VISUALIZING DYNAMIC QUANTITATIVE DATA IN HIERARCHIES

TimeEdgeTrees: Attaching Dynamic Weights to Tree Edges

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Abstract: In this paper we introduce a technique for visualizing the dynamics of quantitative data in static hierarchical structures. We exploit the straight links of orthogonal tree diagrams as a timeline on which we visually encode dynamic quantitative information. We use color coding and varying thicknesses to represent the time-varying data. Bimodal data can also be displayed by exploiting both sides of the time axes simultaneously. Our TimeEdgeTrees tool allows us to explore dynamic quantitative data in tree diagrams by interactive data filtering and zooming. The spatial proximity of neighboring hierarchically structured elements allows us to easily explore trends, countertrends, periodicity, temporal shifts, or anomalies during the evolution synchronously. Interactive features such as expanding or collapsing of subhierarchies additionally help to detect the aforementioned phenomena on different levels of granularity. The usefulness of our visualization technique is illustrated by water level data acquired at more than 450 measurement stations along German rivers for 768 points in time.

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1 INTRODUCTION

The most common visual metaphors for representing hierachical kind of data are node-link representations that encode the hierarchical objects as some kind of circular or rectangular glyphs and the parent-child relationships as links connecting the related hierarchical elements. There are alternative approaches that avoid explicit links, e.g., layered icicle diagrams (Andrews and Heidegger, 1998; Stasko and Zhang, 2000; Yang et al., 2003), tree-maps (Shneiderman, 1992), or indented outline plots (Burch et al., 2010).

All these diagrams have more or less proved to be useful for visually encoding static hierarchical data. These are able to show parent-child relationships in a single view and additional quantitative information by color coding of nodes or sizes of rectangular boxes as it is typical for tree-map representations.

In this paper, we focus on the problem of comparing dynamic quantitative data for all hierarchical entities—inner nodes as well as leaf nodes—simultaneously. We introduce a representation where each link of an orthogonal node-link tree diagram is divided into as many segments as are necessary to display the different time steps in the hierarchical data. Color coding and varying thicknesses are used to visually distinguish differently evolving branches in a tree over time.

With our diagrams we intend to explore dynamic quantitative data in a hierarchy for the following behaviors on different levels of granularity:

- **Trends.** Quantitative information behaves similarly for a group of hierarchical entities, that means, the metric for all entities shows a growing or shrinking behavior in the same or a nearly similar way in the same time interval.
- **Countertrends.** Quantitative information behaves differently or even in opposite direction for a group of hierarchical entities in the same time interval.
- **Periodicity.** The data shows some kind of periodic behavior: there are repeating patterns in the time-varying data with the same period length.
- **Temporal Shifts and Scale.** The dynamic quantitative data shows the same characteristics for certain hierarchical entities but with a temporal distance or at a different scale.
- **Anomalies.** There is some kind of strange or unexpected behavior in the dynamic data such as missing data points or values outside a trend behavior.

The most natural way to visualize time-series data

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is by mapping the dynamics of the data to time that is represented by an animated sequence of diagrams. In general, it is difficult for human viewers to remember all visual properties of all elements in an animation because of their limited short-term memory (Ware, 2008). As a possible solution to this problem, they might have to let play the animation several times until they understand the dynamic data. Visualizing the hierarchical organization of the dynamic data in the same animation increases the cognitive load for a viewer immensely.

To overcome these problems we use a static representation of the time-series data instead. To allow better exploration of the visualized data, interaction methods can be applied to the visualization to browse through large data sets with high complexity of the hierarchy or a large number of time steps. As additional features, the dynamic quantitative data can be shown in a bimodal fashion or in a logarithmic scale. Representing all these visual dimensions at once is at least very difficult or even impossible in animated diagrams.

We show the usefulness of the visualization technique by visually exploring a data set from a web site that contains time-varying water level data (PEGELONLINE, 2010). We requested water level data for 768 points in time at more than 450 measurement stations along German rivers.

2 RELATED WORK

The TimeEdgeTrees visualization is inspired by orthogonal node-link diagrams for representing hierarchies. The main benefit of those diagrams is that they already contain straight links that are exploited as timeline representations.

2.1 Static Hierarchy Visualization

In general, there is a huge body of previous research on the visualization of static hierarchies (McGuffin and Robert, 2009). For instance, (Battista et al., 1999), (Herman et al., 2000), and (Reingold and Tilford, 1981) use conventional node-link diagrams to depict relationships between hierarchically ordered elements. Several variations exist for node-link representations that make use of differently oriented diagrams. Attaching an attribute to all of the nodes—for example a text label—using node-link diagrams may lead to overlaps in the display and visual clutter. Moreover, a simultaneous comparison of all attributes is problematic since these are not aligned in the same way in such a diagram. A similar problem occurs when showing quantitative information for each of the nodes in the diagram.

Radial node-link approaches organize tree nodes on concentric circles, where the radii of the circles depend on the depths of the corresponding nodes in the tree (Battista et al., 1999; Herman et al., 2000; Eades, 1992). On the one hand, this technique leads to a more efficient usage of space; on the other hand, it is more difficult to judge if a set of nodes belongs to the same hierarchy level. This apparent drawback of radial diagrams can be explained by the fact that the human visual system can judge positions along a common scale with a lower error rate than positions along identical but non-aligned scales, as demonstrated in graphical perception studies by (Cleveland and McGill, 1986). Balloon or bubble tree layouts are another strategy to display hierarchical data as node-link diagrams: they represent the hierarchical structure in a clear way but do not scale for large and deep trees (Herman et al., 2000; Grivet et al., 2006). As another drawback, it is difficult to attach an attribute to each tree node for comparisons between hierarchy levels.

Tree-maps (Shneiderman, 1992) are a space-filling alternative for displaying hierarchies. One drawback of tree-maps is the fact that hierarchical relationships between parent and child nodes are hardly perceived in deeply nested hierarchical structures. Nesting can be indicated by borders or lines of varying thickness—at the cost of additionally needed screen space. Tree-maps are an excellent choice when encoding quantitative data attached to hierarchy levels. However, showing dynamic quantitative data in the tree-map boxes makes comparisons between single hierarchical entities difficult. In many cases, the tree-map boxes are scaled down to pixel-based graphical elements and hence, a timeline representation is not possible in a static tree-map.

Layered icicle plots require substantial amount of image space: they use as much area for parent nodes as the sum of all their related child nodes together. A benefit of this representation is that the structure of the displayed hierarchy can be grasped easily and moreover, this type of diagram scales to very large and deep trees. Variations of this idea are known as Information Slices (Andrews and Heidegger, 1998), Sunburst (Stasko and Zhang, 2000), and InterRing (Yang et al., 2003). These diagrams make use of polar coordinates, which may lead to misinterpretations of nodes that all have the same depth in the hierarchy. As another drawback, all icicle-oriented techniques require separation lines between adjacent elements allowing differences in hierarchy levels and nodes to be perceived.

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Indented outline approaches (Burch et al., 2010) can be scaled down to pixel-based and indented line plots to represent the hierarchical structure. This approach has the benefit that attributes can easily be attached to all of the nodes in the represented hierarchy and aligned to allow better comparisons. (Burch et al., 2010) showed in a user study that indented outline approaches for visualizing hierarchies do not have significant benefits over conventional rooted node-link diagrams with respect to typical exploration tasks in hierarchies but can be easily learned after a short explanation time of just ten minutes.

2.2 Visualization of Timelines

Our approach is similar to the concept of sparklines (Tufte, 1990). Sparklines show trends, countertrends, periodic behaviors, temporal shifts, and also anomalies of quantitative time-varying data, such as average temperature or stock market activity, in a simple and condensed way. A group of sparklines is often placed close to each other as elements of small multiples. We extend this concept by adding a hierarchical structure to the set of sparklines that supports the exploration of time-varying data on different levels of granularity as well.

There exists only little work on the representation of dynamic quantitative data in hierarchies. The TimeTree technique (Card et al., 2006) allows the user to explore a changing hierarchy, encoding the information about each element at each time step in the corresponding node of the tree represented as a node-link diagram. A time sliding function can be used to interactively browse and search organizational hierarchies over time. However, only one static diagram can be explored at a time. In contrast, the TimeEdgeTrees can show the whole dynamic data or at least a large portion of it in a static view, which preserves one's mental map of the data. (Tu and Shen, 2007) use a different visual metaphor to represent changes of hierarchical data. They introduce a new tree-map layout algorithm to reduce abrupt layout changes and produce consistent visual patterns.

The Timeline Trees technique (Burch et al., 2008) and its radial counterpart TimeRadarTrees (Burch and Diehl, 2008) make use of node-link diagrams attached to a matrix-like representation that shows evolving quantitative data in a timeline. Additionally, relations are shown among commonly changed hierarchical entities by a thumbnail view. The drawback of these diagrams is that timelines are only visible for leaf nodes but not for inner nodes, and that they show the timelines in a different view than the hierarchy itself.

(Hadlak et al., 2010) describe a way to embed hierarchies into regions of a map display by using a point-based layout. The dynamics in the data is visually encoded by layering and animations.

3 TimeEdgeTrees

The TimeEdgeTrees approach relies on the oberservation that the visual metaphor of node-link diagrams for hierarchical data already contains straight lines connecting related hierarchical elements. These lines can easily be exploited as timelines to visually encode the dynamics of quantitative data. Each link is divided into as many segments as time steps have to be represented simultaneously. Additionally, each segment is color coded with respect to the strength of the hierarchical entity at the point in time. If the strengths vary in some kind of exponential fashion, a logarithmic color scale can also be used to make the differences between smaller values more apparent. If the user is interested in small and large deviations from mean values, a bimodal color scale may also be applied. For this, we additionally exploit both sides of each timeline.

3.1 Data Model

We model an information hierarchy as a tree $T = (V,E)$, where V denotes a set of vertex-function pairs

$$V = \{(v_1,f_1),(v_2,f_2),\ldots,(v_n,f_n)\}$$

with $f_i : \mathbb{N} \longrightarrow \mathbb{R}$. The set $E \subseteq V \times V$ contains the parent-child relationships of the hierarchy. The functions f_i map discrete time steps to real valued numbers—the quantitative data for each node v_i at each point in time. A single time step can be identified by a unique number $j \in \mathbb{N}$, i.e. the set of all discrete time steps $\{t_j \mid 1 \leq j \leq n, j \in \mathbb{N}\}$ has a natural order.

We define the arithmetic means $\overline{f_i}$ of some function f_i in an interval $[t_l,t_m]$ as

$$\overline{f_i} := \frac{\sum_{j=l}^{m} f_i(j)}{m-l+1}$$

Later, we need $\overline{f_i}$ to transform the representation into the bimodal mode.

3.2 Encoding of Time-varying Data

The dynamic quantitative data is initially represented in a color coded segmentation of each link depending on the number of time steps.

Figure 1 shows an example of dynamic data visualization in an orthogonal node-link diagram. We

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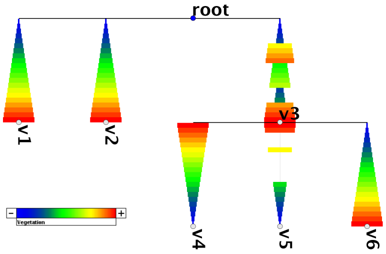


Figure 1: An orthogonal node-link diagram with additionally color coded timelines and varying thicknesses showing 21 time steps of dynamic quantitative data at each of the links.

choose an orthogonal layout since the timelines on each hierarchy level with the same depth are aligned in a common scale; this layout is best suited when judging and comparing differently sized rectangular boxes for each time step (Cleveland and McGill, 1986). Throughout this paper, we use color coding by vegetation scale: smaller values are represented in blue, larger ones in green to yellow, and the largest ones in red. The timeline for a node $v \in V$ always starts where the corresponding link is entering the parent node and chronologically leads to the respective node $v \in V$.

Using color coding as the only visual feature makes efficient use of space, but as a drawback, individual colors cannot be perfectly differentiated when there are too many colors and when those are hardly differing (Ware, 2008). For this reason, the TimeEdgeTrees tool additionally supports visual encoding by varying thicknesses to improve the perception of weakly changing metric values when following a link with the eye.

Figure 2 illustrates our approach for just one node of a tree. In Figure 2 (a), we use color coding to show the evolution of quantitative data over time. Figure 2 (b) depicts encoding by varying thickness, which makes differences in the single data points apparent. Typically, we combine both features—color coding and varying thickness—to encode dynamic quantitative data because similar patterns in differently located tree branches can be better detected and compared when visualizing the data in this way, see Figure 2 (c). Furthermore, color coded diagrams are aesthetically appealing.

The data can also be displayed in bimodal mode, i.e., we divide the data values into two separate categories where each is displayed on one side of each time axis. For the river level data, we first subtract the arithmetic means $\overline{f_i}$ from all other values. Negative values are displayed on the left part of the time axis and positive values on the right side. Figure 3 (a) shows the same dynamic quantitative data as in Figure 2 in the bimodal mode. One can see that the data behaves differently on both sides of the axis. The bimodal mode has another advantage: the display space may be used more efficiently and a bimodal color coding might additionally strengthen the visual appearance of the diagram.

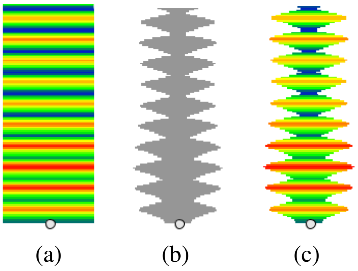

(a) (b) (c)

Figure 2: Different representations for dynamic quantitative data: (a) color coding only; (b) varying thickness without color coding; (c) combination of both.

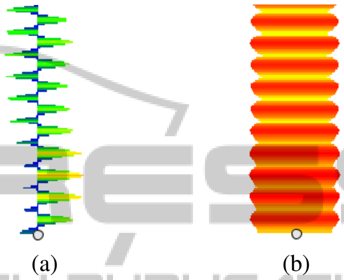

(a) (b)

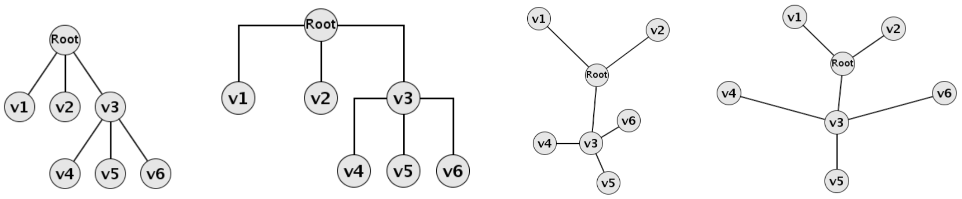
Figure 3: Dynamic data may also be displayed in (a) bimodal mode or (b) logarithmic mode.

A logarithmic scale allows a comparison of the quantitative data points even if they differ to a very large extent. Figure 3 (b) shows an example of a logarithmic scale. One can easily see that there are only small differences at the peaks and their neighboring data points.

3.3 Node-link Layouts

Apart from orthogonal node-link layout, many other layouts exist. In this section, we discuss the pros and cons of them with respect to aesthetic tree drawing criteria, space-efficiency, and the suitability for typical exploration tasks for this kind of data.

- **Rooted Tree.** The rooted tree diagram is the most common way to visualize a hierarchy. The root of the hierarchy is the topmost node in the representation and the root nodes of the subtrees are located on layers depending on the depth of the subhierarchy in the tree, see Figure 4 (a). Rooted trees can also be arranged from bottom to top, from left to right, or from right to left.
- **Orthogonal Tree.** Using orthogonal bends for the



(a) (b) (c) (d)

Figure 4: Node-link tree diagrams may be laid out in a variety of styles: (a) rooted tree diagram; (b) orthogonal tree diagram; (c) bubble tree diagram; (d) radial tree diagram.

Table 1: Several criteria for the discussed node-link layouts (**+** = good, **o** = average, **-** = bad).

Technique	**Space-Efficiency**	**Comparability of Timelines**	**Hierarchy Structure**	**Exploration of Deeper Levels**
Rooted tree diagram	-	o	+	o
Orthogonal tree diagram	-	+	o	o
Bubble tree diagram	-	-	o	-
Radial tree diagram	+	-	o	+

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links leads to an orthogonal tree diagram that is best suited to compare the timelines of all hierarchical elements simultaneously, see Figure 4 (b).

- **Bubble Tree.** Another strategy to visualize trees is by a bubble or balloon tree layout that recursively represents subtrees on circles whose circle center lies somewhere on the circumference of the circle representing the parent node, see Figure 4 (c).
- **Radial Tree.** A radial tree visualization positions the root node in the center of a circle. Child nodes on the same depth of the hierarchy are located on circles with the same radius, where the radius linearly depends on the depth of each hierarchical element in the tree, see Figure 4 (d).

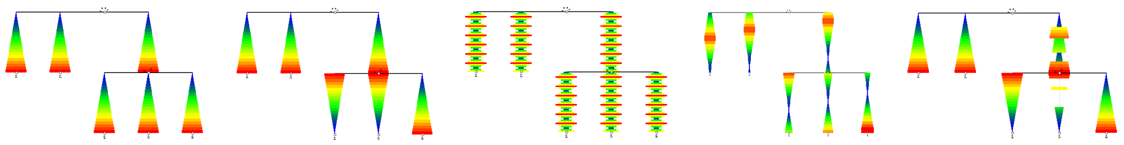
Table 1 gives an overview of several criteria for these node-link layouts and shows if a certain technique meets the criterion (**+**) or not (**-**) or if it cannot be classified clearly (**o**). In this table, we briefly summarize four different criteria for visualizing dynamic quantitative data in hierarchies by means of several node-link layouts. Radial diagrams are the most space-efficient layout since trees normally grow exponentially with depth. The rooted tree layout is best when exploring the hierarchical structure whereas orthogonal layouts allow for better comparisons of the dynamic data since the timelines are aligned as common scales. The least useful type of diagram for this visualization task is the bubble tree layout since there the hierarchical structure is not as well expressed and the smaller circular shapes for deeper trees lead to timelines that are differing in length, orientation, and scale. This again leads to problems when exploring and comparing temporal shifts in the dynamic data.

3.4 Dynamic Behavior Analysis

As already discussed in Section 1, dynamic quantitative data may show different behaviors for a list of certain subhierarchies or hierarchical entities such as trends, countertrends, periodicity, temporal shifts, or anomalies. Figure 5 illustrates how the novel technique can be used to explore time-varying quantitative data for these phenomena and for a group of hierarchical entities at the same time.

In Figure 5 (a), all branches are evolving with the same characteristic, hence, we would classify this behavior as a typical trend in dynamic data. Figure 5 (b) shows that some hierarchical entities are evolving in the opposite direction, a phenomenon that we would classify as a countertrend with respect to the dynamic data of other tree branches. In Figure 5 (c), there is some kind of periodic behavior for all subhierarchies in a similar way. The same pattern is reoccuring after the same time interval again and again. Figure 5 (d) shows that the same pattern or subpattern reappears in all hierarchical entities but each after some delay. Finally, Figure 5 (e) shows an anomaly. Some branches seem to evolve in a trend behavior whereas single hierarchical entities are showing gaps in their time-series data. Furthermore, some data points are missing or are error-prone.

In Section 4, we apply our technique to a data set that contains water level data of German rivers. This data set is well suited to explain all the behaviors of dynamic data described above.



(a) (b) (c) (d) (e)

Figure 5: The dynamic quantitative data may show five different types of behaviors: (a) trends; (b) countertrends; (c) periodicity; (d) temporal shifts; (e) anomaly.

3.5 Interactive Features

The visualization tool supports certain interactive features that can be used to manipulate the hierarchical data. Generally, we follow the visualization seeking mantra of Ben Shneiderman: Overview first, zoom and filter, then details-on-demand (Bederson and Shneiderman, 2003).

- **Expanding and Collapsing of Subhierarchies.** By clicking on a node its corresponding subtree is collapsed. If it is already collapsed it will be expanded again.
- **Selecting Specific Time Intervals.** Only relevant intervals in the evolution can be selected and hence, the remaining time-varying quantitative data can be represented in more detail.
- **Weight Filtering.** To support the viewer in comparing the quantitative information, only those line segments are color coded that lie in between the selected weight interval. All other values are grayed out.
- **Geometric Zooming.** The tree diagram can be scaled up/down by mouse drag and drop.
- **Apply Color Coding.** Different color codings can be applied and tested if explorative tasks become easier.
- **Thickness Slider.** The thickness of line segments can interactively be changed.
- **Labeling.** To minimize visual clutter, text labels can be represented in a vertical or horizontal arrangement or as some kind of spiral representation around each corresponding node.
- **Details-on-Demand.** Moving the mouse cursor over a node or a timeline gives additional textual information about the object in focus.

4 APPLICATION EXAMPLE

To show the usefulness of our novel technique we applied it to a data set that contains the water levels of more than 450 measurement stations at the larger rivers in Germany. The river system itself is a good example of a naturally structured hierarchy formed by natural processes over several thousand years. A measurement of the water level is taken every hour in the time period from September 3rd, 2010 until October 4th, 2010. A simultaneous representation of all water levels at each point in time with an additional hierarchy is very difficult but can give many insights about the behavior of the water level movements and the water level minima and maxima over time.

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4.1 Dynamic River Tides

The measurement stations are ordered from left to right with respect to their location at the river. The stations are ordered starting with the one closest to the source and ending with the one closest to the mouth into a larger river or into the sea. If a smaller river flows into a larger one its subhierarchy is visually displayed between the corresponding measurement stations. This spatial proximity allows us to explore if the water levels of river subsystems influence the water levels of the larger rivers or vice versa.

Figure 6 presents an overview of the whole data set in an orthogonal tree layout. We use a vegetation color scale to distinguish the water levels at each point in time. The more red a color is the higher is the water level at this point in time. Green color means normal water level and blue color indicates that the water level is below normal. Points in time where no data is available are grayed out. Since the values often differ to a high extent we initially apply a logarithmic color scale.

The first observation that one can make from Figure 6 is the hierarchical information that is explicitly given by the orthogonal diagram. The root level expresses that all rivers flow into one of several possible seas; that information can be obtained by inspecting the three elements at the first level of the hierarchy—the North Sea, the Baltic Sea, and the Black Sea.

Even if this diagram hides most of the details, it may let us observe some interesting phenomena. Some of the water levels show periodic behavior. This phenomenon is the result of the heavy tides of the North Sea, which have a period length of approxi-

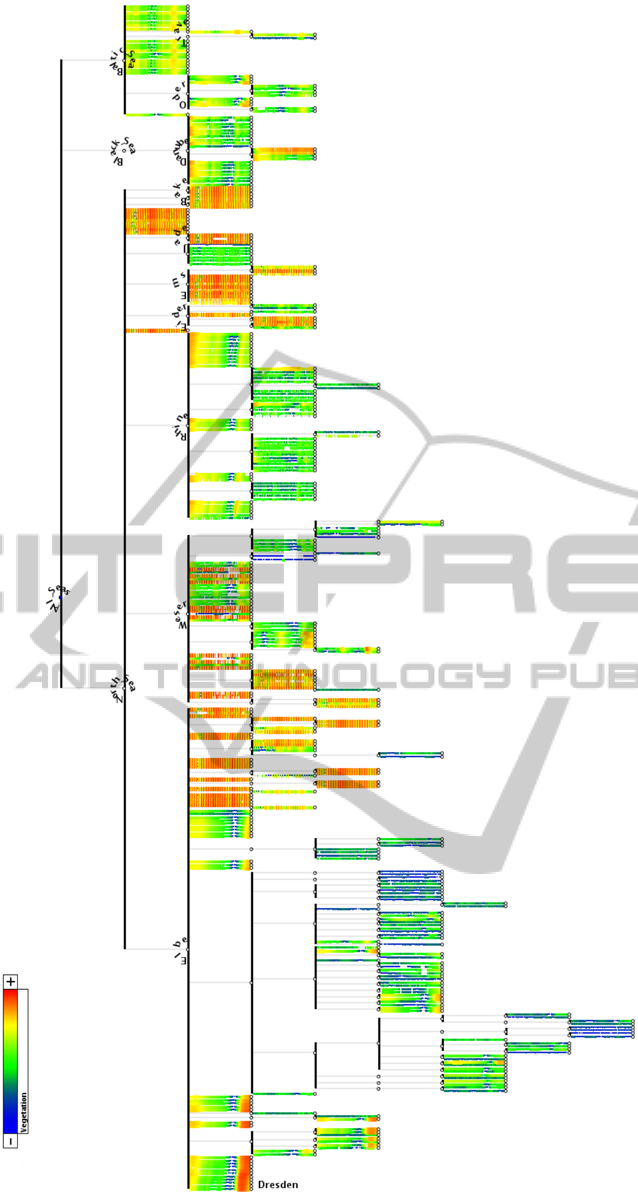

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Figure 6: A visualization of dynamic water level data of the larger rivers in Germany and their hierarchical structure can give interesting insight in the evolution of the water behavior on different levels of granularity.

mately twelve and a half hours. Even the times and amplitudes of the tides at the measurement stations differ, from time to time, which depends on the combined effects of the gravitational forces exerted by the moon and the sun and the rotation of the earth.

Some subsystems show a pattern that crosses each measurement station with a temporal shift. This is apparently visible for the rivers Elbe on the left hand side and the river Rhine close to the center of Figure 6. A detail-on-demand request for the river Elbe shows that the water level near the city of Dresden is more than four meters above normal height. The temporal shift shows that the cities and villages downward the river have to be aware of high watermarks and flooding in the near future.

For Figure 7, we filter the river hierarchy for the river Rhine and all of its confluents, which include the river Neckar, the river Main, the river Lahn, and the river Mosel, which again has a confluent, the river Saar. We can easily see that there are 24 main measurement stations along the river Rhine. Around the 26th of September, there is a larger flood wave above the normal water level at the measurement station Iffezheim. In the next days, the flood wave is passing

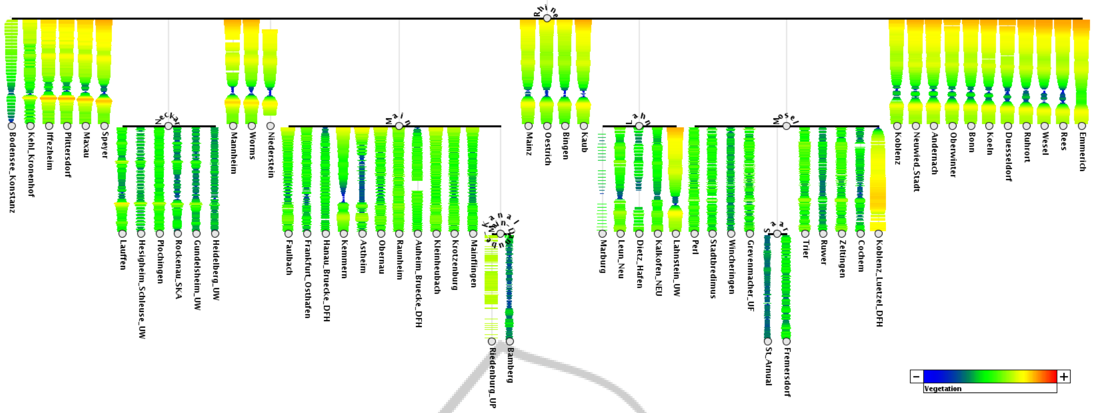


Figure 7: A visualization of the water level data for the river Rhine can uncover interesting phenomena: waves with different amplitudes are crossing the measurement points with a temporal shift and their amplitude shows a decreasing behavior.

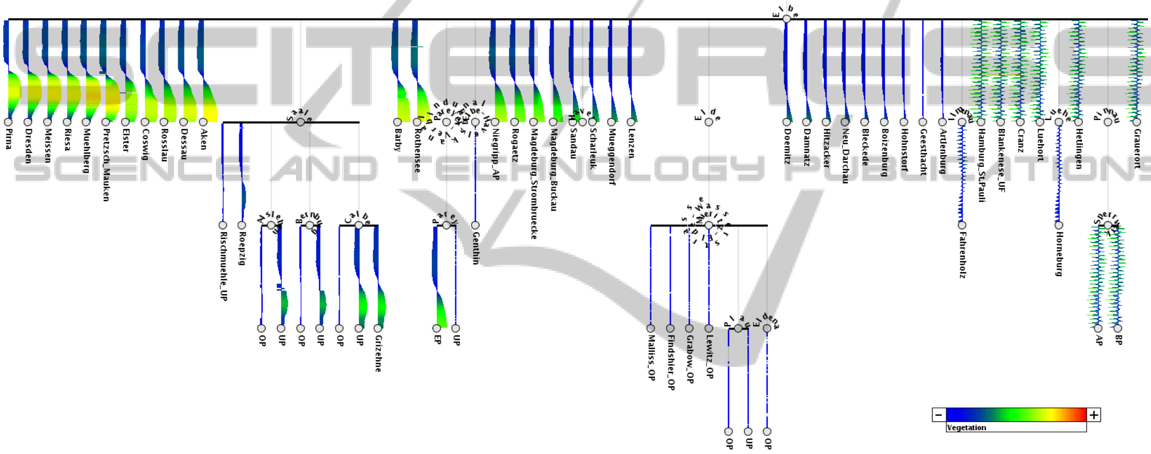


Figure 8: A representation of dynamic water level data for the river Elbe shows different behaviors: one big wave is crossing the measurement stations near the source of the river, whereas the measured data at the mouth to the North Sea shows periodic behavior because of the large tides there.

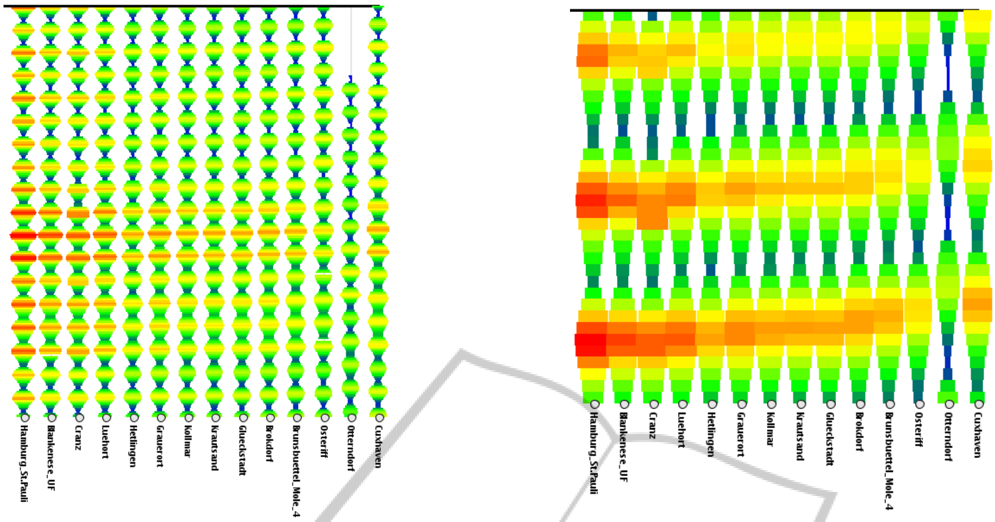
the other stations subsequently but is weakening over time. This can be detected by inspecting the changing color from an orange color over yellow into a yellowish green.

The confluents of the river Rhine do not show this large flood wave behavior apart from two exceptions. The stations Lahnstein-UW and Koblenz-Luetzel-DFH can be classified as anomalies. Although the water levels are low overall, these two measurement stations have high water levels. A closer look at the hierarchy reveals that the rivers Lahn and Mosel are converging there into the river Rhine and hence, are above normal all the time.

Another interesting water level behavior can be seen at the river Elbe, see Figure 8. Here, we applied the bimodal mode that makes use of both sides of the time axes. The left hand side represents water levels below the normal level, whereas the right hand side shows the water levels above the normal water level. The measurement stations seem to fall into two categories if we inspect the left and the right parts of the figure in more detail. Again, the yellow color and the larger thickness on the right hand side of each axis give us the insight that a flooding is crossing each of the stations over time. If we have a closer look at the data visualized for the first five measurement stations, we can easily see that the amplitude at the beginning of the flood wave color coded in yellow remains constant and only the wave's length is growing. The flooding has not reached the measurement stations near the mouth to the North Sea.

The second category of dynamic data behavior can be seen on the right hand side of Figure 8. The data values show periodic behavior caused by the high and low tides of the North Sea and the spatial proximity of the measurement stations to the North Sea.

Figure 9 (a) shows that even the high and low tides differ with respect to the size of their ampli-



(a) (b)

Figure 9: The tides of the North Sea show some kind of periodic behavior and: (a) the amplitudes of high and low tides are also changing; (b) temporal shifts can be detected when just showing dynamic data for one and a half day.

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tudes from time to time. Furthermore, a temporal shift in the wave pattern can be detected easily, see Figure 9 (b). Interesting is the fact that the station Hamburg St. Pauli has the highest tides even though the station is the furthest away from the North Sea among all the stations with periodic water level behavior.

5 CONCLUSIONS

In this paper, we demonstrated how the visual metaphor of node-link diagrams may be used to display a hierarchy with additional dynamic quantitative data. Straight links that encode parent-child relations can easily be interpreted as a timeline starting at the parent node and ending at the child node. The link is divided into as many line segments as time steps have to be visualized. Color coding is used to show the strength of the hierarchical entities for each time step.

We conjecture that using orthogonal layout is best suited for representing this kind of data since only there the timelines in each subhierarchy are aligned and hence, allow for direct comparisons of dynamic data between single hierarchical entities. Possible alternative layouts such as the traditional rooted tree from top to bottom, radial diagrams, and bubble trees have also been discussed.

We have applied the technique to a data set that contains water level data for German rivers acquired between September 3rd, 2010 and October 4th, 2010 at more than 450 measurement stations.

The visualization tool supports interactive features such as expanding or collapsing of subhierarchies, selecting time intervals, weight filtering, details-on-demand and the like.

In the future, we plan to apply the tool to different application domains, for example software evolution data and we also plan to evaluate the visualization technique by a user study.

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REFERENCES

Andrews, K. and Heidegger, H. (1998). Information slices: Visualising and exploring large hierarchies using cascading, semi-circular discs. In *IEEE Information Visualization Symposium (InfoVis ’98), Late Breaking Hot Topics*, pages 9–12.

Battista, G. D., Eades, P., Tamassia, R., and Tollis, I. G. (1999). *Graph Drawing: Algorithms for the Visualization of Graphs*. Prentice Hall, Upper Saddle River, NJ.

Bederson, B. B. and Shneiderman, B. (2003). *The Craft of Information Visualization: Readings and Reflections*. Morgan Kaufmann, San Francisco, CA.

Burch, M., Beck, F., and Diehl, S. (2008). Timeline Trees: Visualizing sequences of transactions in information hierarchies. In *International Working Conference on Advanced Visual Interfaces (AVI '08)*, pages 75–82.

Burch, M. and Diehl, S. (2008). TimeRadarTrees: Visualizing dynamic compound digraphs. *Computer Graphics Forum*, 27(3):823–830.

Burch, M., Raschke, M., and Weiskopf, D. (2010). Indented pixel tree plots. In *International Symposium on Visual Computing (ISVC '10)*, pages 338–349.

Card, S. K., Suh, B., Pendleton, B. A., Heer, J., and Bodnar, J. W. (2006). Time Tree: Exploring time changing hierarchies. In *IEEE Symposium on Visual Analytics Science and Technology (VAST '06)*, pages 3–10.

Cleveland, W. S. and McGill, R. (1986). An experiment in graphical perception. *International Journal of Man-Machine Studies*, 25(5):491–501.

Eades, P. (1992). Drawing free trees. *Bulletin of the Institute for Combinatorics and its Applications*, 5(2):10–36.

Grivet, S., Auber, D., Domenger, J. P., and Melançon, G. (2006). Bubble tree drawing algorithm. In Wojciechowski, K., Smolka, B., Palus, H., Kozera, R. S., Skarbek, W., and Noakes, L., editors, *Computer Vision and Graphics*, pages 633–641, Dordrecht, The Netherlands. Springer.

Hadlak, S., Tominski, C., Schulz, H.-J., and Schumann, H. (2010). Visualization of hierarchies in space and time. In *Workshop on Geospatial Visual Analytics: Focus on Time at the AGILE International Conference on Geographic Information Science*.

Herman, I., Melançon, G., and Marshall, M. S. (2000). Graph visualization and navigation in information visualization: A survey. *IEEE Transaction on Visualization and Computer Graphics*, 6(1):24–43.

McGuffin, M. J. and Robert, J.-M. (2009). Quantifying the space-efficiency of 2D graphical representations of trees. *Information Visualization*. DOI: 10.1057/ivs.2009.4.

PEGELONLINE (2010). Gewässerkundliches Informationssystem der Wasser- und Schifffahrtsverwaltung des Bundes. http://www.pegelonline.wsv.de.

Reingold, E. M. and Tilford, J. S. (1981). Tidier drawings of trees. *IEEE Transactions on Software Engineering*, 7(2):223–228.

Shneiderman, B. (1992). Tree visualization with tree-maps: 2-d space-filling approach. *ACM Transactions on Graphics*, 11(1):92–99.

Stasko, J. T. and Zhang, E. (2000). Focus+context display and navigation techniques for enhancing radial, space-filling hierarchy visualizations. In *IEEE Symposium on Information Visualization (InfoVis '00)*, pages 57–66.

Tu, Y. and Shen, H.-W. (2007). Visualizing changes of hierarchical data using treemaps. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1286–1293.

Tufte, E. R. (1990). *Envisioning Information*. Graphics Press, Cheshire, CT.

Ware, C. (2008). *Visual Thinking for Design*. Morgan Kaufman, Burlington, MA.

Yang, J., Ward, M. O., Rundensteiner, E. A., and Patro, A. (2003). InterRing: a visual interface for navigating and manipulating hierarchies. *Information Visualization*, 2(1):16–30.

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