (Steele and Iliinsky, 2010).

The aforementioned aspects can enrich the capabilities of the flow maps. The possibility to visualize more than a variable will be studied, in particular the time dimension is an aspect that lacks in the flow maps.

Analysis of movement is currently a hot research topic in visual analytics. Andrienko et al., (Andrienko et al., Visual analytics tools for analysis of movement data, 2007) provided an overview on the methods and tools studied for the analysis of movement data. The problem stated in this research regards the visualization of origin-destination data such as flow of goods or immigration trends where

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only the origins and the destinations of the flows and the flow magnitudes are known, but not the exact movement routes.

Flow maps represent in a simple and clear way origin-destination data.

The main objective is to automatically generate flow maps and represent also multivariate attributes with temporal dimensions through interaction techniques, animations and the use of the 3D.

2 RESEARCH PROBLEM

The research problem faced so far is the automatic generation of flow maps. The main aspect to take into consideration is the necessity to reduce the visual clutter while keeping a good visual appearance. Due to the fact that the flows can be considered as a rooted acyclic graph the research problem regards the graph drawing problems. In the graph drawing domain the emphasis is on finding a layout, i.e., positions of nodes and edges of a given graph that satisfies certain aesthetic criteria, e.g., few edge crossings device.

In visualization techniques, the usefulness of a drawing of a graph depends on its readability, that is, the capability of conveying the meaning of the diagram quickly and clearly. These issues are expressed by means of aesthetics, which can be formulated as optimization goals for the drawing algorithms. (Battista et al., 1994).

The major challenge is how to bring together the spatial and temporal dimensions in a way which makes it possible to explore the relationships between these two aspects of the data.

In general, not much has been written on the exploration of temporal changes in origin-destination data. Marble et al., (1997) noted in 1997

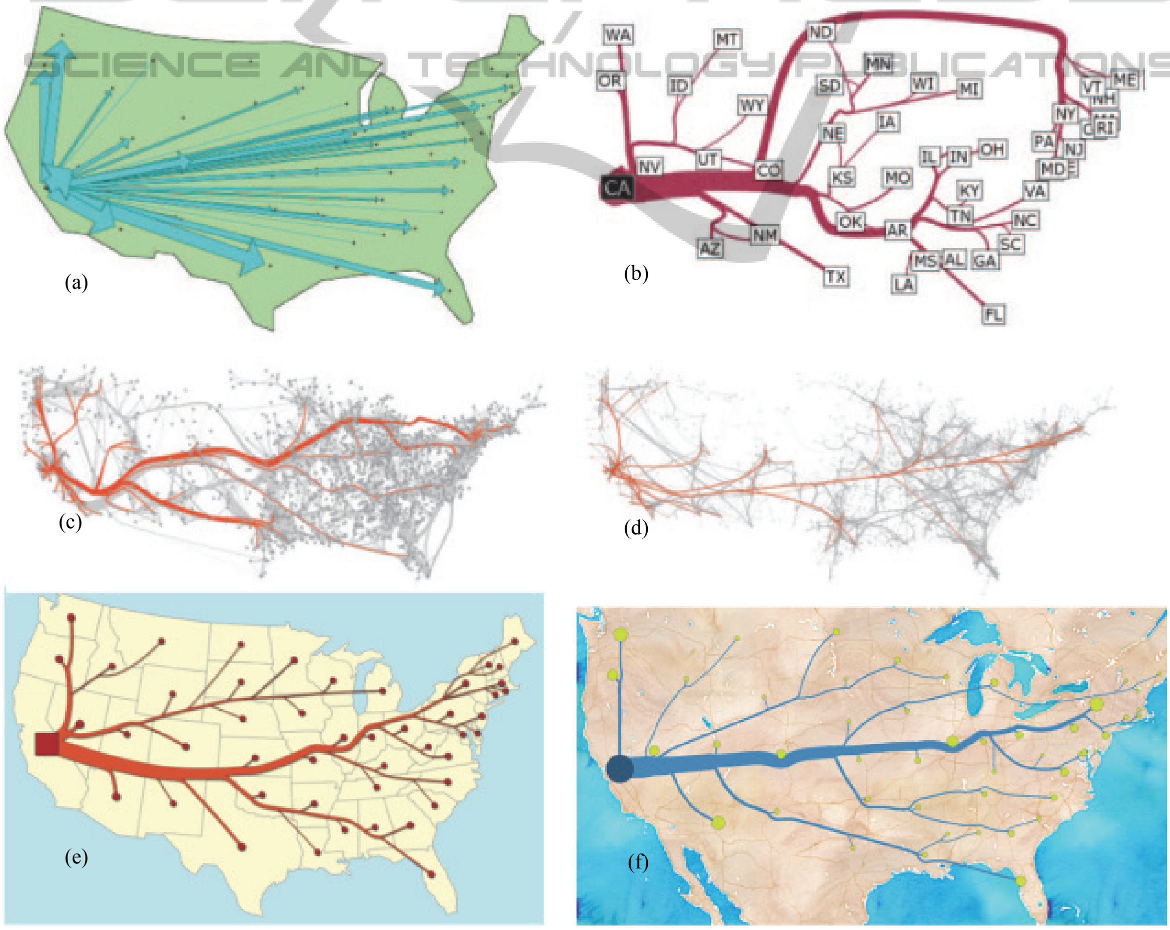

Figure 1: Different maps representing the migration from California in 1995-2000. (a) the first software that automatically generate flow maps (Tools, 2001), (b) algorithm taking into account aggregation of flows (Phan et al., 2005), (c) (d) the force directed algorithms in graph drawing domain (Cui et al., 2008), (Holten and Van Wijk, 2009), (e) the algorithm based on spiral tree (Verbeek et al., 2011), (f) the force directed algorithm described in the stage of the research.

that the limitations of the data and the empirical difficulties encountered in their analysis have restricted researchers to the examination of flows within a single time period. This situation has not changed much since then, and there is still a strong need for techniques capturing the spatio-temporal aspects simultaneously.

3 STATE OF THE ART

3.1 Automatic Generation of Flow Maps

This section focuses on a specific domain of the analysis of the movement that is related to the flow maps. There are other methods used to represent origin-destination data, anyway maps are well familiar to everybody and allow to reason about the geographic patterns of the movement as no other representation.

The book "Handbook of Graph Drawing and Visualization" (Tamassia, 2007) gives an overview of the actual technique for the automatic generation of flowmaps. Tobler in 1987 developed a computer program called FlowMapper (Tools, 2001) used to visualize migration maps; this mapper produces generic maps without any optimization with respect to the visualization of the data. For each flow, it generates an arrow on the map with a width varying accordingly to its magnitude. As the number of links increases, it becomes increasingly difficult to represent new flows without creating a visual clutter (see Figure 1a). Tobler not only created the software for basic flow mapping, but also investigated various approaches for making flow maps more readable by addressing their problems.

The main aspect of a flow map is the aggregation of the flows. In 2005 Phan et al. (Phan, Xiao, Yeh, & Hanrahan, 2005) introduced a method to reduce the visual clutter by merging the flows (see Figure 1b). The author used a binary hierarchical clustering formulating the layout in a simple and recursive manner. To make the final layout of the flow map more aesthetically pleasing, the polygonal paths that represent the edges are drawn as Catmull-Rom splines, that is, as special cubic curves that go through the given points. The advantage of this algorithm is its $O(n^2)$ time complexity, where n is the total number of nodes used in the algorithm. However this algorithm has a few limitations: during the first step the nodes are moved if their proximity is too small. Hence, it might lose the geographical reference associated to each node. Furthermore, if there are too many destination nodes in a small area, by forcing binary splits introduces too many extra routing nodes, which then leads to clutter.

Verbeek et al., (2011) describes a method to overcome the aforementioned limitations through the use of spiral trees. The authors used spiral spline (Buchin et al., 2011), which have $O(n \log n)$ complexity, to generate maps that are crossing-free. Another key property concerns the weights of the leaves. If there are two flow maps with the same origin and destinations but with different magnitudes, then the layout of the flow map will be represented differently. Moreover the flow tree produced is constrained to avoid crossing its own nodes, as well as user-specified obstacles (see Figure 1e). In order to have a high-quality map, a quality function that takes into account the obstacles, the smoothness, the angles and the straightness, has to be minimized. The time required to perform a flow map is mentioned in the paper as a "couple of minutes". Two limitations of this algorithm are the complexity in the construction of the tree structure and the non-intuitive body cost function used to improve the aesthetic results.

The reduction of visual clutter has been studied extensively in the graph drawing domain. The objectives are not the same of the methods described above but the following works have some points in common. Cui et al., (2008) use a control mesh that reflects the underlying control pattern reducing the visual clutter (see figure Figure 1c). Holten and van Wijk (2009) presented a force-directed algorithm in which the edges are modelled as flexible springs that can attract each other while node positions remain fixed (see Figure 1d). The input to these methods is a graph rather than a tree; in the output, the curved edges are bundled in order to better reflect the structure of the graph.

The automatic method for the flow map generators do not permits to visualize multivariate variables and in particular the time dimension. Some techniques to use in conjunction with the flow maps are developed in order to overcome the above limitations.

The "small multiples" display is one of the most often used techniques for representing temporal data. It uses multiple charts laid side-by-side and corresponding to consecutive time periods or moments in time (Boyandin et al., Using flow maps to explore migrations over time, 2010). The problem with this technique is the scalability: the more small multiples are represented, the more difficult it is to see the details. Animation can be used to show how flows of subsequent time periods change (Becker et

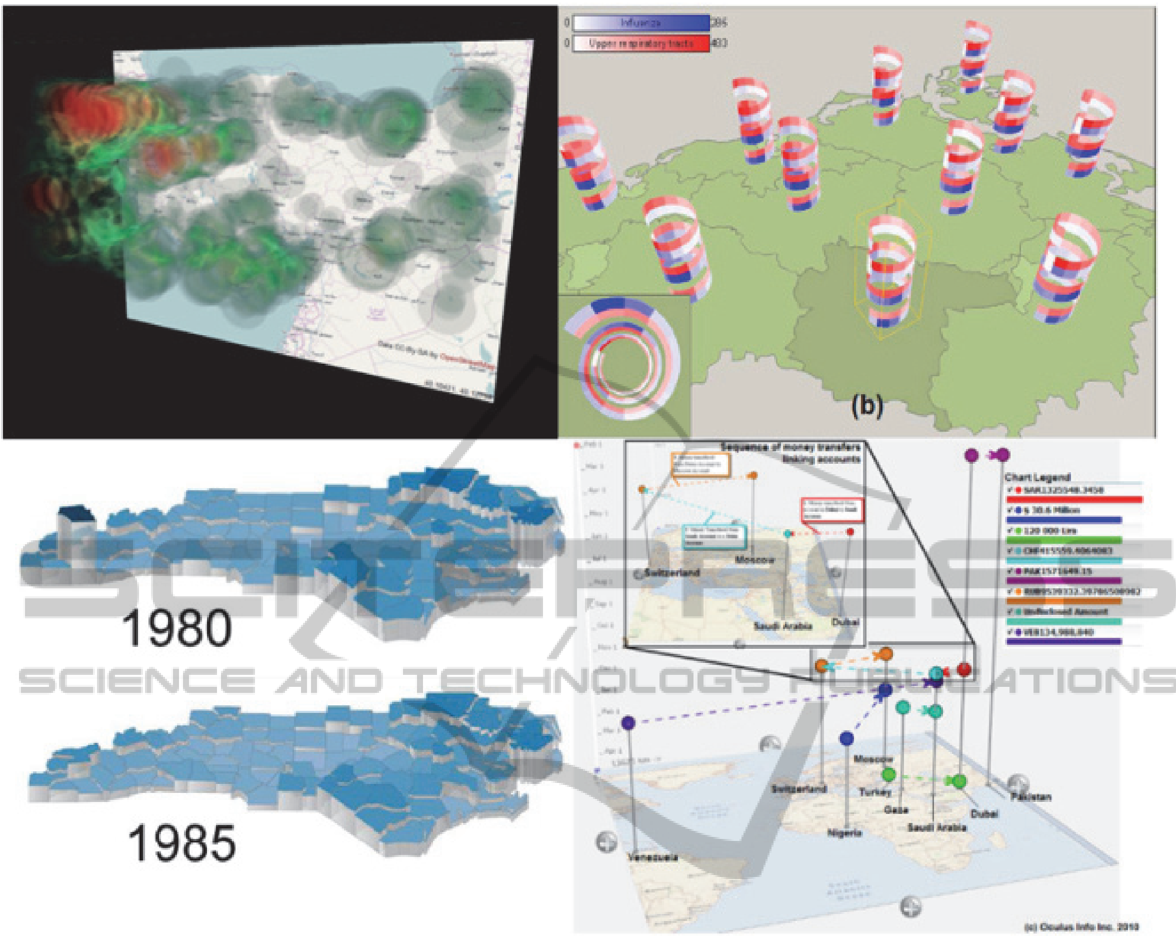

Figure 2: Some examples of multivariate visualizations with the 3rd dimension used to depict time.

al., 1995). An animated flow map showing thousands of flow lines could hardly be accurately perceived as it would be too difficult to keep track of changes in it.

A direct embedding into a flow map would mean representing the temporal changes by mapping temporal data to each of the visual features of the flow lines (color, size etc). A more sophisticated way of embedding might be able to overcome this problem though (Boyandin et al., 2011).

3.2 Alternative Techniques for Origin-destination Data

There are also techniques that are able to represent also the time dimension such as the "flowstrates" (Boyandin et al., 2011). It provides means of interaction for controlling filtering, zooming and aggregation: the origins and the destinations of the flows are displayed in two separate maps, and the changes over time of the flow magnitudes are represented in a separate heatmap view in the middle. Mosaic diagrams were introduced in (Andrienko and Andrienko, Spatio-temporal aggregation for visual analysis of movements, 2008) for displaying spatiotemporal patterns in traffic situations. A set of multiple small calendar-like views representing temporal data are displayed in a regular rectangular grid on top of a geographic map. Distorting map projections are sometimes used to make geographic maps more readable or to highlight the most important elements in them. (Stefaner, 2010), (Wood and Dykes, 2008) and (Brunet, 1986) provided some techniques.

When the 3D representation is included one of the dimensions is used to show the temporal changes and the two others for a 2D representation of the data at each specific moment in time. (Proulx, Khamisa and Harper), (Adali, Eren, Turk and Balcisoy); (Tominski et al., 2005) are some example of this approach.

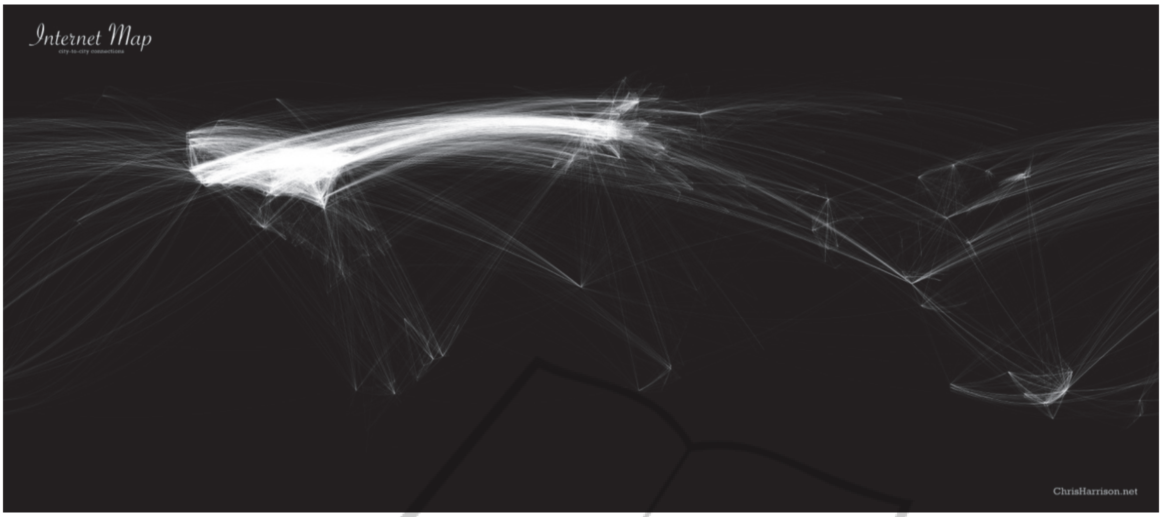

Figure 3: This maps show some kind of connections in a 2D map using arcs in 3D. The main idea is to merge the flows with the same origin in order to reduce the visual clutter. The concept is the same of aggregation techniques in 2D flow maps but in a 3D environment.

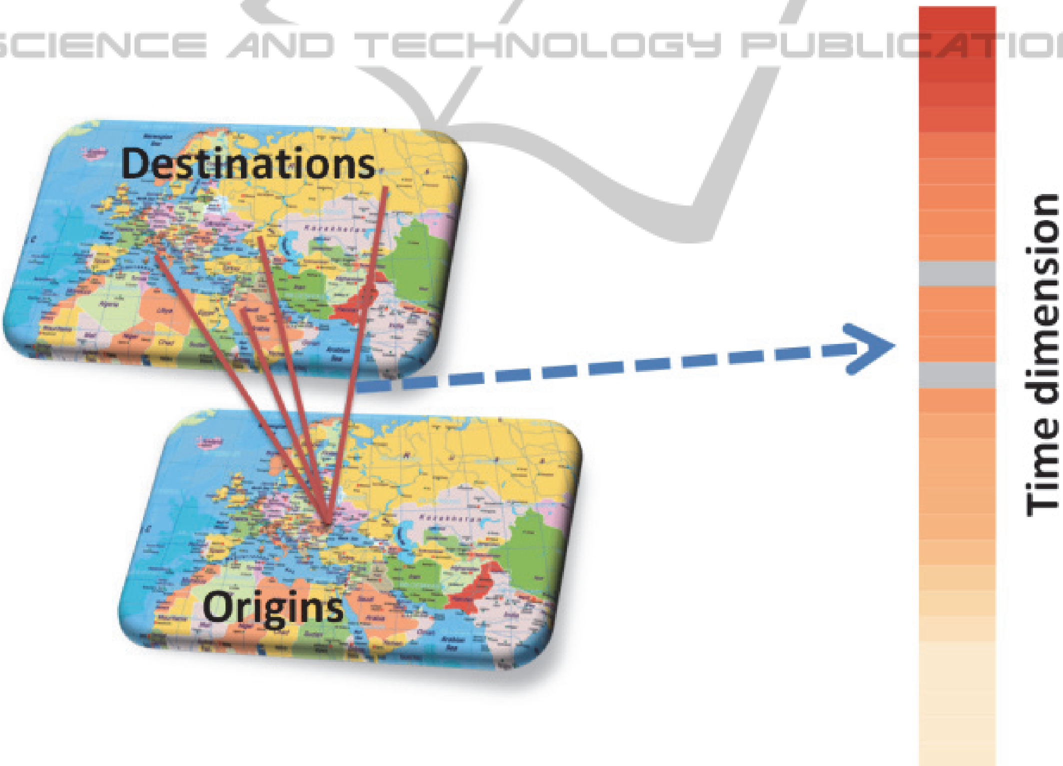

Figure 4: Sketch of a possible visualization technique. Two 2D maps connected with flows. Each flow line depicts the temporal pattern.

4 METHODOLOGY

The methodology of this research is divided into the following steps:

1. Study the available techniques for temporal OD-data visualization, describing in which way the animation, the interaction and the 3rd dimension are used.

2. Define which are the tasks the tool can support;
3. Define in which way the interaction metaphor, the 3D and the animation techniques can be used in order to represent multivariate attributes with temporal dimensions.
4. Implement the algorithm on a target platform.
5. Perform a user study to evaluate the proposed tool. Interview will be done and an analysis on the user interaction must be performed.

5 EXPECTED OUTCOME

The first results will be a list of novel methods for the depiction of origin destination data, using the 3rd dimension in conjunction with interaction metaphors and animations. The basic idea is to use the 3rd dimension not only as a way to depict the time dimension.

A first idea can be the definition of an algorithm for the creation of flow maps with aggregation techniques but enriched for a 3D environment (see Figure 3).

Another idea can be the use of 2D maps but in a 3D environment with flows connecting both maps, one representing the origin and the other representing the destinations. In this way should be possible to use flows as temporal indicator (see Figure 4).

The next outcome will be a developed tool with the algorithms implemented. This tool will be used to evaluate the techniques with the users.

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