Exploration of Component Diagrams with Multifocal Highlighting

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Keywords: Graph exploration, Highlighting, Component Diagram.

Abstract: In the paper we present multifocal highlighting in reverse engineered component diagrams to support software engineers in answering questions on relations between a number of components. With component oriented systems such questions arise quite often. We use color to highlight all components relevant to selected focus components. Further, we allow the users to filter the diagram. Our approach, unlike the state-of-the-art methods allows analysis of relations between dozens of components. We have performed an user study to evaluate our multifocal highlighting. The results of the subjective evaluation show that the multifocal highlighting supports software engineers in answering questions on relations between components.

1 INTRODUCTION

Software engineers maintaining a component oriented software repeatedly deal with questions on relations between several components: What functionality of the system may be broken if certain component/s do not work properly? If several components do not work properly, what is the functionality they all require (as this is the potential source of the problems)?

The architecture of a component oriented system is typically visualized as a component diagram. A component (a node of the diagram) provides certain functionality to other components and may require functionality from other components. Often several components cooperate together to provide a higher level functionality. A component is seen as a black box, in the system. A component can be replaced with another one providing the same functionality. Unfortunately, the number of relations that a component has with other components is typically high, therefore the component diagram is not a sparse graph.

Visualizations of graph data-sets often aspire to present the user with the whole graph. In other words, to fit the whole graph into the available space on the screen. However, if the graph is large then the user see mainly the global structure of the graph, but cannot distinguish between the individual nodes and edges. This makes even very basic tasks such as locating certain node or following and edge almost impossible (Shneiderman and Aris, 2006).

To reduce the structural complexity we can utilize clustering techniques. However, the clusters are typically formed based on the topological structure of the graph. In the case of the component diagram of a software system the topological structure can be very different from the semantics of the graph. In consequence also the resulting clusters do not reflect semantics of the graph which can be confusing for the user. Therefore, we rather provide the user with tools to explore the graph as it is.

We can solve the problem with limited screen space by zoom and pan, however in such case we introduce temporal separation. When we zoom out we cannot distinguish between the individual nodes and edges and when we zoom in it is hard to see the broader structure of the graph and follow long edges. In consequence we will very often zoom in and then again zoom out while concentrating to not loose the desired nodes and edges from our sight.

The main contribution of the paper is the multifocal highlighting that allows arbitrary number of focus nodes. We use color to highlight the relevant components. The multifocal highlighting is a relatively simple technique that is easy to implement, yet allows the users to solve a number of different tasks needed when analyzing component diagrams. Results of our user study confirm that the users are able to find answers to such tasks in short time when the multifocal highlighting is utilized. Further, they reported that the multifocal highlighting supported them in solving the tasks.

Cmolik, L. and Holy, L.
Exploration of Component Diagrams with Multifocal Highlighting.
DOI: 10.5220/0005781301460152
In *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016) - Volume 2: IVAPP*, pages 148-154
ISBN: 978-989-758-175-5

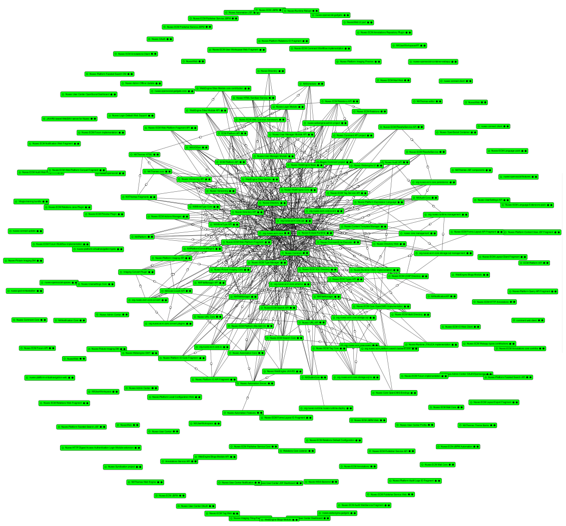


Figure 1: Reverse engineered component diagram of Nuxeo system (consisting of 203 components) depicted in notation of Holy et al. (2012) . Layout of the nodes is determined by force-based layout of Kamada and Kawai (1989) .

When combined with filters the multifocal highlighting, unlike the state-of-the-art methods, can be used to analyze mutual relations between many components. In the paper we use this approach to analyze subsystem composed from 58 components, which yields to 58 focus nodes.

Further, the components can be filtered based on software metrics. Software metrics allow us to filter the diagram based on information that is not encoded directly in the diagram (e.g., reliability of the components or coverage by unit tests).

In this paper we use reverse-engineered component diagrams (hundreds of nodes) of component based software systems to demonstrate our approach (see Figure 1 for an example). Nevertheless, we believe that the presented approach can be adapted to any kind of graph.

2 RELATED WORK

In this section we present work related to the graph exploration. We expect that the graph has a reasonable layout and thus we do not focus on this area. A multitude of automatic layout algorithms have been developed (see bibliography by Battista et al. (1994) or handbook by Tamassia (2013)). In our implementation we are using force-based layout of Kamada and Kawai (1989) implemented on GPU. We focus mainly on existing techniques that can be utilized to explore relations of one or several focus nodes.

Focus+Context. The Focus+Context techniques can be divided into two categories. In the first category are techniques that are built directly into the calculation of the layout of the graph. Such technique is the layout of a graph in hyperbolic space (Munzner, 1997). However, in the hyperbolic space only one focus region is possible.

In the second category are techniques that deform the space on which is the graph rendered after the layout is calculated. These techniques are independent of the layout algorithm. Basic example of such technique is fish-eye deformation used by Sarkar et al. (1992). Their fish-eye deformation is based on degree-of-interest and it is an extension of generalized fish-eye views by Furnas (1986).

Later, the fish-eye deformation was extended for multiple foci by Sheelagh et al. (1996) and Keahey et al. (1996). However, even with the multiple focus regions it is hard to track relations between the nodes in the focus regions.

Movable Filters. Another category of tools to explore graphs are movable filters also known as lenses. Movable filters are rectangular or circular area where information is filtered out or emphasized. By overlaying several movable filters we can combine their effects. Note that movable filters used to explore graphs are also Focus+Context techniques where the focus are edges or nodes inside of the filter area.

Wong et al. (2003) are using circular movable filter to separate close edges with fish-eye deformation. Hurter et al. (2011) and Panagiotidis et al. (2011) use movable filters to bundle and unbundle edges of the graph. Tominsky et al. (2006) are using movable filter to filter out edges that are not incident with nodes in the area of the filter.

Further, Tominsky et al. (2006) are using circular movable filter to bring neighbors of one or several nodes of the graph in the area of the filter into the area by changing positions of the neighbors in the graph layout. Similar technique was applied by Moscovich et al. (2009) with the difference that the whole screen was used as the area of the filter. Unfortunately, these approaches cannot be easily extended to work with multiple foci in order to track relations between the focus nodes.

Highlighting. Static highlighting (e.g., with color) of information relevant to one selected node is quite common. Barsky et al. (2007) is using color to highlight neighbors of a node in network representing biological system or process. Holy et al. (2013) is using color to highlight neighbors of a node in a component diagram of software system. Unfortunately, with

Figure 2: Visually emphasizing interacting components (yellow) of the focus component (red) in the diagram (shown for two different components) does not help to identify components that interact with both selected components quickly.

highlighting that allows only one focus node it is still very hard to gain insight into relations between more than one node (see Figure 2 for an example).

Heer and Boyd (2005) allow specification of two focus nodes and use color to highlight the neighbors of both nodes. Ware and Bobrow (2005) use both static (with color) and motion highlighting to highlight neighbors of two nodes in artificial graphs of varying complexity. By performing a user study they found out that by using color to highlight neighbors of the first focus node and motion to highlight neighbors of the second focus node the users are able to identify which nodes are neighbors of the first node, neighbors of the second node and neighbors of both focus nodes. Unfortunately, extension of this approach for more than two focus nodes is not possible.

Byelas and Telea (2006) use color to highlight several sets of interest in software architecture diagrams. An area containing all nodes of each set is constructed and filled or outlined with a chosen color. All areas are rendered underneath the visualized graph. Nodes belonging to several areas can be identified when the areas are outlined, or filled with semitransparent color. However, if the shapes of the areas are complex or the number of areas is high it can be difficult to identify nodes belonging to several sets.

Glyphs. Glyphs are graphical objects that convey multiple data values. Here we focus on glyphs that support identification of nodes belonging to several overlapping sets in the graph. Termeer et al. (2005) use colored icons to indicate that nodes belong to several sets. The number of icons corresponds with the number of sets. An icon is displayed if the node belongs to the set associated with the icon and hidden otherwise. Vehlow et al. (2013) and Liu et al. (2014) are using pie-charts to depict nodes that belong to several sets. However, if the number of overlapping sets is high (e.g., higher than 8) than it is hard to quickly identify all nodes belonging to the desired sets.

3 MULTIFOCAL HIGHLIGHTING

In this section we present static highlighting that is using color to visually emphasize relevant neighbor nodes of focus nodes in the graph. We allow arbitrary number of focus nodes, although usually only low number of nodes is needed to support answering questions stemming from our use cases. We demonstrate our approach on reverse-engineered component diagrams of a component system. In the following text we will refer to the nodes of the graph as components.

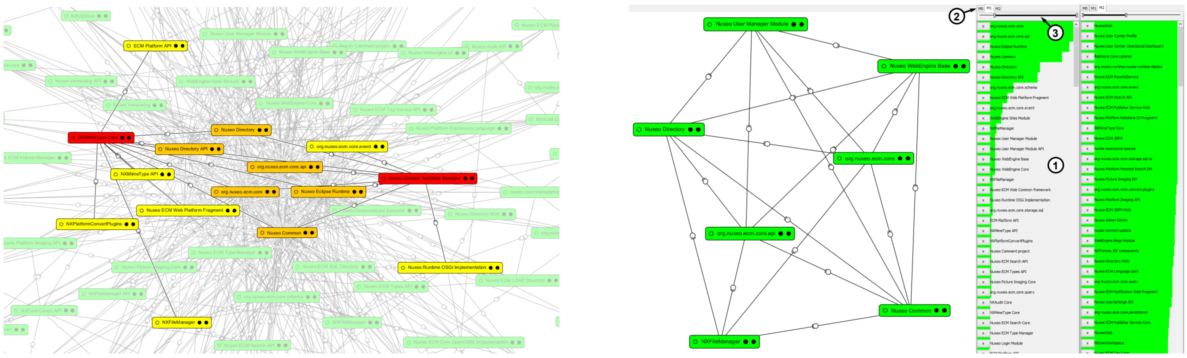
Our objective is to support rapid visual identification of components that interact with all focus components. We share the opinion of Ware and Bobrow (2005) that the most common task is to identify if two or several subsets of the diagram have nodes/components in common. Further, we aim to provide information also about those components that do interact at least with one (but not with all) of the focus components.

Our approach is based on assigning importance to each component in the diagram. The visual emphasis of component C_i is driven by importance $I_i \in [0,1]$ calculated as

$$I_i = \frac{N_i}{N_F} \tag{1}$$

where N_i is the number of focus components that interacts with component C_i and N_F is the total number of focus components. For each focus component the user can specify which edges will be considered in calculation of N_i: edges representing functionality that is provided to other components, edges representing functionality that is required from other components, or both types of edges.

We map the importance on color of the components in the diagram. As people cannot perceive dif-



(a) (b)

Figure 3: (a) Multifocal highlighting of two selected components. The components interacting with all focus components are emphasized (orange). (b) Side panel utilized to display software metrics (1), the user can choose desired metric using tabs (2) and specify low and high thresholds for the metric with range slider (3). The graph shows the result of filtering out components with low connectivity to other components (M1) and high coverage of code with Unit tests (M2) from component diagram of Nuxeo system. We show here the used metrics and thresholds side by side.

ference in color hue precisely (Baker and Wickens, 1995) we use only four colors: red for focus components, orange for components interacting with all focus components, yellow for components interacting with at least one of the focus components (we denote the orange and yellow components as context of the focus components), and green for components that do not interact with any focus component (we denote these components as components outside of the context).

To reduce visual clutter and make the important components and the edges between them more prominent we render the components and edges in specific order:

1. We render the edges that are not incident with any focus component.
2. We render the components outside of the context.
3. If the number of focus components is not zero we render white semitransparent layer over the whole diagram otherwise we end the rendering process.
4. We render edges between the components in the context and the focus components.
5. We render components in the context.
6. We render edges between the focus components in red color.
7. Finally we render the focus components.

We use painters algorithm to render the components, the edges and components that are rendered later are rendered over those rendered previously which ensures their visibility. Step 3 visually suppresses the edges and components rendered in Step 1 and Step 2.

The multifocal highlighting not only allows to visually emphasize context of a focus component (see Figure 2), but also to emphasize components that are interacting with two or more components without introducing spatial or temporal separation (see Figure 4(d)).

To provide additional information about the components in the context we visualize their importance as a length of horizontal bars that are displayed in the side panel (see Figure 4(f)) and allow the users to filter the components according to the importance. We map the importance on the length as difference in length is perceived by people much more precisely than difference in color (Baker and Wickens, 1995).

4 FILTERS

We allow the users to filter the diagram according to different software metrics. A metric is a number associated with each component that expresses certain characteristic. In our prototype we use two types of software metrics. The software metrics of the first type are connected to the structure of the diagram. We are using two such metrics: connectivity to other components and connectivity to focus components. Note that the later metric is in fact the importance calculated with Equation 1. The software metric of the second type provides additional information that is not encoded in the diagram. As a proof of concept we use coverage of the code with unit tests.

Components can be filtered out from the side panel based on any given metric, using one or two thresholds - high and low values of the selected metric. In the filters panel each metric is represented as a tab where the components names are sorted according the given metric. The value of the metric is visualized

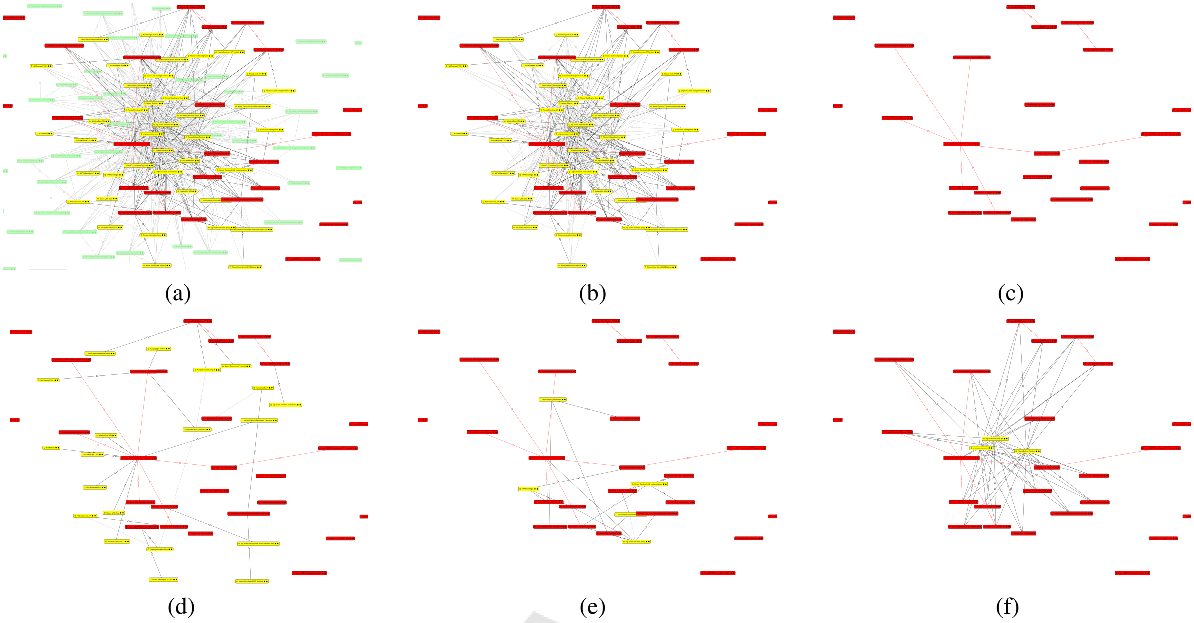


Figure 4: In all figures we display only the connected part of the ECM subsystem: with all components (a), with connected components (b), only the focus nodes (c). In the bottom figures we display only components that are connected to 1 focus component (d), to 3-5 focus components (e), and to 18-19 focus components (f).

as a length of a horizontal bar. The color of the bar matches the color of the component in the diagram which helps to locate the important components in the diagram quickly.

For example, filtering out components with low degree of connectivity to other components will leave only the tightly connected core of the system visible. Several metrics can be combined together to filter the graph. For example, if we want to improve the unit tests then the components used by many other components, but with the low unit test coverage are good candidates to start with (see Figure 4(f)).

In situations when there is a need to analyze mutual relations between many components the user can use the connectivity to focus components and the two thresholds to filter all components except those interacting with the desired number of focus components. By sequentially increasing both thresholds the software engineer can analyze relations between the focus components, component interacting only with one focus component, components interacting with two focus components, and so on. At the same time the number of displayed nodes an edges is significantly decreased. For analysis of ECM subsystem (composed from 58 components) of the Nuxeo system see Figure 4.

5 EVALUATION

We have evaluated the multifocal highlighting with an user study. We have chosen the tasks to represent real-life situations (e.g., find components that interact with one or two specific components, find dependencies of a subsystem composed from several components). We have performed subjective evaluation where the participants rate the effect of the multifocal highlighting in terms of confidence, speed, comfort, and support with regard to the solved tasks.

Six participants were recruited from our university. All were daily users of computers and have basic experience with analysis of component diagrams. They ranged from 25 to 30 years (Mean = 27.33, SD = 1.8).

The hardware consisted of standard PC computer with 24 inches LCD display (resolution 1680 1050 pixels), keyboard and optical mouse with 2 buttons. The test was performed on reverse engineered component diagram of Nuxeo system (see Figure 1) consisting of 203 components depicted in notation of Holy et al. (2012). Layout of the nodes was determined by force-based layout of Kamada and Kawai (1989).

Before the experiment the moderator explained the GUI of our application and the tasks. The experiment began with a training session. The training session consisted of 7 tasks similar to those in the test, but performed on different components. The goal was to let participants to get familiar with the multifocal highlighting, to get used to the experiment procedure and to minimize any learning effects. Training session was followed by the test where completion time was measured for each task. The test was consisting of 7 tasks:

1. Which components are connected to Management part (*management) of the system?
2. Which dependencies are not mutual for *HTML* components?
3. Which components are needed by every NXFile-Manager* component?
4. Which components are connected to Nuxeo ECM LDAP Directory component?
5. How many components are connected to both org.nuxeo.ecm.core.storage.sql.management and org.nuxeo.runtime.management?
6. Which components are connected to Nuxeo ECM Search API but not to NXFileManager?
7. Which components are removed from common dependencies when adding component Nuxeo Platform Expression Language to the set of NX-Audit Core and Nuxeo Audit API components?

Participants were asked to proceed as quickly and accurately as possible. Between each task the participants were allowed to take short breaks. Participants were interacting with the application with mouse.

After the test, participants completed a questionnaire investigating their subjective judgment about the level of confidence, speed, comfort, and support for the given tasks. Likert scale 1-5 was used for the subjective evaluation where 5 is the most positive mark (e.g., the user thinks that the tool helped him to be absolutely confident when answering the questions), 3 is a neutral mark, and 1 is the most negative mark (e.g., the user thinks that the tool did not helped him at all to be confident when answering the questions).

6 RESULTS AND DISCUSSION

All 6 participants successfully completed all 7 tasks. We report the results of our user study in Table 1.

In the following text we report arithmetic mean and standard deviation (SD) for the subjective evaluation. For the completion times we report geometric mean and 95% confidence interval calculated according to Sauro et al. (2012) these methods give the best estimates for completion times when the number of participants is lower than 25.

Table 1: Results of our user study. Completion times (in seconds) needed by participants P1-6 to complete the individual tasks and cumulative time needed to complete all tasks (T1-7). Results of subjective evaluation as reported by the participants. Likert scale 1-5 was used.

	P1	P2	P3	P4	P5	P6
Task 1	173	58	80	74	67	133
Task 2	32	121	54	84	215	155
Task 3	40	24	37	25	39	33
Task 4	26	23	30	31	23	47
Task 5	16	9	39	42	20	37
Task 6	74	107	34	59	66	148
Task 7	37	24	67	54	35	62
T1-7	398	366	341	369	465	615
Confid.	5	2	5	4	3	4
Speed	4	4	4	4	4	3
Comfort	5	3	4	3	2	3
Support	5	5	5	5	4	5

In average the participants have strongly agreed (Mean = 4.83, SD = 0.37) that the multifocal highlighting provided support for solving the tasks. In terms of the confidence (Mean = 3.83, SD = 1.06), speed (Mean = 3.83, SD = 0.37), and comfort (Mean = 3.33, SD = 0.94) the participants were in average positive on those aspects of the multifocal highlighting.

We report the average times and the 95% confidence intervals in seconds. Task 1: Mean = 89.94s, 95% CI (57.4s,140.8s), Task 2: Mean = 91.46s, 95% CI (43.7s,191.5s), Task 3: Mean = 32.33s, 95% CI (25.5s, 41s), Task 4: Mean = 29.05s, 95% CI (21.9s, 38.5s), Task 5: Mean = 23.64s, 95% CI (12.4s,45.1s), Task 6: Mean = 73.3s, 95% CI (43s,124.8s), and Task 7: Mean = 43.71s, 95% CI (28.8s,66.2s). The average time needed to complete all 7 tasks: Mean = 416.79s, 95% CI (331.5s,524s).

7 CONCLUSION

In this paper we have proposed multifocal highlighting of nodes in a graph to help users quickly explore mutual neighbors of several nodes. For situations when users need to explore mutual relations and neighbors of dozens of nodes we provide filtering of the components based on the number of connections to the focus components. Further we allow the users filter the diagram based on software metrics. We have demonstrated our approach on reverse engineered component diagrams of component oriented software system where questions regarding mutual neighbors of several components arise very often. We have evaluated the multifocal highlighting with 6 software engineers. The results of the subjective evaluation show that our multifocal highlighting supports the engineers in solving tasks related to identifying the mutual neighbors of several nodes. In the future work we would like to perform comparative user study with various different techniques.

ACKNOWLEDGEMENTS

This publication was supported by the project LO1506 and by the Aktion OE/CZ grant number 68p5 of the Czech Ministry of Education, Youth and Sports.

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