The Time Diagram Control Approach for the Dynamic Representation of Time-oriented Data

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ABSTRACT

The dynamic representation of time-oriented data on small screen devices is of increasing importance. Most solution approaches use issue-specific requirements based on established desktop technologies. Applied to mobile devices with small multi-touch displays such approaches often lead to a limited usability. Particularly, the time-dependent data can only be fragmentarily visualized due to limited screen sizes. Instead of reducing the complexity by visualizing the data, the interpretation of the data is getting more complex. This paper proposes a Time Diagram Control (TDC) approach, a new way of representing time-based diagrams on small screen devices. The TDC uses a principle of cybernetics to integrate the user in the visualization process and thus reduce complexity. TDC focuses on simplicity of design by only providing 2D temporal line diagrams with a dynamic zooming function that works via standard multi-touch controls. Involving the user into a continuous loop of refining the visualization, TDC allows to compare data of different temporal granularities without losing the overall context of the presented data. The TDC approach ensures constant information reliability on small screen devices.

Keywords: time-oriented data, data visualization, mobile devices, time diagram control, 2D temporal line diagrams

1. INTRODUCTION

For decades, time has been a central aspect of human existence [1]. Related to its every day importance for most people, the visualization of time itself and time-oriented data is still an important task [2].

Importance of Specific Time Diagrams

Time-oriented data is a major subject in most different aspects of our daily life. Whether measuring cardiac frequencies in a hospital [3], analyzing network traffic within an IT infrastructure [4] or monitoring stock market changes, the availability of time-oriented information in a specific form, on a level of detail and at the right moment is crucial. Thereby the challenge of the application always lies in balancing data aggregation and information detail. An adequate time-oriented visualization technique must be able to provide its users with only the required information, without leaving out any important details [5]. Achieving this central purpose usually leads to the development of very requirement-specific solutions that ensure a maximum benefit within its narrowly defined field of application.

Visualization on Limited Space

The availability and daily use of smartphones and other mobile devices has tremendously increased in the last decade. Consequently, the usage of time-based diagrams on small screens has increased as well [7]. These platforms and their technology yield various new operating possibilities such as multi-touch zooming and handling [8]. Such functionalities provide new possibilities, especially when designing an interactive time-based diagram. On the other hand, their constant limitation in display size poses the challenge of delivering sufficient information detail without losing the overview. Therefore, both the benefits and drawbacks of time diagrams on mobile devices generally require specific solutions.

Chapter 2 analyses existing design approaches for time-based diagrams as well as general design techniques related to mobile device usability. In chapter 3, the research of the representation of time-oriented data is motivated, while chapter 4 discusses an appropriate design for time-based diagram representation on small screen devices. In chapter 5, the verification of the defined solution approach along a practical example with focus on new possibilities and existing restrictions is given. Chapter 6 concludes with discussing the proposed solution approach.

2. STATE OF THE ART

The variety of different design approaches for time-oriented data visualization is enormous. The generic time visualization theory, existing requirement-specific approaches as well as the design on limited space is discussed in the following.

Time Visualization

Visualizing time-oriented data and its specific complexity is not a new topic [9]. The importance of time and its depiction is well stated e.g. by Slaney and Lyon [10]. Aigner et al. [11] divide the area of time visualization into four sub parts which are time-orientation, visualization, interaction and analytical support. Each of these fields has to be considered to create a proper time-oriented diagram.

Time-orientation is crucial to achieve a relation between time and data. The analysis of the available data leads to the question of how the temporal axis of the diagram can be structured. As a second aspect of time visualization, the visualization itself must be investigated. Thereby the three basic questions have to be answered: What data have to be visualized, why this diagram type is used and how it is representing the data. These questions usually lead to strong task-orientated solutions.

Aigner et al. [12] [13] analyze different aspects of visualization. The third aspect of time visualization is the interaction of a human and a visualization device. This aspect focuses on how the visualization can be accessed. Related to that, operations such as selecting, zooming and moving the presented data are implemented. The fourth aspect focuses on supporting the analytic functions of a diagram whereas the significance of presented information has to be ensured. As stated by Walla [15], an improper representation of information may lead to wrong interpretations and conclusions.

Issue-Specific Design Approaches
The issue-specific design approaches for time-oriented data visualization have to be respected. Klimov et al. [16], Kosara et al. [17] and Shahar et al. [18] define solution approaches for the graphical and time-oriented representation of important data which lead to similar time-based diagrams such as given in Figure 1: Time is on the x-axis, single values or continuous progressions are on the y-axis.

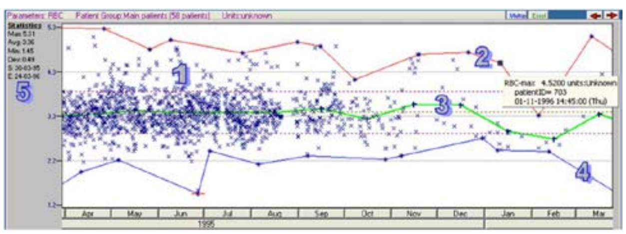

Figure 1. Representation of medical information by Klimov et al. [19]

Fernandes Silva et al. [22] present an overview of the main visual techniques for interactive exploration of time-oriented information stored in databases. They conclude that visualizations often have no interaction mechanisms with the user [23].

Focus on Space Limitation
A very important topic is the limited visualization space on small devices. In order to define the generic terms of small screens, Wagner [26] presents an overview of current and widespread display sizes of mobile devices. Related to that, operating and usability concepts of smartphones and tablets are investigated [27]. Finally, those influencing quantities have led to an investigation of what possibilities along dynamic and interactive data representation are available on small screen devices [28].

3. RESEARCH PROBLEM

This paper investigates how to transfer and apply time-oriented visualization methods on mobile devices with limited display space. The following statements shape the research on the representation of time-oriented data:

1) A large graphical representation is not manageable on mobile devices due to limitations of display space [30].
2) Current diagram types are usually created with a focus on desktop systems which means that no dynamic control concepts are implemented [31]. Thus the huge advantage of mobile devices remains unused when operating such approaches without adaptations.
3) Due to their limited space, common diagram types are not able to provide the user with an adequate information context when comparing data of different types or from different time scales [32].

According to the identified problems, this paper defines a new conceptual design approach that provides answers on how a complex time-based diagram…

1) … is visualized with a simple line diagram:
The big challenge is to create an approach which provides the possibility to explain complex data patterns just by the easily understandable line diagrams in the second dimension.

2) *… is usable in a dynamic way regarding zooming and moving:*
A time-based diagram designed for mobile usage should clearly take advantage of the operating concepts of tablets and smartphones. Therefore, intuitive zooming and moving using multi-touch control must be possible.

3) … allows the usage on limited display space devices:
As our approach focuses strictly on current smartphone devices, it has to be properly adaptable to a common display size [34] of at least 5 inches providing an HD-resolution of 1280x720 pixels which results in an aspect ratio of 16:9.

4) … ensures the reliability of the presented data:
The purpose of any diagram is to provide the users with aggregated information out of given data. To guarantee proper conclusions the new approach must support general design aspects [35] to ensure data reliability.

5) … becomes universally reusable for various business cases:
Our new approach of time-oriented data visualization on limited display space is not defined in a solution specific manner, but strictly focuses on time representation on the x-axis. Optimization of content representation on the y-axis is not part of this research.

4. TIME DIAGRAM CONTROL APPROACH

As the new design approach for representing time-oriented data on limited display space has to focus on a clear practice-oriented reusability, an existing classic design approach for mobile diagram visualization is taken into account as the initial situation.

Figure 2 shows the time-oriented visualization of energy values which represent the daily production capacity of a solar power plant [39]. Thereby this bar diagram provides a monthly overview with "day" as the timed value on the x-axis and "kWh" as the measured value on the y-axis. As a month is predefined with a maximum of 31 days, this specific type of diagram is able to provide an appropriate overview even on a small screen device. But, unfortunately, this diagram, due to the restricted display space of a mobile device, is not able to provide any possibilities to present hourly energy values, which are measured during the entire day, in relation to the monthly information.

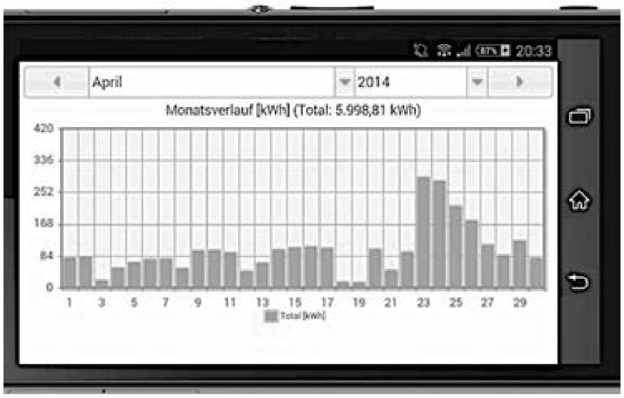

Figure 2. Displaying energy values on small screen devices by Solarmax [38]

But, in fact, exactly this information is of interest when analyzing solar plants, because energy production is depending highly on the solar intensity which of course changes during the day, from season to season. Local weather conditions as well as air density, purity and even the cleanliness of solar panels directly influence the efficiency of energy production [40]. This app provides a daily (as well as a yearly) overview to recognize the desired information but lacks the important monthly context. Therefore, the user is compelled to switch between various views of the app in order to compare a defined day of the current year with the same day a year or a month before. Thereby it will be necessary to store the different views and information by making print screens or extracting information in different ways to achieve the desired context.

2D Widget Attempt

Our new solution approach for time-based diagrams focuses on the time-axis, providing detailed information about it, without losing the context of the current shown data in the diagram. The y-axis represents any value and is static. We call our approach, "time diagram control" (TDC). It is a simple two dimensional representation of time and is designed for mobile devices with a screen size of 5 inches. The TDC-approach is based on the principle of cybernetics, "closing the loop", and thus allows the user to interact with the diagram to iteratively determine the level of the sought detail.

Table 1 indicates all levels of detail possible to display if the data provided to the TDC-approach contains such a granularity. It is possible to provide a lower granularity, to use an intermediate sequence or even to leave out levels.

Level	Metric
0	N-Year
1	Year
2	Quarter
3	Month
4	Week
5	Day
6	Hour
7	Minute
8	Second
9	Millisecond

Table 1. Different granularity steps in TDC

According to the granularity of the data a context can be defined. This context represents the current data, shown in the diagram from which further details can be sought.

Starting with a certain context, the user has the possibility to increase or decrease the granularity level before the context is changed. Assuming that a TDC-approach is provided with data that contains the detail of year, month, day, hour and minute and the context is set on *year*, it is possible to show a detail of hours within the context of twelve months. In case of a third step in detail, the context will change to the next level of detail as well. Regardless of the current level of details shown or context set, it is possible to move the focus on the x-axis.

Figure 3 explains the case described above, where the context is set on *year* but no further zooming is done. The diagram simply provides an overview of a year with the granularity *month*. To the left and right of the x-axis the total data is indicated. This gives the user a clear sense of the context's current position within the total data provided to the TDC-approach. It shows on the left, that year 0-1 is available in the past and on the right, that years 3-10 are available in the future. Because of the limited space, only the first and last scale points are labelled with a clear time indication, where the intermediate months are numbered only.

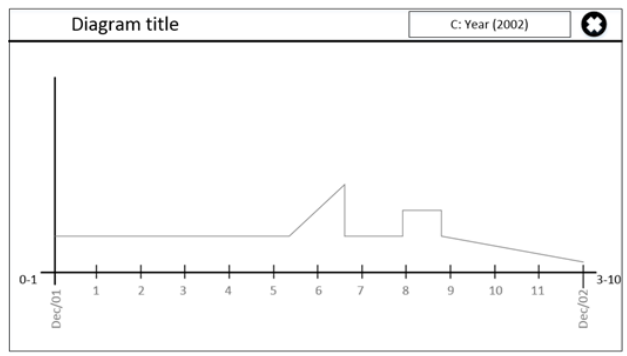

Figure 3. TDC-approach with no expansion: The x-axis shows the year 2002 for months 1 – 12 and indicates the years 2000-2001 and 2003-2010

To display the next level of detail, the x-axis has to be expanded in the range of the zooming and contacted in the remaining context. The maximal expansion of the next level always consists of two thirds of the previous level. The position of the zooming depends on the user's interaction and is not necessarily centralized on the x-axis. If the zooming were automatically centralized, the initial context would change.

Figure 4 shows the maximal expansion of the next level in our example. The zooming provides the overview of a month with the granularity of days. The position of the expansion is the seventh month, therefore six months are allocated to the left, using 6/11 of the third for the context, and five months are allocated to the right, using 5/11 of the third for the context. To clearly visualize the new granularity the scale and the graph are displayed in different intensities.

Furthermore, a smooth dashed line in the graph supports the distinction between the levels. As well as in the context, only the first and last scale points of the expansions are labelled with a clear time indication. At this point, the user already has the detail of days and still can go one level further without changing the context of a year.

Further zooming is only possible within an already completed expansion of a level. The granularity of the contracted context cannot be changed if proceeded with zooming into the next level. Again the maximal expansion of the next level takes two thirds of the maximal expansion of the previous level. This leaves a total of 4/9 of the total x-axis for the second expansion. The same behavior with the position of the zooming and the division of the remaining third is applied as on the previous level.

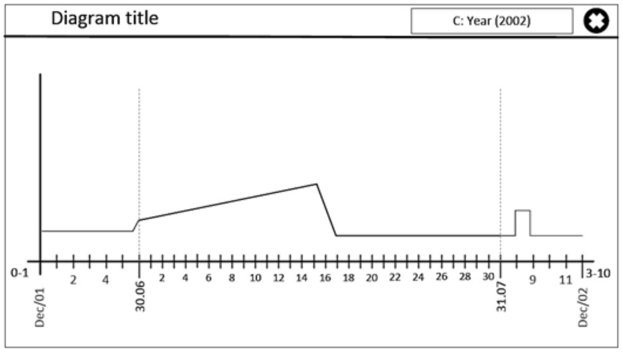

Figure 4. TDC-approach with one expansion: Zooming into one month. The months before and after are shown in compact format.

Figure 5 represents one more step in detail without changing the context. The expanded range is represented in a third grey tone and only the first and last scale points have a clear time indication. This shows that each expansion behaves according to the same pattern. The expansions are restricted to a maximum of two because of the limited space. If the user continues with the zooming the context of the currently shown data changes to the next lower level. If the context is changed, all expansions increase their granularity to the next level of detail. In our example the context changes to *month*, the first expansion represents the hours and the newly expanded range is represented in minutes.

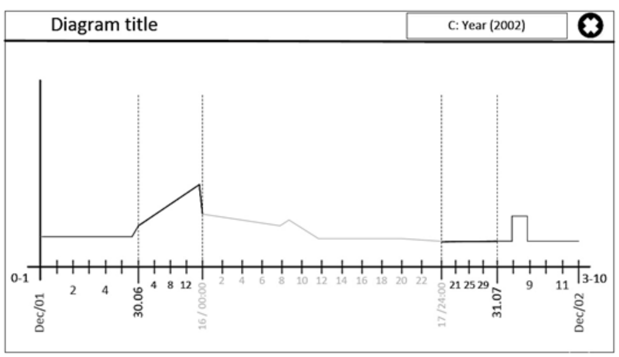

Figure 5. TDC-approach with two expansions: Detailed hourly information (center) is given for the 16th of June 2002. Floating time context is given for days and months, shown by the two areas next to the center depiction.

At any point the user has the opportunity to shift the focus of the current expansion on the x-axis. All the upper levels will move accordingly if done so. This interaction is restricted to the current expansion and does not apply to the contracted levels. This behavior limits the movement on the x-axis in its size according to the current level of detail. To move in bigger steps on the x-axis, the current level can be contracted by zooming out until the previous level is in focus. Another option is to remove an expansion instantly which results in a complete expansion of the previous level. Decreasing the granularity by removing the expansion, without changing the context, is only possible until all expansions are removed or contracted to the minimum and only the context is represented. If further zooming out is proceeded the context changes to the next level above, if available. The zooming in and out can always continue if a next or previous level is available. If no further levels are available to increase or decrease the granularity, the interaction of zooming in or out is blocked. The same applies to the movement on the x-axis. If there is no data for the future or the past the shift to the right or left is blocked.

If the user has reached the intended position with the desired granularity, he or she has the opportunity to store the current expansion with its position on the timeline as a snapshot. The snapshot contains the context and all expansions made at the moment of storing and can be taken at any level of detail. After the snapshot has been taken and stored, the graph is used again regularly. But with the obtained snapshot the user has the opportunity to swap the currently shown data with the snapshot. This allows to switch quickly between two different views within the total data.

If a snapshot is used for comparison of different views of the data, the TDC-approach is split vertically and represents the snapshot on one side and the current data on the other side (see Figure 6). At this stage, the TDC-approach does not provide the interaction of expanding and contracting on either of the graphs represented but still enables movement on the x-axis.

Assuming the user has stored the graph shown in Figure 4 and compares it with the graph shown in Figure 5, the TDC-approach displays a complete month starting on the 1st of July and the complete day of the 17th of July starting at midnight. The user can choose whether to position the snapshot to the left or right. For a better comparison, the graphs should ideally have the same granularity. Therefore, the user can store up to two snapshots and sees at any time which granularity it contains.

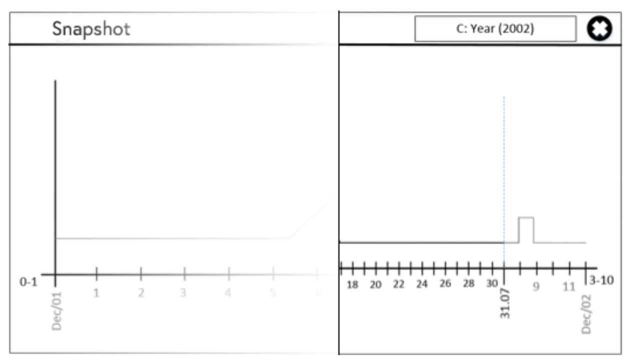

Figure 6. Split screens vertically: Comparing a snapshot (left) with the current data (interactive screen, right)

Dynamic Usage

The TDC-approach allows several interactions which require a device with a touch screen so that all possible moves and features can be used. For design simplification and space saving reasons there are only two buttons: the first to close the diagram and return to the position in the application where the TDC-approach was called initially, and the second which shows when pushed a popover menu with all possible contexts as a selection option. After a selection the popover closes automatically and the focus is back on the diagram showing the newly chosen context.

To expand and reach a higher granularity the user defines the position by touching the graph with two fingers and spreading them horizontally in opposite directions. This interaction affects the expansion only to its maximum. Another interaction to zoom in is to double tap the display. It expands the next level of detail to its maximum instantly. To zoom out the display has to be pinched with two fingers. An expanded level can be removed by tapping, holding and dragging it downwards to the border of the display. To move along the x-axis the user can tap the graph and slide to the left or right, allowing a slow and accurate shift. A flick to the left or right allows an accelerated shift of the time.

To store a snapshot the user can tap, hold and drag the graph upwards to the border of the display. The snapshot appears as an icon on the top center of the display. If two snapshots are already stored, the action is blocked and one snapshot has to be removed first. To remove a snapshot the user taps, holds and drags the icon downwards to the border of the display. If the user wants to compare a snapshot with the currently shown data, she or he taps, holds and drags the icon either to the left or to the right towards the border of the display. On the selected side the stored graph is positioned next to the data to compare. If two graphs are positioned for comparison the zoom in/out function is no longer available.

If a snapshot is stored the user can swap the snapshot with the currently shown data by tapping and directly dragging the icon of the snapshot into the center of the display. This function is also available if the display is split for comparison.

Display Size Handling

As the TDC-approach is designed for a screen size of a minimum of 5 inches and a 16 to 9 aspect ratio it is possible to scale it up to a bigger size but the aspect ratio of 16 to 9 will remain. If a display provides a different aspect ratio the TDC-approach does not change its ratio. In case of a smaller than 5 inches display the TDC-approach scales down but the readability of the captions is no longer guaranteed.

Data Representation Reliability

To decrease misinterpretation, the TDC-approach always provides information about the beginning and the end of the total data. Furthermore, the different levels of granularity in a graph are emphasized with different colors and indicated with a clear time at the start and end of an expansion. The y-axis is static in order to avoid any misinterpretation resulting from different granularities. In our opinion, focusing on the changing x-axis is already complex enough. Another factor for a reliable representation is the fact that the TDC-approach aggregates the different levels of detail itself based on the highest level of detail provided to the control.

Universality

The TDC-approach is independent whether there is data shown in seconds or in years. Almost any level of detail can be represented in the diagram. A configuration allows to skip or add steps in the metrics of time. The structure of the data provided to the TDC-approach is simple and remains the same for any level of detail. It only requires a clear reference date and a number of values in a given sequence. The reference date defines the position zero on the x-axis and the level of detail in which the values have to be interpreted. If for example each value represents a second the reference date has to include a year, a month, a day, the hour of the day, the minute of the hour and the second of the minute as a starting point of the x-axis.

5. EVALUATION

Figure 7 shows a bar diagram depicting the monthly production of the photovoltaic installation in a landscape display mode on a smart phone. By touching a certain day of month, additional information is given in a small popup window (grey). The menu bar provides the opportunity to select a specific date or month. A quick selection in the total data is then possible. This works as a descriptive method, where the user knows what date to look for.

The TDC-approach does not provide the selection of a specific date, instead it offers a rapid search by navigation. With the interaction of removing and adding expansions instantly, the user can move on the x-axis on different levels of details. The method of navigating through unknown data can be seen as an explorative approach.

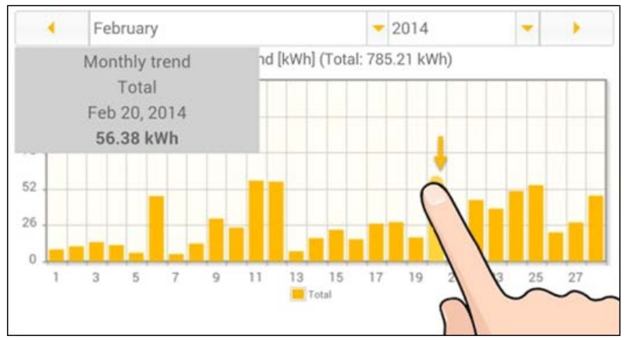

Figure 7. Screenshot from Solarmax, showing the productivity of the solar power system from February 2014. Descriptive selection of data [32].

For evaluation purposes, it is very important to compare two values of different points of time and to check the hourly energy produced in a day without losing the context of the month.

As already mentioned, it would be practical to compare the same day of two different months. With the presented application this is only possible if a snapshot is taken or the graph printed and then compared to each other. For a quick comparison on a frequent basis, this is no feasible solution. At any point a shift on the x-axis is possible which allows a quick gain of information in the closely surrounded date of the two chosen days to be compared.

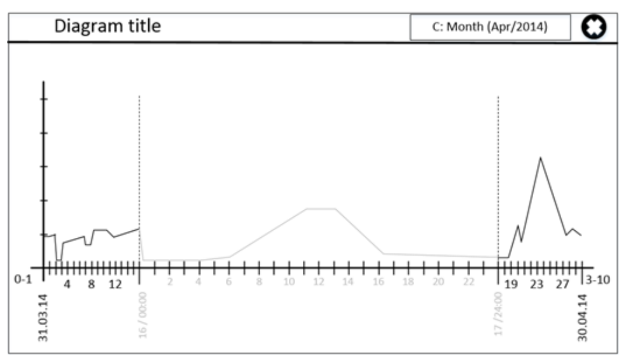

Figure 8. TDC approach: Detail of a day without losing the context of the month. Explorative navigation through data.

Furthermore, the user could want to check the hourly energy values on a specific day, but still wants to see how the hours are in comparison to the remaining daily average of all the other days in the month. With the TDC-approach the user can set the context on a month and scroll to the month of interest. Only one expansion will be necessary to reach the expected detail of a specific day.

6. CONCLUSIONS AND OUTLOOK

With the TDC (Time Diagram Control) approach, this paper presents a new advance towards the dynamic representation of time-oriented data on limited display space, particularly of complex graphical representations which are not simultaneously manageable on small screens of e.g. smartphones. Classical approaches are too much based on desktop solutions and thus are missing dynamic control concepts. The comparison of different points in time is hardly possible on small screens.

Our TDC approach is based on the principle of cybernetics, "closing the loop", and integrates the user by interacting with the diagrams to access and iteratively determine the level of the sought detail. This alternative approach enables the user to "travel through time" in order to visit different periods and identify new temporal patterns in data. The TDC approach brings back simplicity into time-oriented data visualization. By focusing on only 2D line diagrams, on the one hand, and by integrating current multi-touch operation concepts of mobile devices such as smartphones and tablets, on the other hand, the TDC approach focuses strictly on usability on especially small screen devices. Thereby, due to the simple visual approach, users do not need to have a deep understanding of the underlying design concept to be able to derive suitable conclusions from the presented data. Regardless of its simplicity in design, the TDC approach provides its users with new possibilities in context-oriented data analysis by establishing a zooming function that allows the visual connection between time-oriented data of different temporal granularities. With this functionality, a TDC-user is able to analyze data in detail without losing the context of the surrounding data. The TDC-approach needs its data only in form of the lowest temporal granularity, for example, data related to "minutes". The user can then define which higher granularity levels should be visualized, and the TDC-approach will automatically assemble data for the desired levels.

However, the TDC-approach is not able to provide any design approaches other than line diagrams. For instance, it cannot be used for pie charts. The TDC-approach is also not able to provide context-oriented zooming over more than three levels of temporal granularity, because, once again, the limitation in display space would cause improper readability of the provided data. Another limitation of the TDC-approach is that it is only designed for the usage on small screen mobile devices, because multi-touch operability is necessary to maintain usability. Also, there are better solutions for representing time-oriented data on mediums with larger display space available.

Nonetheless, the TDC-approach represents a feasible step towards a future standard in representing time-oriented data on limited display space. Thereby questions along the coloring of different levels of granularity as well as of how to optimize the scalability between different levels of granularity should be the focus of future research. Additionally, usability in general can be improved with, for example, animations indicating current interactions.

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