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Electrical Appliance Usage Timeline Data Visualization: Machinima and Dynamic Circle

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ABSTRACT

In a storytelling context, the visualization of the timelines for appliance usage could convey a great amount of information to audiences about the patterns or habits of households when using appliances in smart home. However, today's research on smart home visualization is more focused on time series data, while research on timeline does not focus much on expressiveness in a storytelling context. If we simply visualize the time series or use traditional visualization methods to visualize the timeline, the intention and effectiveness of storytelling may be reduced. In this paper, we analyze the above issues in detail and propose a new visualization design based on machinima and a dynamic circle.

CCS CONCEPTS

• Human-centered computing ~ Visualization ~ Visualization design and evaluation methods • Human-centered computing ~ Visualization ~ Empirical studies in visualization

KEYWORDS

Smart Home, Energy Data, Appliance Usage, Time Series, Timeline Visualization, Machinima

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1 INTRODUCTION

With the popularization of smart homes, people can obtain more and more detailed electrical appliance usage data. After data processing, these data can be used to infer daily patterns for use of electrical appliances in homes in the form of timelines. These patterns drawn from the analysis of complex electrical appliance usage data can be communicated to laypeople through visualization to give them a general view on how people use appliances in the home. The traditional visualization of the smart home tends to focus on the detailed raw *time series*, which requires the audience to recognize appliance use for themselves. We want to focus the audience's attention on a *timeline* of appliance use, which highlights when appliances are being used. This article describes a specific timeline pattern form drawn from smart home time series data in section 2. It discusses traditional time series and timeline visualization and compares them to our proposed timeline visualization, introduces a design space for timeline visualization, and proposes a new timeline visualization method based on *machinima* and *dynamic circle*, in section 3. This new timeline visualization method vividly represents the timeline of electrical appliance use, without losing the precision in the underlying time series data.

2 DATASET

Within a certain period of time, assume that we have N appliances in one home and the ith is denoted as $A_i, i = 1, \cdots, N$. The collected appliance raw usage data for A_i can be described as a timeseries of data consisting of a sequence of M_i pairs $(t_{ij}, p_{ij}), i = 1, \cdots, N, j = 1, \cdots, M_i$, where p_{ij} is the measured instantaneous power value at the timestamp t_{ij} for A_i. We can process these data by using some algorithms, such as cluster analysis [1] and pattern recognition [2], into a representative daily timeline pattern consisting of a sequence of K pairs $(\Delta t_k,\ a_k), k = 1, \cdots, K$, where a_k is a subset of $\{A_i\}$ at the time range Δt_k. The timeline pattern indicates the tendency to use which electrical appliance during what time period in this home. It is what we are going to visualize and tell a story to audiences to give them a view on the habits of using appliances in this home.

An example is the dataset we used in this article, which comes from the IDEAL Household Energy Dataset [3]. It records the use of household electrical appliances for a person during a certain period of time, in tabular form. There are 51 appliances over the 8 homes collected over months or years in the whole dataset (each home may have various appliances and time period of data gathering). For each appliance we have a time series of data (an example is shown in Table 1). Some items usually considered to be furniture, such as electric beds, are also included as appliances. This is because the bed is also equipped with motors and sensors, which can record the use of the bed.

Time Stamp	Power
2020-01-08 14:42:45.630	1.3
2020-01-08 14:45:00.627	1.4
...	
2020-10-17 22:50:52.040	1.3
2020-10-17 22:55:48.057	1.4

Table 1: Raw time series data for one appliance in one home

Data cleaning, data re-sampling, and some specific algorithms are used in dataset processing. The final data we then have is the daily *timeline* pattern of the user’s use of electrical appliances during this period, illustrated in Table 2.

Time Range	Appliances Used Set
00:00 - 06:00	elec bed
06:00 - 07:00	elec bed,coffee
07:00 - 08:00	elec bed,coffee,tv
08:00 - 11:00	tv
11:00 - 12:00	microwave,tv
12:00 - 14:00	microwave,tv,coffee
14:00 - 17:00	tv
17:00 - 19:00	tv,coffee
19:00 - 24:00	tv,elec bed

Table 2: Data after processing in one home

3 DATA VISUALIZATION

3.1 Visualization for Energy Data in Smart Home

When sensors of different appliances collect energy data in a smart home, visualization for these energy data are used to infer the energy usage. Castelli et al. explored a visualization tool to meet individual data-related demands in a smart home [4]. In terms of visualization of energy use data over time, they used standard time series graphs, using color and stacking to indicate different traces.

Goodwin et al. used a user-centered design process to explore more possibilities for smart home visualization [5]. The visualizations included time series and heat lines, which are combine action of heat map and time series.

These visualizations for smart homes are visualizations of time series so people need to draw their own conclusions from these visualizations. Research on the visualization of time series is common and also not limited to smart homes, such as using a cluster and calendar based visualization to infer employee attendance [6]. However, what we are going to visualize is the *timeline*, which is different from time series. A timeline is a sequence of events, or interval event data [7]. With the help of various data analysis methods, we could transform energy data into a timeline (see Table 2), which is a kind of conclusion obtained by data scientists in fact. The visualization of this timeline can enable the audience to quickly obtain the required information - people's habit of using electrical appliances.

3.2 Timeline Visualization

The purpose of a visualization of a timeline may be divided into two categories: exploratory data analysis and storytelling. In the context of storytelling, expressiveness is considered important, where expressiveness indicates the degree of support for various narrative points, or the extent to which one narrative point is made in different ways [8]. The degree of expressiveness may result in different kinds of feedback for story listeners. However, in a traditional exploratory data analysis context, events on the timeline are often encoded as lines or glyph-based marks and placed on a horizontal line according to the sequence of events [8,9] and this is called a linear and chronological timeline. This visualization can intuitively show the sequence and time points of each event but lacks expressiveness to some degree. This is because the goal for these timelines is to let users recognize “distributions, trends, and anomalies once large amounts of data have been compressed into concise overviews” so leads to a better in-depth analysis [10]. For example, Plaisant et al. designed the visualization for personal history timeline to trace back history records in detail [11]. This visualization was designed for expert data exploration, providing access to many different dimensions of the data. Due to the need to support the display of a large amount of information, interactivity is essential in such timeline visualization [10]. However, in a storytelling context, the timeline usually does not contain too much information, such as the habit of using electrical appliances in our example, so these free explorations of the timeline either increase the complexity of the timeline or are unnecessary. What the audience needs is a conclusion that can be taken away directly. Therefore, visualization that is intuitive, vivid and has a high degree of expressiveness is needed more.

This paper introduces a new idea for timeline visualization, which is composed of the use of *machinima* and *dynamic circle*, which are described further below. These were initially developed for an application in social care, and are illustrated in a video from that application [16].

3.3 Inspired by a Design Space of Timeline Visualization

Brehmer et al. proposed a design space that can balance expressiveness and effectiveness when visualizing timelines [8]. They divided a visualization into three dimensions: the *representation* of the timeline, the *scale* of the time and the *layout* of multiple timelines, as illustrated in Table 3. They combined different elements in the three dimensions to get various timeline visualizations. Inspired by this design space, we can design the best suitable visualization to meet our goal.

Representation	Scale	Layout
Linear	Chronological	Unified (single)
Radial	Relative	Faceted (multiple)
Grid	Logarithmic	Segmented
Spiral	Sequential	Faceted + Segmented
Arbitrary	Sequential + Interim Duration	

Table 3: The three dimensions of Brehmer et al.'s timeline

For the timeline representation (left row, Table 3), *radial* is suitable because a shape consistent with the circle of the clock is intuitive for expressing people's daily routines [8,12], which is exactly in line with our dataset. For the scale dimension (middle row), *chronological* is selected to match people's traditional conception of time on the clock. Since we only need to express one pattern of people in a certain period, the *unified* layout is appropriate, which means a single timeline. Inspired by this design space, our design now is a single circular timeline with chronological scale.

However, it is static. This kind of stillness leads to the compression of information in time and a lack of guiding the audience step by step. But in many storytelling cases, dynamic timelines are allowed, meaning that the timeline can be played in the form of a video (not necessarily interactive). Thus, we can transform the above static visualization into a dynamic clock like visualization, so that the audience follows the guidance of the pointer to recognize this timeline. When the timeline dynamically completes a circle, the pointer leaves a trail of different colors to indicate different events in different time periods. This is similar to the way long exposure photography will flatten a continuous scene from second, minutes, or hours to a single image [13] while if the photographer records a video while taking the long-exposure photo, the information obtained will be increased.

The above design is the basic structure of our visualization and we name it ***dynamic circle***.

3.4 Visualization: Machinima

Machinima, which is depicted as a way to use a video game to produce animated cinema, is now widely used in visual storytelling due to its high flexibility and low cost [14,15]. For the timeline of our dataset, using *machinima* technology to make an animated cinema based on the timeline to assist storytelling is very attractive. The animated cinema can use the perspective of the protagonist of the game to show the timeline of a household's use of electrical appliances in a similar home layout and thus adds a new narrative point to the timeline. For example, when the storytelling time now is 08:00 - 11:00, the producer could follow the timeline to control the protagonist in the game to watch TV and then record a certain length of video. Finally, the videos of different time periods are combined together to produce a collection to show this timeline and some diary subtitles from the first-person perspective can appear next to the animated cinema, so that the audience can vividly gain a feeling of the story, as depicted in Figure 1.

Figure 1: Use *Animal Crossing* [17] to produce an animated cinema based on timeline

3.5 Visualization: Dynamic Circle

Based on the basic structure of *dynamic circle* in section 3.3, we designed a more vivid and interesting *dynamic circle* to visualize the timeline, illustrated in Figure 2. The circular animated cinema in the middle of the visualization is made by *machinima* technology, and the two circles on the outside represent the timeline of appliances usage from 00:00 to 12:00 and 12:00 to 24:00. Different colors represent different types of appliances and the small icon of the electric bed on 12 o'clock direction represents the position of the hour hand to indicate the current status of electrical appliances in use.

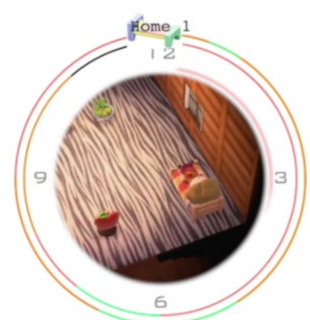

Figure 2: The screen shot of one dynamic circle when it ends

When this visualization is presented to the audience, it is dynamic (see Figure 3). This means that the icon of the previous electric bed will move clockwise like an hour hand and change with the electrical appliances currently in use (a computer in Figure 3) and leave tracks of different colors. At the same time, the animated cinema in the middle will also change synchronously. A line segment between the two outside circles and cinema circle will turn around to reflect the passage of time and also change color synchronously. Compared with the static circular timeline, the dynamic feature allows the audience to experience the changes in the appliance's usage with a narrative point of protagonist in the game from 0 o'clock in the day when storytelling, which increases the interest of audiences and makes the information transmission more efficient.

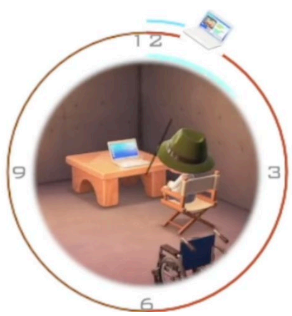

Figure 3: The screen shot of one dynamic circle when it runs

4 CONCLUSION, LIMITATIONS AND FUTURE WORK

This paper introduced a new idea for timeline visualization, which is composed of the use of *machinima* and the new *dynamic circle*. This new timeline visualization, as illustrated in a video from a social care application [16], can help the storyteller to depict a more vivid and interesting story about timeline through different narrative points.

We presented these visualizations to Smart Energy GB, an organization focused on communicating the benefits of smart meter-based technologies. Their comments include: that the *dynamic circle* is easy to understand, visually appealing and could help solve the problem of energy use information not being obvious to consumers; that this can help people to monitor their energy consumption patterns and so change their behavior to reduce energy use and save money on their energy bills; and that the visualization of appliance use through the day could be particularly valuable for consumers who have time-of-use tariffs, as they will be enable to user their appliance at times when electricity is cheap and plentiful

This visualization aims to be used in storytelling on a given dataset form so it just allows for a small and cropped temporal dataset to be visualized. Also, more user tests under a storytelling context and a more rigorous evaluation process is needed in the future. In addition, this visualization is in the unit of home. When there are multiple people in the home or multiple appliances are being used, although we can change the protagonist in *machinima* or add more icons, it is obvious that the visualization does not differentiate them in more dimensions. On the other hand, the visualization only focuses on the process of storytelling, so that the narrator can describe the process more vividly, but lacks some overview for all appliances throughout the day to let the audience intuitively recall the habit after storytelling. This problem may be mitigated by replacing the visualized trajectory with various appliance icons.

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