Interactive Revision Exploration using Small Multiples of Software Maps

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Keywords: Software Visualization, Visual Analytics, Software Maps, Small Multiples, Interactive Visualization Techniques.

Abstract: To explore and to compare different revisions of complex software systems is a challenging task as it requires to constantly switch between different revisions and the corresponding information visualization. This paper proposes to combine the concept of small multiples and focus+context techniques for software maps to facilitate the comparison of multiple software map themes and revisions simultaneously on a single screen. This approach reduces the amount of switches and helps to preserve the mental map of the user. Given a software project the small multiples are based on a common dataset but are specialized by specific revisions and themes. The small multiples are arranged in a matrix where rows and columns represents different themes and revisions, respectively. To ensure scalability of the visualization technique we also discuss two rendering pipelines to ensure interactive frame-rates. The capabilities of the proposed visualization technique are demonstrated in a collaborative exploration setting using a high-resolution, multi-touch display.

1 INTRODUCTION

In software analytics, gathered data of a software system is often temporal, hierarchical, and multi-variate, e.g., software modules associated with per-module metrics data (Telea et al., 2010; Khan et al., 2012). We consider common tasks of the various stakeholders of the software development process. For software consultants, manual exploration of a software system revision in combination with a specific metric mapping represents a frequent use case (Charters et al., 2002). During this exploration process, revision and metric mappings are often changed to compare system states at different revisions (Voinea and Telea, 2006). This process is time-consuming, error-prone, and does not facilitate the creation and preservation of a mental map (Archambault et al., 2011).

One specific technique to visualize and analyze software system information, especially for planning and monitoring software development and communicating insights into its characteristics, properties, and risks, is the software map (Bohnet and Döllner, 2011; Trümper and Döllner, 2012). The hierarchical components of a software system are depicted using a tree map (Shneiderman, 1992) and different associated metrics can be mapped onto several visual variables, e.g., ground area, height, color, and texture of cuboids that result when extruding the rectangles of the layout.

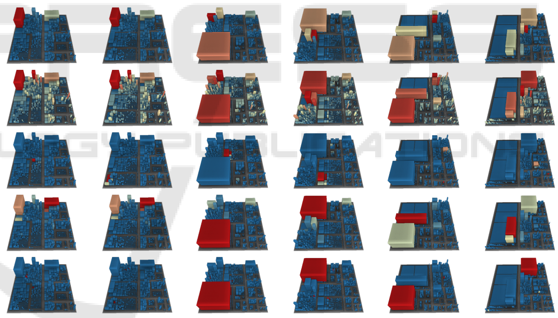


Figure 1: The POCO software project development depicted using a small multiples visualization of software maps showing 6 revisions (columns) and 5 different software maps themes (rows). The size of a cuboid depends on the implementation size. The color mapping indicates inconspicuous (blue) and suspicious modules (red) according to the current theme (further explanations in section 3).

Thus, the software map is a 2.5 dimensional visualization technique (Bladh et al., 2004). Combinations of specific metrics and their mapping onto visual variables are organized by software map *themes* to support specific issues and information needs that are required by different stakeholders. The use of cuboids and placing margins between tree map nodes lead to the impression of a virtual 3d city composed of buildings and streets (Panas et al., 2003).

One approach to overcome the problem of comparing software maps of different revisions and

Scheibel, W., Trapp, M. and Döllner, J.
Interactive Revision Exploration using Small Multiples of Software Maps.
DOI: 10.5220/0005694401310138
In *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016) - Volume 2: IVAPP*, pages 133-140
ISBN: 978-989-758-175-5

themes consists of applying small multiples (Wong and Bergeron, 1994), a visualization concept based on using a basic reference geometry to display different aspects of a dataset (Tufte, 1990). Small multiples enable the depiction of multi-dimensional datasets without yielding visual clutter, over-plotting, or visually complex depiction introduced by the display of multiple variables simultaneously (Roberts, 2007). This facilitates to compare across different variables and communicate the range of potential patterns in the charts, i.e., a reader can learn to read an individual chart and apply this knowledge as they scan the remainder of the charts (Javed et al., 2010). Thus, it shifts the readers effort from understanding how the chart works to what the data says. A regular layout of small multiples allows for both, comparison between units and an understanding of the respective categories (MacEachren et al., 2003).

Problem Statement. The approach to use small multiples has a strong limiting factor in the available screen size, especially for the past years. Additionally, rendering systems have to handle the additional effort required for rendering each small multiple in the case of massive datasets. Today, the application of display walls as well as the increased screen resolution and display sizes overcome the issue of the available screen size (Yost and North, 2006). For example, modern displays offer resolutions up to 4K (3840×2160 pixels) and even higher resolutions, providing screen space for over 30 multiples, each at a resolution of 640×432 pixels. Using a display wall, this number increases further. Insofar the rendering represents the key limitation that has to be capable of handling massive amounts of data for small multiples.

Contributions. This paper contributes a combined visualization technique of small multiples and interactive software maps, arranged in a matrix and extended by interaction techniques to support the exploration and analysis of multiple software system revisions using multiple themes (Figure 1). The proposed rendering can be implemented using either a multi-pass or a single-pass approach. Our technique has been used on a high-resolution screen for collaborative exploration (Isenberg and Carpendale, 2007).

2 RELATED WORK

Previous research includes visualization of software and its evolution, general hierarchy visualization and changes upon them, and small multiples used in in visualization.

Visualization of Hierarchies and Their Evolution. As software maps should help with monitoring changes over several revisions of a software system, the mental map of the user should be preserved. This can be achieved with tree map layouting algorithms having a spatial stability for the location of tree map nodes. Typically, this is a trade-off between spatial stability and readability of tree map nodes (Tak and Cockburn, 2013). When choosing a tree map layout algorithm for one state of a hierarchy, the spatial stability for the next state can be optimized by reapplying the *template* of the first one (Kokash et al., 2014). Besides rectangular tree maps, the voronoi tree map provides an inherently more stable layout algorithm, especially when using an initial distribution of nodes (Hahn et al., 2014). The gosper map provides a more map-like look and a high spatial stability for changing hierarchical data (Auber et al., 2013). An effective use of multiple visualization techniques to examine changes in hierarchies is presented by Guerra-Goméz et. al. (Guerra-Gomez et al., 2013).

Visualization of Software and Its Evolution. When visualizing the changes of a software system over time, i.e., its evolution, graph-based approaches were made first (Collberg et al., 2003). Kuhn et. al. propose a multidimensional scaling approach to map multidimensional vectors, representing source code files, to a two-dimensional layout (Kuhn et al., 2008). The resulting software maps (not to be confused with the software maps from Bohnet et. al.) are spatially stable due to the typical similarity of source code between two revisions. Two other visualization techniques using the city metaphor are software cities (Steinbrückner and Lewerentz, 2010) and CodeCity (Wettel et al., 2011). Where the former concentrates on streets and buildings on their sides, the latter is more similar to the software maps used in this paper. A matrix-based approach supported by animated transitions named AniMatrix supports in understanding the evolution of source code entities and their dependencies (Rufiange and Melançon, 2014). Caserta et. al. published a survey with an overview on visualizing the static aspects of software, including visualization techniques for software system evolution (Caserta and Zendra, 2011).

Small Multiples. Small multiples is a visualization technique widely used to enable multi-dimensional and multi-variate data for the use in visual analytics. For example, it can be used to visualize thematic mappings of geo-referenced data, even with a temporal component (MacEachren et al., 2003; Bavoil et al., 2005). Small multiples of virtual three-dimensional scenes are used to compare wing beat patterns (Chen et al., 2007). The comparison of structured data in two dimensions was examined by Bremm et. al. (Bremm et al., 2011) using trees and by Burch and Weiskopf using graphs (Burch and Weiskopf, 2014). More generally, small multiples can be used as an alternative to otherwise intertwined visualization of data (Perin et al., 2012) and even different visualization techniques for the same data (van den Elzen and van Wijk, 2013). The layout of the small multiples can be derived from the use case (Kehrer et al., 2013), the user (Phan et al., 2007), or the data (Liu et al., 2013).

Software Visualization using Small Multiples. There exist software visualization techniques that use small multiples to depict changes between software revisions. For example, Lanza and Ducasse propose rectangles for each software entity and software revision with two degrees of freedom (width and height of the rectangle) that are laid out using the time component as the x-axis (Lanza and Ducasse, 2002). CodeCity uses a similar approach but maps the identity of software sub-entities to explore the system's implementation (Wettel and Lanza, 2008). Even a display wall is used for different visualization techniques of a software system (Anslow et al., 2009).

3 CONCEPT

The software map serves as a visualization technique that allows us to explore software system information and to communicate key insights about its status and progress. A software map is configured by parameters that specify the current project, a revision, and a theme, i.e., the mapping of metrics onto visual variables. Although parameterizable, the software map is currently limited to only one denotable revision and one theme. To compare several revisions of software maps, the user has to switch between them. Further, only one theme can be shown at once. Context switches and loss of the mental map are inevitable.

Current Approach. While exploring the software system, multiple instances of the software map visualization can be used simultaneously at the cost of a separated interaction context and rendering. To communicate the insights, a list of software revisions and themes is chosen and an image for each combination is generated and placed next to each other, creating a static version of small multiples of software maps. The proposed visualization technique combines the two unsupported usages of software maps – switching between software system revisions and the comparison of multiple themes – by the use of small multiples of software maps.

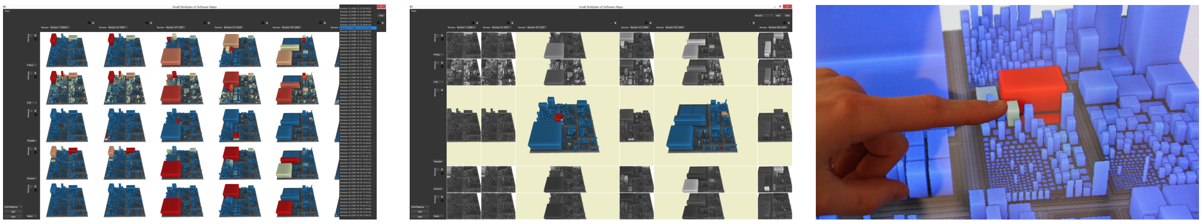
Example. Given software system information of the POCO project (`http://pocoproject.org/`) an analysis can focus on the development from September 2006 to March 2009 (Figure 1). The development activity is sampled two times a year, resulting in six displayed revisions. The weight of the tree map nodes is dependent on the real lines of code and the nesting level is mapped into the height for all themes to correlate implementation size with cuboid size. The following choice of themes, consisting of changes in color for this example, allows for specific insights into the development process and state of implementation:

- McCabe complexity per function, indicating modules with much logic,
- nesting level per function, indicating modules requiring high understanding effort,
- use of C++ templates, indicating modules with complex implementation,
- uncommented lines of code, indicating modules requiring high understanding effort,
- number of hacks, indicating modules with unfinished code.

3.1 Small Multiples Configuration

To enable small multiple visualizations for software maps, each software map has to be configured separately for each small multiple. Given a matrix arrangement, the configuration varies in horizontal and vertical dimension. One dimension is used to depict different revisions of a given software system, the other dimension is used for different themes. The parameters that are common for all software maps are grouped and denoted as *base configuration*.

Base Configuration. This configuration is shared among all software maps and includes parameters that are not influenced by the revision or theme. For example, these include the software project, the layout algorithm and margin, and the maximum height for nodes. Two approaches can be used for the camera position and perspective. The first uses the position and view of the users eyes to adjust each small multiples on an adapted view frustum. The second and chosen approach uses the same camera and projection for all software maps. This base configuration results in a general similarity of all software maps; especially for a common revision.



(a) A configuration user interface to select the revision and theme.

(b) Focus+context visualization to compare two specific software maps.

(c) A close-up of a problematic software module identified through direct comparison.

Figure 2: The graphical user interface of the small multiples visualization of software maps. The small multiples are arranged as a matrix where rows represent different themes and columns different revisions.

Per Small Multiple Configuration. For the chosen use case, the per small multiple configuration includes the revision and the theme. The theme can specify the weight metric for the tree map layout, the metric for the height mapping, the metric for the color scheme, the color scheme itself, and the side face texturing scheme. Further, the configuration includes the screen sub-rectangle where this small multiple is placed. The sub-rectangles of all small multiples do not have to be disjunct and do not have to form the full screen rectangle when unified, but they are chosen to fulfill these requirements.

3.2 Rendering

The rendering of all software maps (laid out in a grid) uses the geometry of each software map, the associated sub-rectangle and the common camera perspective and projection to render the software map on the screen. If small multiples may overlap, this rendering has to take a separate canvas for each small multiple to explicitly handle overlapping areas later.

3.3 Interaction Techniques

Besides the computation and rendering of all software maps, the visualization technique has to be configurable by a user. This includes the software map configuration for each small multiple and the virtual scene navigation as well as managing the focus on one or multiple software maps.

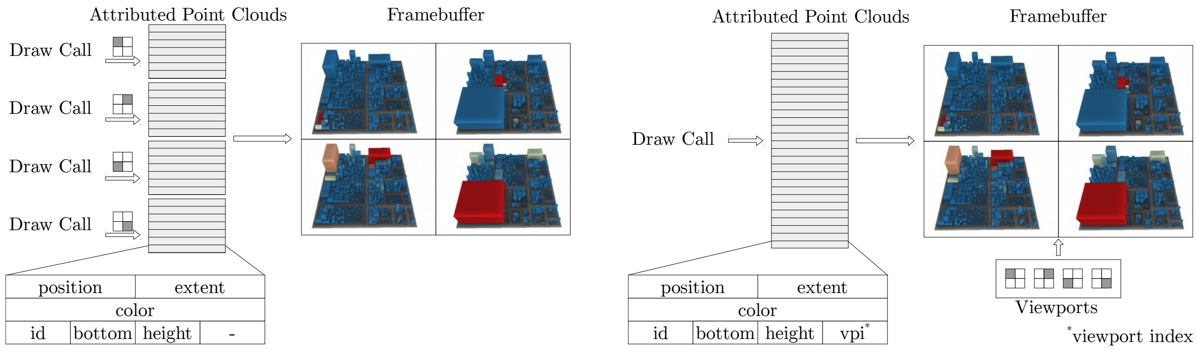
Small Multiple Configuration. The configuration of the software map is proposed to be available over a graphical user interface that is placed on the left and upper side of the canvas where the small multiples are aligned using a matrix of multiple rows and columns (Figure 2(a)). For the given use case, the revision can be configured on the horizontal axis and the theme on the vertical axis. To support fine-grained configuration on a per-row and per-column base, the user interface shows one configuration template for each column and each row. This part of the configuration is applied for a complete column or row, respective, resulting in a matrix where each small multiple has a different configuration.

Navigation (Pan, Rotate, Zoom). To support navigation in the matrix of software maps, interaction functionality for panning, rotating, and zooming is integrated. This navigation is synchronized for all software maps to show the same part of the virtual scenes.

Focus+Context. The matrix layout supports a flexible mapping, i.e., software maps in focus gets more space than software maps in the context. By default, all matrix cells are equally sized. Through the graphical user interface, the user can select one or more rows and columns to be in focus, resulting in a higher portion of the overall space in comparison to the unfocused rows and columns. If either columns or rows are selected, the small multiples in these rows or columns gets enlarged. If both columns and rows are selected, the intersecting small multiples of the rows and colums are enlarged. The enlarged small multiples then represent the focus, the smaller ones the context (Hauser, 2006) (Figure 2(b)).

4 IMPLEMENTATION

We have implemented our concept in a software prototype that supports loading of software system revision data, provides a graphical user interface for the interactive configuration of software maps, processes the configuration, and computes and renders the matrix software maps. Navigation techniques complement the interaction within the prototype. The software map geometry encoding and the implementation of the hardware-accelerated rendering are the key techniques for the proposed concept. The prototype is



(a) The multi-pass rendering pipeline uses per-pass viewport manipulation and vertex buffer offsets. There is one draw call per software map and a previous restriction of the rasterization viewport to the viewport of the small multiple. All vertices of all software maps are stored using a single vertex buffer, that is traversed using vertex buffer offsets.

(b) The single-pass rendering pipeline uses virtual viewports and screen-space vertex displacement. All vertices from all software maps are input to the rasterization pipeline using a single draw call. Prior to rasterization, the virtual viewport is fetched and the projected vertices (in normalized device coordinates) are applied to it.

Figure 3: Two proposed rendering pipelines for small multiples of software maps. The multi-pass rendering pipeline (a) denotes the traditional approach and is straight-forward to implement. The single-pass rendering pipeline (b) reduces state changes and uses virtual viewports and screen-space vertex displacement to handle all vertices in a single draw call.

implemented using C++ and Qt for the executable application and OpenGL for the hardware-accelerated rendering.

Software Map Encoding. The geometry for the hardware-accelerated rendering of the software maps is stored on the graphics hardware for efficiency. This is feasible as the data does not change often. The encoding of the geometry uses the concept of an *attributed point cloud* (Trapp et al., 2013) using 48 bytes per vertex that is extruded to a cuboid during the OpenGL geometry shader stage. The concept of *attributed point clouds* is adapted to small multiples insofar that each software map conceptually builds its own *attributed point cloud* but all of them are stored adjacently within a single vertex buffer.

Small Multiples Rendering. The image synthesis can be performed using either a multi-pass or single-pass rendering technique. Here, the multi-pass rendering approach constitutes a traditional implementation, while the single-pass approach makes extended use of the programmable rendering pipeline of OpenGL.

Multi-pass Rendering. The multi-pass rendering pipeline operates on the list of *attributed vertex clouds* and the list of viewports. For each pair, the viewport of the small multiple is configured and a draw call for all vertices of the *attributed vertex cloud* is triggered (Figure 3(a)).

Single-pass Rendering. The single-pass rendering pipeline uses the list of viewports during the hardware-accelerated vertex processing, thus it is available to the shaders using uniform buffers. The rendering pipeline is triggered using one single draw call covering all vertices from all *attributed vertex clouds*. For each vertex the corresponding virtual viewport is extracted from the uniform buffer using programmable vertex pulling (Riccio and Lilley, 2013). This viewport is then used to apply screen-space vertex displacement after the amplification in the geometry shader, transforming each vertex of the cuboid into the virtual viewport (Trapp and Döllner, 2010). After rasterization, all fragments outside the virtual viewport are discarded (Figure 3(b)).

5 EVALUATION

The application of small multiples of software maps is depicted using the scenario of a software consultant who shows a client findings in a software system. A performance analysis and a discussion indicates the properties and limitations of the proposed technique.

5.1 Collaborative Displays

The visualization of a software system using small multiples of software maps is suited to support a software consultant in communicating the findings and insights into the development to the client. The consultant can start with one revision and introduce the status to the client. Later, other themes and revisions can be added to guide the client through the

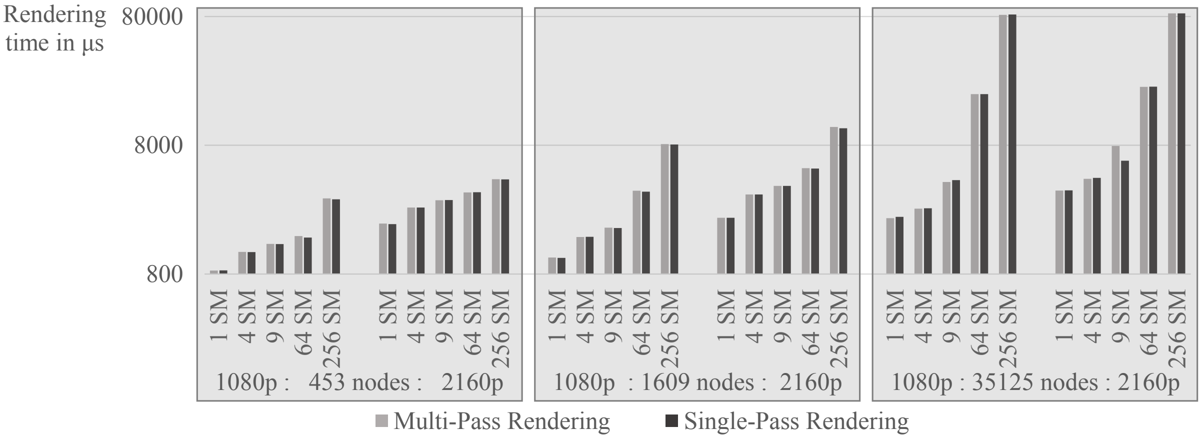


Figure 4: Performance comparison of single-pass rendering and multi-pass rendering (logarithmic scale), depending on the size of the software project (number of nodes), the resolution and the number of small multiples.

development of the software system. As new software maps do not replace older ones, the client can build up a mental map of the software system and thus can focus on the differences and the development of the software system. The consultant can further guide the focus on specific software maps by setting up the focus+context visualization. Given a large, high-resolution display a single software map is presented at haptic sizes, inviting to discuss and explore the states of the software system (Figure 2(c)).

5.2 Performance Evaluation

The run-time performance is evaluated for both the multi-pass and the single-pass approach. The actual GPU run-time for per-frame configuration and rendering of all small multiples is measured and averaged over 2000 samples. The used datasets comprise 453, 1609, and 35125 tree map nodes, where each node is represented by 12 vertices forming 10 triangles prior to rasterization. All measurements were taken on a Ubuntu 14.10 x64 Machine with an Intel Xeon at 8×2.8Ghz with 6GB RAM and an Nvidia GTX 680 graphics card with 1536 cores at 1215Mhz and 2GB video memory. The performance measurements indicate that both algorithms perform equally fast and all datasets can be rendered at interactive frame-rates, even at high resolutions (Figure 4).

5.3 Discussion

Although small multiples for software maps are an effective tool to visualize multiple revisions and multiple themes at once, the proposed approach has limitations and inherent properties, resulting from the nature of small multiples. As small and medium software system datasets can be rendered using a high number of small multiples, massive datasets requires higher performance by the rendering hardware. Further, the overall number of modules in a software system and the number of small multiples can result in too small matrix cells for a meaningful software map visualization. A generalization of software maps reduces both the required geometry and the visual clutter and thus improves rendering performance and enables for an overview of the software system (Rosenbaum and Hamann, 2009). Such generalization has to be aligned to the characteristics of the given software system, especially generalizing inconspicuous modules and highlighting suspicious ones. Further, the proposed visualization technique is not restricted to software maps but can be applied to other space-restricted, implicit hierarchy visualization techniques as well (Schulz et al., 2011).

6 CONCLUSIONS

This paper presents an interactive visualization technique for small multiples of software maps. It is suitable for visualizing a number of software maps simultaneously to facilitate direct comparison of the software system's structure with respect to different revision and variable themes. Conducted performance evaluations shows real-time rendering capabilities for large-sized software maps and a high number of small multiples. We further present suitable interaction techniques for synchronized navigation and a user interface that combines small multiples with focus+context techniques. The presented concept was tested with real-world datasets of different complexity. It supports the exploration and analysis of software system revisions in collaborative environments, a common task for a software consultants.

There are various directions for future work. For example, using eye-tracking support or head tracking systems, it can be examined if a tilted software map, depending on the viewpoint of the user, can improve the view on small multiples in three-dimensional scenes. Further, the alignment and management of the small multiples can be improved for scalability in both number of revisions and themes.

ACKNOWLEDGEMENTS

The authors would like to thank seerene GmbH (http://www.seerene.com/) for providing the datasets. This work was funded by the German Federal Ministry of Education and Research (BMBF) in the InnoProfile Transfer research group "4DnD-Vis" (http://www.4dndvis.de/). We would also like to thank the anonymous reviewers for their valuable comments and suggestions to improve the paper.

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