Eurographics Conference on Visualization (EuroVis) (2012)
M. Meyer and T. Weinkauf (Editors)

Short Papers

MorphingProjections: Interactive Visualization of Electric Power Demand Time Series

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Abstract

MorphingProjections is an interactive tool to explore time series of electric power demand in a public building. The core idea of the interface is a smooth continuous transition –morphing– between several 2D views, each providing a different insight on the data. For power demand analysis three types of encodings were considered: a) manifold learning projections, that result from mapping 24-dim day patterns on 2D points organized according to similarity of demand profile; b) "clock-type encodings" that give insight into daily, weekly and yearly periodicities and c) specific encodings, providing insight into calendar-dependent demand patterns. Morphing allows the user 1) to track interesting points or selections between conceptually different views, and 2) to produce new views by blending basic ones. The combination of morphing and other interaction elements such as zoom, pan and multiple selection, results in a highly dynamic interface that allows the user to link and combine the demand information in ways unseen in previous approaches.

Categories and Subject Descriptors (according to ACM CCS):
J.2 [Computer Applications]: Physical Science and Engineering—Engineering
H.5.2 [Information Interfaces and Presentations]: User Interfaces—Graphical user interfaces

1. Introduction and related work

Electric power demand time series stem from human activities, resulting in temporal patterns that are more complicated than the regular periodicities often handled by classical frequency methods –such as Fourier transforms– or visualization methods based on a fixed periodicity, such as spirals proposed in Carlis et al. [CK98] and Weber et al. [WAM01]. Electric power demand time patterns are multiscale (daily, weekly, yearly) and contain also irregularly distributed periods, such as holiday periods, weekends, etc. as described by Wijk et al. [VWVS99] and can be strongly affected by singular events such as a football match. One of the main requirements for electric power demand analysis is that information about different kinds of periodicities can be combined. For instance, it is desirable to know the hourly or yearly distribution of the demand on a given weekday. Also, in a context of liberalization of energy markets, it is also important to have a characterization or clustering of the different types of day patterns of the demand, as well as to track when they occur (working days, holidays, eves of holidays, etc.). The need to understand the demand behavior under a rich set of social time granularities, as well as to classify demand patterns for tariff optimization, often leads to a large number of different –but related– views that pose a visualization challenge for the user to keep track of information when changing between views. One way to deal with that is coordinated multiple views. Recently, Steinberger et al. [SWS*11] proposed a clever approach of developing visual links between related visual elements that minimizes occlusion. While links are powerful associative elements, such approach requires maintaining all views active, with individual configurations, demanding large screens and potentially making it difficult to focus on parts of interest. Animation can be a good alternative for data visualization of multiple views. In a thorough work, Tversky et al. [TMB02] suggest that despite animations would only be efficient for conveying the notion of temporal change, interactivity and control by the user improve perception, suggesting the use of animation in other contexts. Animated transitions are a promising approach for an efficient integration of different related graphics, allow-

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‡ The authors would like to thank financial support from MICINN and FEDER funds under grant DPI2009-13398-C02-01.

DOI: 10.2312/PE/EuroVisShort/EuroVisShort2012/121-125

ing the user to perceive and track changes by morphing between views, resulting in an improved interaction and understanding, and being a natural way to represent changes and cause-effect relationships. This was demonstrated by Heer et al. [HR07], with the excellent application *DynaVis*. Another application for the analysis of household power consumption of different appliances using animated transitions between different types of views –clocks, flows, calendars– , was recently developed by General Electrics [Gen11]. However in these works, intermediate states do not have a specific meaning and serve mainly to provide a connection between views and provide perception of changes. The idea behind animated transitions is powerful and can be further exploited if intermediate states are crafted to serve as analysis tools by themselves. In this paper we propose a design study that exploits the core idea of animated transitions among basic views consisting of specialized scatter plots. Blending scatter plots with structures recognizable by the user –such as calendar or clock like encodings–, results in interpretable and intuitive intermediate states, allowing to combine different time granularities in a single view (e.g. a "clock of clocks" showing the yearly demand for each weekday) or showing up "clustered clouds of 24-hour clocks" organized by similarity of the daily demand pattern.

2. Visual encoding

Rationales for spatial encodings. Data are represented as dynamic 2D scatterplots $\mathbf{p}(i)$, with spatial coordinates $p_x(i,t)$, $p_y(i,t)$ at sample i, to encode time or similarity between day patterns and using color and size to encode the attribute values. We used circular –"clock"– encodings to reflect the periodic nature of daily and weekly time granularities and specific calendar grids to account for social granularities. Clock and calendar encodings –see also [OPP*94, GJ05, SM08, VWVS99]– are widely accepted conventions for time representation and provide a natural way to aggregate periodic events complying with the *congruence principle* [TMB02].

Clock-like encoding. Let's consider a set of $N = 8760$ samples of the electric demand for a whole year, obtained in an hourly basis. Let $h(i)$ and $d(i)$ denote integer numbers with the absolute hour and day of the i-th sample since the beginning (consider $i = 0$ midnight). We considered daily, weekly and yearly scatterplots, $\mathbf{p}_D, \mathbf{p}_W, \mathbf{p}_Y$, containing 2D points distributed in a circular way –"clocks" on Fig. 1– with a period of one day, one week and one year, respectively:

$$\mathbf{p}_D(i) = \left[\cos\left(2\pi\frac{h(i)}{24}\right), \sin\left(2\pi\frac{h(i)}{24}\right)\right] \quad (1)$$

$$\mathbf{p}_W(i) = \left[\cos\left(2\pi\frac{d(i)}{7}\right), \sin\left(2\pi\frac{d(i)}{7}\right)\right] \quad (2)$$

$$\mathbf{p}_Y(i) = \left[\cos\left(2\pi\frac{h(i)}{365\cdot 24}\right), \sin\left(2\pi\frac{h(i)}{365\cdot 24}\right)\right] \quad (3)$$

Note that the daily $\mathbf{p}_D$ and weekly $\mathbf{p}_W$ basic views yield only 24 and 7 different locations, respectively. Each of the 24 locations of $\mathbf{p}_D$ will contain all samples of a given day hour; similarly the 7 locations of $\mathbf{p}_W$ contain all samples of a given weekday. Later, it will be seen that the user can immediately remove this ambiguity by blending with other views. For instance, a blend $\mathbf{p} = \lambda\mathbf{p}_D + (1-\lambda)\mathbf{p}_W$ of both views, will give a "clock of clocks" with 7×24 points, each with a specific combination of day hour and weekday. Such *intermediate states* can be obtained "on the fly" and unlike other animated transition approaches –such as [HR07]– are meaningful themselves, showing data organized by two criteria.

Calendar and 365x24 encodings. A specific calendar 2D point set $\mathbf{p}_C(i)$ was built by assigning to each sample its position on a classical calendar according to its day –see Fig. 1. We also included a matrix-shaped encoding $\mathbf{p}_{365\times 24}(i)$ composed of 365 rows and 24 columns, that represent the hourly demand profile for all the days of the year. Both kinds of encodings specifically highlight different kinds of calendar regularities in the daily demand profile.

Encoding the similarity of day patterns. Let $x(i)$ be the power demand at sample i, for $i = 0, \cdots, N-1$. The k–th *day pattern* can be defined as the 24-dim vector containing the demand of a whole day, $\mathbf{x}(k) = [x(24\cdot k), x(24\cdot k+1), \cdots, x(24\cdot k+23)]^T$. To provide the user with a method to identify groups of similar day patterns of demand, we used the tSNE manifold learning algorithm [vdMH08] to project $\mathbf{x}(k)$ on a 2D space, resulting in a new 2D point set $\mathbf{p}_{tSNE}(i)$. The tSNE algorithm is able to retain the local structure of the demand profiles in the 24-dim space, as well as to reveal its global structure –such as clusters at multiple scales. The rationale for this encoding is to get days grouped by similarity, exploiting the strong association between proximity and similarity.

Encoding of attributes. Color and size encodings were chosen to describe the values of the attributes –hourly active and reactive power demand. A multihue –blue/white/red– divergent colorblind-safe and perceptually uniform color scale was selected using the ColorBrewer tool [BHU11] to emphasize differences between low/high demands. The rationale for this choice is to favor good pop-out features for quick detection of changes and large demands. To increase the perception of change, size is encoded as an exponential function of the attributes. Accurate numerical information of attributes can be obtained from barcharts with a mouse right click, as seen later. Manually tunable transparency allows to display points that share a same location providing an aggregate view, useful when the user is only interested in global hourly or weekly distribution of data. Different sized transparent points naturally result in glyphs composed of concentric circles with different combinations of radii and colors, allowing to distinguish between points with different overlapping data. For instance, the basic tSNE view results in 365 glyphs, each composed of 24 concentric circles, where

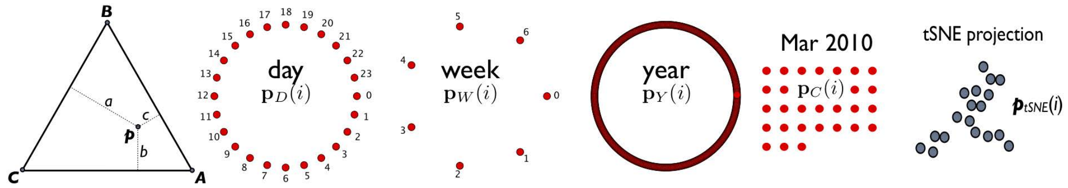

Figure 1: *Ternary plot (left) and some encodings used in the interface: clocks, calendar and dimension redution (tSNE).*

two similar daily profiles will produce similar glyphs, being an additional mechanism for the user to relate patterns.

3. Interaction mechanisms

Ternary plot interface. The main interacting element is an equilateral triangle called *ternary plot*, see Fig. 1 left, whose vertices are associated to three basis 2D views. The term –and the concept– is borrowed from a graph used in metallurgy to describe mixing proportions of compounds. The interface element uses barycentric coordinates a,b,c, for a point $\mathbf{p}$ selected by the user inside the triangle, so that $a+b+c=1$. The scatter plot being displayed will be a mixture with proportions a,b,c with the following properties: i) a point *inside* the triangle represents a mixture with two degrees of freedom ($a+b+c=1$) whose proportions a,b,c depend on the proximity to the vertices; ii) a point *on an edge* of the triangle, say $A-B$, represents a mixture containing only elements A and B in variable proportions and a zero proportion of C; iii) a point *on a vertex* of the triangle, say A, represents 100% of A; and finally iv) for points outside the ternary plot, barycentric coordinates are limited by the interface to force the position of point p to be in the triangle.

Morphing between views. Using the ternary plot, the user can obtain a set of three mixing coefficients $a(t)$, $b(t)$, $c(t)$ that sum up to 1 and can be used to produce a variable "mixture" of three different encodings $\mathbf{p}_A$, $\mathbf{p}_B$, $\mathbf{p}_C$ by evaluating the combination for all the points,

$$\mathbf{p}(i,t) \;=\; a(t)\mathbf{p}_A(i)+b(t)\mathbf{p}_B(i)+c(t)\mathbf{p}_C(i) \qquad (4)$$

for $i=0,\cdots,N-1$. In other words, the user can produce any combination of any three space encodings with manually tunable proportions, allowing to navigate between different representations in a smooth way. Since the ternary plot only allows three simultaneous variables, the user can quickly change, using the keyboard, the three basis point sets $-\mathbf{p}_D,\mathbf{p}_W,\mathbf{p}_Y,\mathbf{p}_{tSNE},\cdots-$ taken in sets of three $\mathbf{p}_A,\mathbf{p}_B,\mathbf{p}_C$. By pressing a key, the ternary plot is enabled, allowing to dynamically select with a mouse hovering a point p in the triangle –automatically constrained to be inside. Every frame, the mixing coefficients are recomputed and the mixing scatter plot is redrawn, according to eq. (4), so the user can interactively explore the result of any combinations between the projections. This full control of the user in the transitions complies with suggestions of Tversky et al. [TMB02] to increase the effectiveness of animation for perception and comprehension.

Selection and contextual information. The interface allows up to four different selections of subsets of points in *any* view. All selected elements are marked using red, blue, green and yellow colors with tunable opacity. Selections in one view are preserved in subsequent views and the resulting density maps of the selections often produce meaningful patterns revealing stationarity, periodicity or singular events. To make selections visible, the color encoding of points can be turned off to gray levels. The interface shows also the aggregated daily profiles of active selections in a small window on top right. The user can also right-click to obtain information of close points through a bar plot showing the hourly power demand in a time order. Since the interface is continuously recomputing the views, the user can see an animated bar plot scroll of the demand just by dragging the mouse over the view –e.g. along the whole year. Finally, the current time is shown when the mouse is moved to a data point, using an adaptive date format suited to the active view type.

4. Results

The interface was programmed using the Processing language [FR07, RF07]. The spatial encodings, that include tSNE projections for active and reactive power demand, $\mathbf{p}_{tSNE},\mathbf{q}_{tSNE}$, the three clock layouts $\mathbf{p}_D,\mathbf{p}_W,\mathbf{p}_Y$, and calendar $\mathbf{p}_C$ and $\mathbf{p}_{365\times24}$ visualizations were precomputed using Matlab and reloaded by the Processing application for interactive visualization. Rendering is done several frames per second, allowing transitions between different views to be displayed in a fluid manner, and operations such as selection, or context information retrieval to take place in real time as soon as the user triggers them. A total amount of $N=8760$ samples ($=365\times24$) with the hourly active and reactive power consumption of a whole year at a university building were considered, ranging from 01/03/2010@00:00 to 28/02/2011@23:00. In Fig. 2 a selection of four possible scenarios is shown. In ② the user selected a combination of year and weekday. Each of the seven circles represents the behavior of the demand along a whole year on a particular weekday. It can be seen how the demand is largest mainly in winter and smallest in summer, which coincides with the lowest activity. Also some sporadic behaviors are seen in particular days that correspond to special events –

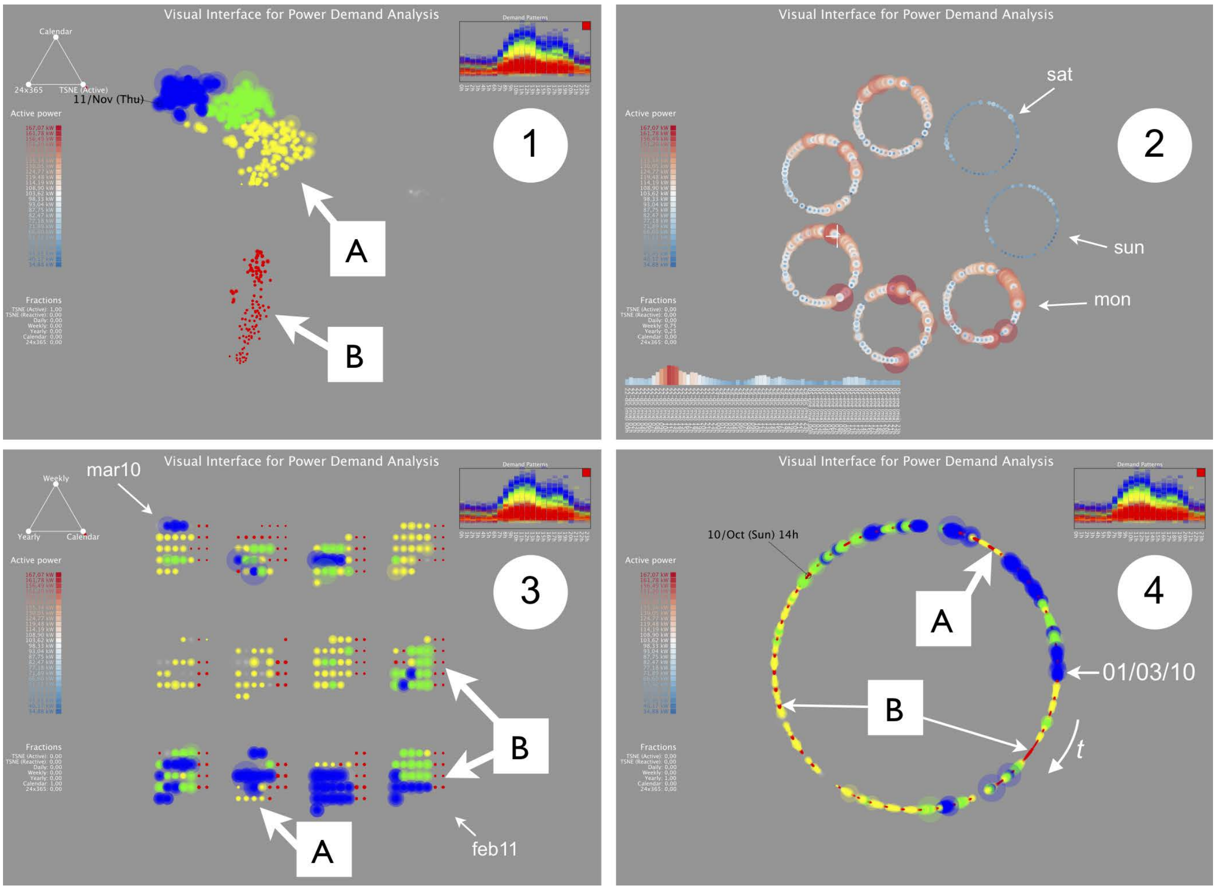

Figure 2: *Snapshots of the interface. 1) tSNE view; 2) year/weekday view with barchart; 3) calendar view (weeks start from Monday); 4) selections seen in the yearly view and time label of a datapoint (in black).*

exams, laboratory tests, etc. In ①, ③ and ④, four selections –blue, red, green, yellow– are shown. For instance, selections in the tSNE view, allow the user to manually cluster the types of daily profiles and can be tracked during morphing towards the other views. The blue selection describes a pattern of heavy demand, that can be seen to correspond in general to winter days –mainly January– in the calendar view ③. The yellow selection (A) describes light demand typical from Christmas or August –non teaching periods, but with some activity, such as research–, as seen in the calendar view ③ and in the yearly view ④. The red selection (B) reveals also in ③ and ④, nonworking days, typically weekends and holidays –such as Easter, in April 2010.

5. Conclusions

This paper presents an interface based on animated transitions of 2D scatterplots called MorphingProjections. The interface blends up to three views in real time with variable mixing proportions defined by the user through an interacting element called *ternary plot*. The result has the advantages of animated transitions, allowing the user to track items during transitions and helping to maintain a mental map of relationships between views. In addition to this, it produces meaningful intermediate states during transitions that can be used as standalone visualizations, along with all the remaining interaction elements, such as zoom, pan and multiple selections that are preserved during subsequent transitions to other views, resulting in a complementary linking mechanism between views. The spatial encodings of the basic views allow to consider different time granularities (hourly, weekly, yearly, month calendar...), as well as similarity between vectors of daily demand profiles, providing a comprehensive view of the demand behavior. Future research will consider including more variables –temperature, occupation, etc.–, application to other promising fields –e.g. spatiotemporal analysis– and a user study to assess the efficiency of morphing in different data analysis problems and user groups.

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