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# Creating Quasi-Maps for Uncovering Space-Time Patterns

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**Abstract:**

For a set of geographically referenced time series, we generate a matrix arrangement with rows corresponding to linearized geographical positions and columns to time steps. This matrix is treated as a background map suitable for application of common methods for thematic data visualization. 2D spatial positions are transformed to 1D ordering of the matrix rows by means of one of existing methods for dimensionality reduction. We illustrate the approach by representing the dynamics of the COVID-19 pandemic and population mobility levels throughout the provinces of Spain.

## Problem statement

Time series referring to locations in geographical or another 2D space are hard to visualize in a way that adequately represents both spatial and temporal aspects of the data and exposes spatio-temporal patterns. Technically, it is possible to represent each combination of a 2D spatial position and a time step by a ball or another 3D object in a space-time cube. Values of a single time-variant attribute can be represented by colors of the balls, as illustrated on the left of Fig. 1. However, unavoidable occlusions in such a display are detrimental to perception of spatio-temporal patterns.

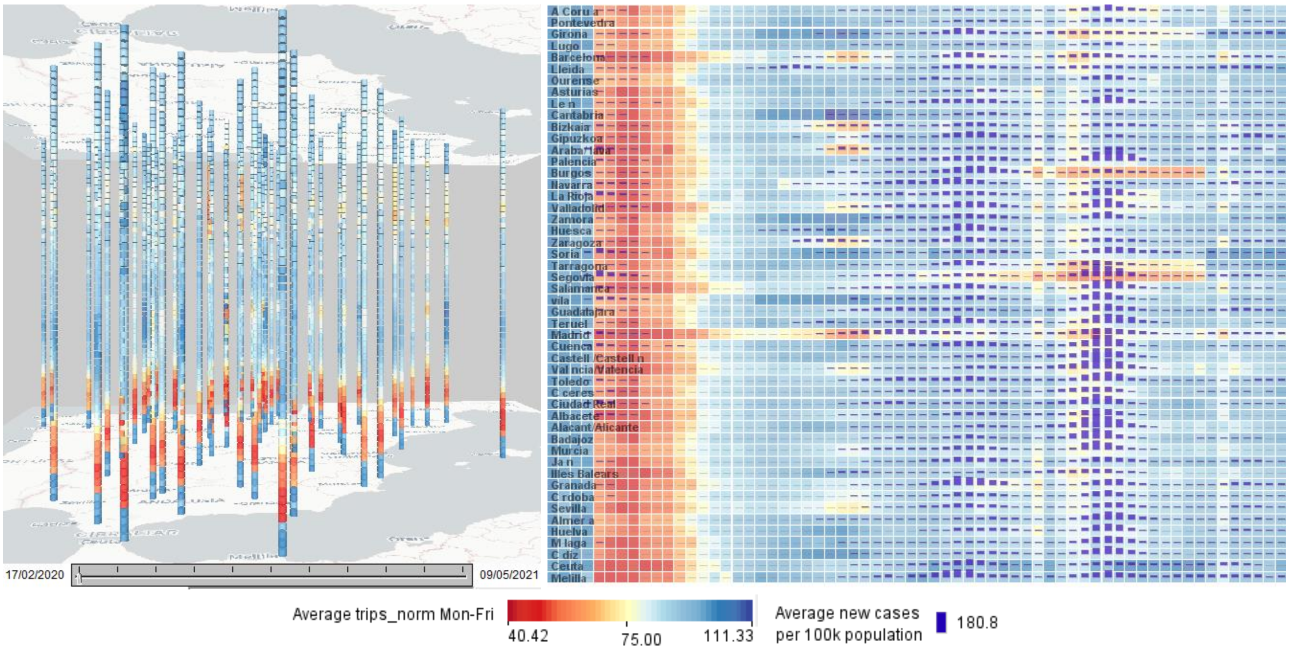


Figure 1. Representation of spatial time series in a space-time cube (left) and in a matrix with rows representing spatial positions and columns corresponding to time steps. The cells of the matrix are treated analogously to area objects on a geographic map.

## Proposed solution

We propose a 2D arrangement where one dimension (vertical) approximates the relative spatial positions of the time series, and the other dimension represents the sequence of time steps. The cells of this matrix correspond to the pairs of location and time step. The cells are treated analogously to area objects on a geographic map, which means that suitable (regarding the sizes of the areas) thematic visualization techniques can be used to represent data corresponding to the


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cells. An example is shown in Fig. 1, right, where the matrix rows correspond to the provinces of Spain and columns to the weekly intervals from 17/02/2020 to 09/05/2021, which was the COVID-19 pandemic period. The cells are colored according to the population mobility levels compared to the baseline (time before the pandemic) using a diverging color scale with shades of red for low mobility and blue for high mobility. Moreover, on top of the painting, the average daily numbers of the COVID-19 new cases per 100,000 province residents are represented by proportional heights of vertical bars in dark blue. Like a usual interactive map display, the matrix display allows zooming, panning, and interactive operations on the cells: viewing corresponding data, highlighting, selection, filtering, etc. Therefore, this display can be called a *quasi-map*. Besides regular time series with equal time steps, this approach can be applied to spatially referenced sequences of events with differing durations. Each event is represented by a horizontal bar with the length proportional to the event duration. The bars are then treated as areas on a map and used for thematic mapping.

To be able to spot spatio-temporal patterns, it is important to create a 1D arrangement that preserves as much as possible the geographic neighborhood relationships between the locations the data refer to. For this purpose, we apply one of existing dimensionality reduction methods (such as Sammon's mapping in Fig. 1). Other approaches include space filling curves and hierarchical clustering of locations (Franke et al. (2021). Since any linearization of 2D spatial positions inevitably involves distortions of the neighborhood relationships, it is important to be aware of the distortions present in the arrangement that is going to be used in the data exploration. A visual approach to revealing distortions is presented in Fig. 2. On the left, a continuous 2D color scale is used to encode the spatial positions of the provinces. We use a color scale called Cube Diagonal Cut B-C-Y-R (Blue-Cyan-Yellow-Red), which was rated highly in a task-based evaluation study done by Bernard et al. (2015). The colors assigned to the provinces are transmitted to the matrix rows, where dissimilar colors of neighboring rows signify distortions. Complementarily, the positions of the provinces in the 1D arrangement can be visualized on a geographic map, as shown on the right of Fig. 2, where distortions are signified by dissimilar painting of close areas and by similar painting of distant areas.

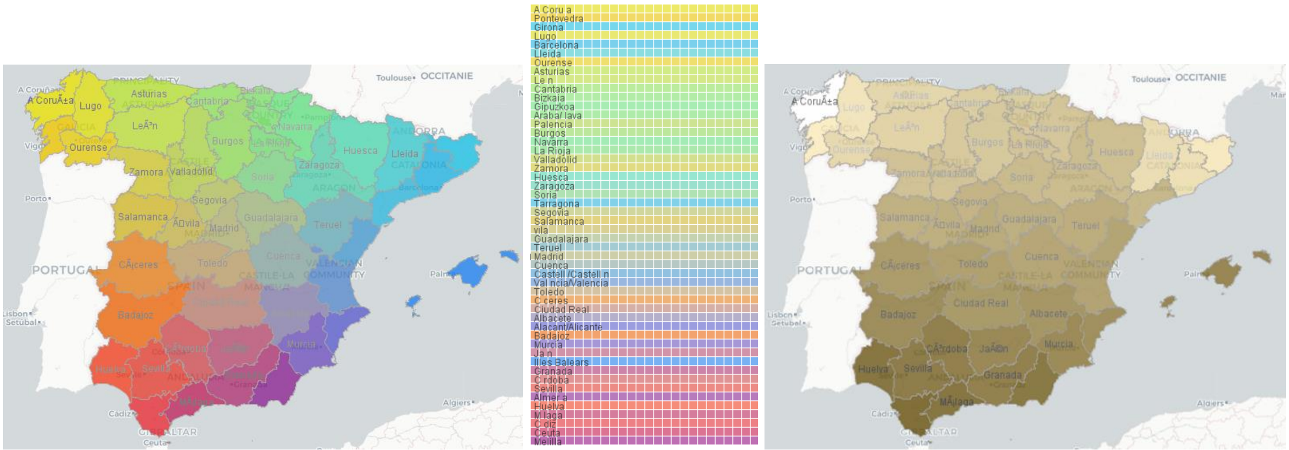


Figure 2. Exploring the quality of representing 2D spatial coordinates by 1D arrangement. Left: colors from a continuous 2D color palette are assigned to the provinces of Spain based on the spatial positions of their centers. Middle: the rows of the matrix are painted in the same colors as the corresponding provinces in the map. Dissimilar colors of neighboring rows signify distortions emerging in the 1D projection of the 2D positions. Right: the relative positions of the provinces in the 1D arrangement are represented by shading the areas on the map. The distortions are signified by dissimilar shading of spatial neighbors and by similar shading of spatially distant provinces.

Unlike Franke et al. (2021) applying linear arrangement to uniform spatial time series and representing only numeric data by shading, we extend this approach to event sequences and use the 2d arrangement (linearized space × time) analogously to a background geographic map for thematic data visualization.

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