Using EVOWAVE to Analyze Software Evolution

Rodrigo Magnavita[1,2,3], Renato Novais[4] and Manoel Mendonça[2]
[1]*Fraunhofer Project Center for Software and Systems Engineering, Bahia, Brazil*
[2]*Computer Science Department, Federal University of Bahia, Bahia, Brazil*
[3]*Software Development Area, SENAI/CIMATEC, Bahia, Brazil*
[4]*Computer Science Department, Federal Institute of Bahia, Bahia, Brazil*

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Abstract: Software evolution produces large amounts of data which software engineers need to understand for their daily activities. The use of software visualization constitutes a promising approach to help them comprehend multiple aspects of the evolving software. However, portraying all the data is not an easy task as there are many dimensions to the data (e.g. time, files, properties) to be considered. This paper presents a new software visualization metaphor inspired by concentric waves, which gives information about the software evolution in different levels of detail. This new metaphor is able to portray large amount of data and may also be used to consider different dimensions of the data. It uses the concepts of the formation of concentric waves to map software evolution data generated during the waves formation life cycle. The metaphor is useful for exploring and identifying certain patterns in the software evolution. To evaluate its applicability, we conducted an exploratory study to show how the visualization can quickly answer different questions asked by software engineers when evolving their software.

1 INTRODUCTION

Software evolution has been highlighted as one of the most important topics in software engineering (Novais et al., 2013). It is a very complex activity because the process generates a huge amount of data. Dealing with these data is challenging: developers may spend more than 60% of the maintenance effort understanding the software (Corbi, 1989).

This has led the software engineering research community to create methods, processes and techniques to improve software comprehension. The goal is to increase the overall effectiveness of software development. The use of software visualization is increasingly being used. It helps people to understand software through visual elements, reducing complexity to analyze the amount of data generated during the software evolution (Diehl, 2007). Nevertheless, building visual metaphors that effectively represent the time dimension with all the information related to software evolution is a difficult task.

Authors have taken different approaches to this task. Some present the big picture of the software, providing an overview of the whole software history (Kuhn et al., 2010)(Voinea and Telea, 2006)(Lungu, 2008)(Lungu et al., 2010)(Telea and Auber, 2008), while others show snapshots of the software evolution in detail (Abramson and Sosic, 1995)(Novais et al., 2011)(Novais et al., 2012)(Bergel et al., 2011)(D'Ambros et al., 2009). They are both important because each approach fits better to specific software evolution tasks. A important issue in the area is to understand how to combine both approaches in a practical and useful way so that users can really take advantages of the proposed visualizations.

A mapping study performed in the area (Novais et al., 2013) highlighted other issues for the software evolution visualization community. Many works address software evolution by viewing only one type of data (e.g. source code change, defects, features). They do not usually display or cross-reference different information that can be recovered from different sources. Again, they are able to help users to perform few or specific tasks.

In this paper, we propose a new software evolution visualization metaphor called EVOWAVE. It is able to visualize different types of data generated in the development process from the overview aspect to the detail of interest. EVOWAVE can represent a great number of events which occurred during the software

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development at a glance. This metaphor was inspired by the formation of concentric waves while seeing it from the top (Section 3). We observed different facts about this phenomenon that could be used to visualize the software evolution and then created the concepts of our metaphor from it (Section 3.1). We developed a tool that made use of the metaphor to help users to perform software evolution tasks. To evaluate its usefulness, we conducted an exploratory study. As a result of this study, we found that the metaphor is able to answer many of the different questions commonly asked by developers (Sillito et al., 2006) (Section 5).

The remainder of this paper is structured as follows. Section 2 presents different related works. Section 3 provides a detailed explanation of the facts extracted from the formation of concentric waves. It also discusses the EVOWAVE concepts created from the analysis of these facts. Section 5 explains how some questions about an open source project were addressed with the metaphor. Finally, Section 6concludes this work presenting some limitations and pointing to future works.

The figures used in this paper have many details that can be better seen in a full resolution version available on https://wiki.dcc.ufba.br/SoftVis/EVOWAVE.

2 RELATED WORK

Several works visualize software evolution. They differ in the strategy used to portray all the data, the type of the data used or according to the task that they are designed to do.

Some authors have proposed overview visualizations that are able to visualize all the software history in one single screen shot. For example, Kuhn et al. (Kuhn et al., 2010) developed an iconography visualization that extracts information directly from the source code. It calculates the source code vocabulary distance to visualize the software evolution using a Cartography metaphor. Voinea et al. (Voinea and Telea, 2006) presented a multiscale and multivariate approach to visualize software evolution. They are able to visualize many data combined with multiple attributes collected from the software configuration management (SCM) and the source code itself. Kula et al. (Kula et al., 2014) proposed a visualization to visualize how the dependency relationship between the program and its dependencies evolves. This work uses the closest metaphor to our work. It uses a radial metaphor to visualize the dependencies. Rufiange et al. (Rufiange and Melancon, 2014) proposed a matrix-based visualization that animates how software designs evolve. In (Lungu, 2008), one visualization for reverse engineering of a software ecosystem was presented. He also used information from SCM data and source code. Ogawa and Ma use visualization techniques in a software project history (Ogawa and Ma, 2009). They used a graph-based visualization that shows a snapshot of the software at a specific time, combined with a bar chart visualization to provide an overview of the amount and type of commits over time.

In contrast to the overview approach, other authors focus on visualizing the software in details, showing a snapshot of the software history, highlighting the software modules. Beyer et al. (Beyer and Hassan, 2006) proposed a graph-based metaphor called Storybords. It aims to highlight the structural changes in the software modules, spotting good design and signs of structural decay. In (Ratzinger et al., 2005), the authors proposed a visualization to explore the data evolution across multiple dimensions. They analyze the co-change coupling information of the software modules. Another work that also analyzes co-change coupling is the one proposed by (D'Ambros et al., 2009). The visualization proposed in (Godfrey and Tu, 2001) aims to help users to understand structural and architectural change. They visualize SCM data and source code using graph-based and tree-based metaphors. Sandoval et al. (Sandoval Alcocer et al., 2013) proposed a visualization that represents the performance evolution of a system. They use a graph-based metaphor to create a performance evolution blueprint of the system.

Our metaphor aims to do both: provide an overview the software history as well as see the software in detail focusing on the information of interest. Furthermore, EVOWAVE is designed to visualize any evolutionary data. It also allows users to visualize combined data from different repositories.

3 THE EVOWAVE METAPHOR

The software development process, i.e. its evolution, generates a huge amount of valuable data from different sources. However, tons of data without analysis tells us little or nothing about the software. Ways

Figure 1: A snapshot of real concentric waves.

to organize well, visualize and analyze the data are needed. For example, it would be interesting to know which software module has been using most of the project resources. Therefore we need to extract this information in an organized way, visualize it in such a way that users can correctly analyze it and get this information.

EVOWAVE is a new visualization metaphor that enriches the analysis capabilities of software evolution. It is inspired in concentric waves with the same origin point in a container seen from the top as Figure 1 shows. This section presents the facts and concepts related to concentric waves which make EVOWAVE a promising software evolution visualization metaphor.

3.1 Concentric Wave Facts

During our research we identified some facts about the formation of concentric waves which can be used to represent evolutionary data. Figure 1 will help to understand the facts related to the proposed metaphor. Each of them is discussed below.

3.1.1 The Concentric Wave Propagation Occurs in All Directions

An external force must be applied in a container filled with liquid to generate the propagation of waves. In normal situations, they are distributed equally in all directions from the center. This happens when the force direction is 90 degrees to the flat surface of the container. This force pushes the same amount of molecules in all directions which creates redundant information. This is by no means what the metaphor wants to achieve. If one installs delimiters in the container following the propagation path from the center (as a radius line), it creates regions that have no influence on adjacent ones. Thus, an external force could be applied to each region to push different amounts of molecules between each pair of delimiters solving the generation of redundant information.

3.1.2 Biggest Waves have More Molecules

The magnitude of the applied force responsible for the wave formation will define how many molecules will be pushed away. During the wave formation the strongest force applied will generate the biggest wave. Thus, it will be the wave with the most molecules.

3.1.3 The Wave Closest to the Center is the Last Formed

Concentric waves are formed from the application of a force at its center and spread over time. When looking at a snapshot of the wave formation process, the least propagated wave is the one closest to the center. This means that it is the last formed. This leads to a conclusion about the existence of a timeline in the wave propagation path where the center is when the snapshot was taken and the most propagated wave distance from the center is the beginner. Therefore, each molecule has information about when some force was applied to it according to its location in the propagation path.

3.2 EVOWAVE Concepts

Based on these wave facts, we derived a set of concepts used in the EVOWAVE metaphor

3.2.1 Layout

We observed from the described facts that the wave propagation path has the behavior needed to represent a period of time in software history. EVOWAVE has a circular layout with two circular guidelines (inner and outer), as shown in Figure 2-A. They represent a software life cycle period (e.g. [01 January, 2000 10:01:20 AM] to [01 January, 2014 05:20:01 PM]). This period, named timeline (Figure 2-A), is composed of a set of small periods (lower possible displayed screen size) with the same periodicity (e.g. ten days, two hours, a month). The periodicity may differ among visualizations according to the available display size. The newest date can be associated with the inner guideline and the oldest date with the outer in order to give some orientation to the path between them, or the other way round. The display region between the two circular guidelines contains the timeline used for an overview of the software history for analysis.

3.2.2 Windows

EVOWAVE has mechanism, named window, which compares a subset of small periods, making it possible to carry out a detailed analysis regarding the overall context. A window (Figure 2-B) is a group of consecutive small periods. It is circular in shape and its length depends on the number of grouped periods. The timeline is composed of these windows and each one of them has the same number of consecutive small periods.

3.2.3 Molecules

All the data generated from the software development process can be associated to a event that occurred during it (e.g. bug reports, file changes, team changes).

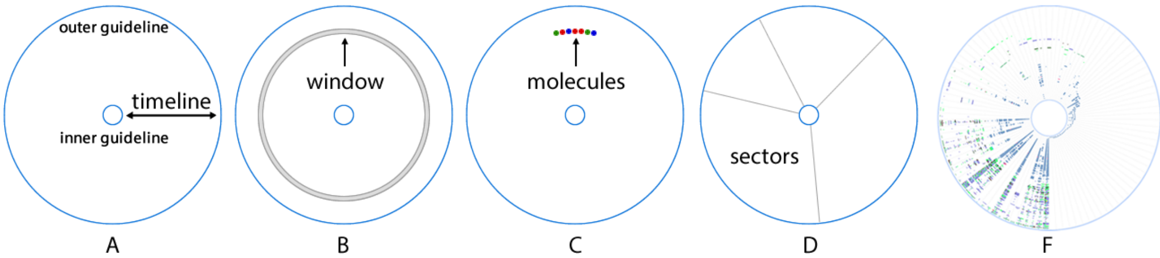

Figure 2: The EVOWAVE concepts (A to D) and one possible visualization of the metaphor using them (F).

Lets consider for example a change in class and therefore in its package. In this example, the event was the change of a java class and its associated data was the package of this java class. These events will be organized between the two circular guidelines, in one window, according to when they occurred

A visual element is provided to actually represent these events because it increases the level of detail provided by the metaphor. Molecules (Figure 2-C) are mainly depicted as circular elements inside the sectors and windows. Each molecule has an event associated to it. Unfortunately, the display size limits the number of molecules that can be drawn inside the window. When it is not possible to fill all the molecules they are joined together and singled drawn as a quadrilateral polygon that fills the region where the molecules are to be put in. Figure 2-F presents a possible visualization of the metaphor with all of these concepts.

3.2.4 Sectors

A mechanism to compare different groups of data must be provided to improve the analysis capabilities of the software engineer. The concept of a circular sector was used to group events that share some characteristic because of the metaphors circular layout. A sector (Figure 3.2-D) is a visual element drawn between the two circular guidelines according to its angle. Each sector can have different angles which will result in different areas. The sectors should be one of the first visual element to be realized during analysis. It will clarify how the events are organized. Once it is understood how EVOWAVE builds the group of events, it is possible to compare the sectors in two levels: globally or periodically. Globally is used to understand how the events flowed through the timeline more abstractly while periodically helps to obtain a higher level of detail by comparing the same window in different sectors.

The defined characteristic used to group the events sometimes has an implicit hierarchy. An example would be the java class package (i.e. com.magnavita.evowave) of a changed file event which before each dot represents a different level in the hierarchy. Treemap (Shneiderman, 1992) means the notion of turning a hierarchical structure into a planar space-filling. This concept was achieved by drawing a sector inside sector according to its level in the hierarchy. This brings the capacity to see tens of thousands of nodes from this hierarchy in a fixed space which certainly will be needed due to the amount of levels it could have.

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Software evolution visualization tools use many strategies to visualize the evolution (Novais et al., 2013) and they are classified in two groups: differential and temporal strategies. The differential strategies analyze the evolution considering two versions per time, while the temporal strategies consider all available versions at once. The support of multiple strategies is an important feature, since each one gives a different view of the software development process. The use of multiple views is encouraged because it gives more information related to the task that the software engineer needs to perform the task (de F. Carneiro et al., 2008).

We believe when we have a metaphor which can generate multiple views of the software according to its setup, it is better than using multiple metaphors because the user needs to understand each metaphor before learn about the software. Furthermore, multiple metaphors need concise navigation among them. The EVOWAVE metaphor has the ability to analyze software evolution using both strategies according to the configuration applied to it.

4 MAPPING SOFTWARE PROPERTIES

EVOWAVE concepts define how the metaphor organizes and displays events which occurred during any general data history. The EVOWAVE metaphor is also able to represent software evolution, by mapping its visual elements to software history attributes. It is important to take into account that each mapping will give different information and should be chosen according to the software development task at hand. We list the EVOWAVE characteristics that can be mapped to software history attributes below.

4.1 Timeline

The timeline defines the period of analysis through two dates: the beginning and the end of a software development phase. We can map two software versions and analyze what happened between them. If we map the first version to the inner guideline, and the last version to the outer one, the history of the software is portrayed from the middle to the boundaries.

4.2 The Pooler of a Sector

A pooler defines how the events will be grouped. The chosen software property to be the pooler has to categorize the events. The events with the same category will be in the same sector. There are many software properties that can be associated with this property. Some examples are: The package of a changed class event; the file type of a changed file event; the author of a bug report event; the bug type of a bug report event. The user should choose the property according to the task goal. For example, if the goal is to analyze developers efforts, the pooler could be the author and the event could be a file changed, created or removed. Figure 3 shows a snapshot of our metaphor set up for this case. In this case it is possible that the developer mapped to a sector labeled as A was the most active developer at the beginnings of the project. Around the project mid life cycle period, he/she stopped working. Then, from that point on, two other developers (the ones mapped to the sectors labeled as B and C) become the main project contributors.

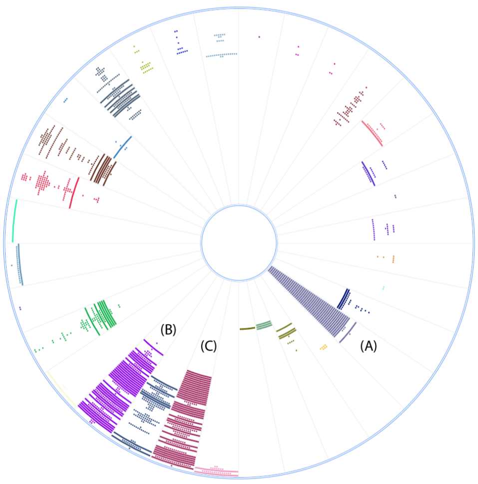

Figure 3: The pooler is the authors and the events are any changed files.

4.3 The Splitter of a Sector

The splitter defines how the hierarchy of the pooler property will be created. The pooler property usually has some delimiter that can be point out to be the splitter property. The splitter needs to be part of the pooler in order to split it into different levels. For example, the slash character could be used as a splitter for the file path of a changed file. It is part of the pooler property and will divide it in many folders where each one is a different level in the hierarchy. Figure 4 shows an example of the metaphor without (A) and with splitters (B). Again, the decision to use splitters or not depends on the task at hand. For example, if the task is to identify the most active packages, the visualization in Figure 4 (A) will achieve the goal faster. Otherwise, if the goal is to identify the big picture of each module, Figure 4 (B) gives a clearer view.

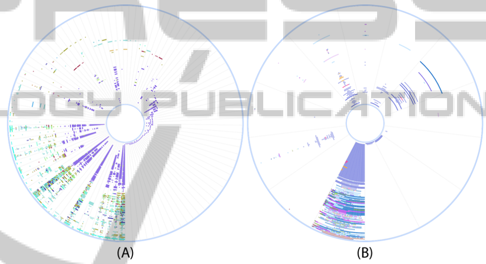

Figure 4: The sectors are the java packages. At (A) no splitter was used and all packages are presented at once and at (B) the dot was used as splitter and only one level of the java package hierarchy are displayed at once.

4.4 The Angle of a Sector

The angle defines how much of some software property the sector has relative to the others. The sum of this software property determines how much bigger it should be compared with the others. If the pooler is the package of a changed class, the angle could be package complexity growth, for example. In this case, all the increased complexities events are summed up for each package. The bigger complexity is mapped to the larger sector angle.

4.5 The Color of a Molecule

The color is other important visual attribute in the EVOWAVE metaphor. It can also be used to map software properties as an event categorization or a numerical property range. An example of the event categorization is the authors of a bug report where each author could have a different color associated to them. For numerical property range we may consider how much a java class complexity grew or shrank. In this last case, we can select two specific colors to paint the changed file with the most increased complexity and the most decreased complexity. Any event between these two ones will have its color interpolated.

When there are too many molecules to display, a quadrilateral polygons is drawn and its color can be associated to the number of molecules in it or the proportion of each color. The second one can be a linear gradient where the amount of each color in it will be related to the number of molecules that have this color.

5 AN EXPLORATORY STUDY

To evaluate the EVOWAVE applicability on a real scenario, we conducted an exploratory study over the jEdit (jEdit, nd). jEdit is an open source programming text editor written in Java with more than fourteen years of development and at least 300,711 lines of code. Slava Pestov started to develop it in 1998. Later, the project received more contributions from the IT community. We collected more than 14 years of changes in the git repository from September 30,1998 to August 08, 2012. However, the user can set the EVOWAVEs timeline to any period of interest in order to answer questions about a specific time. We mapped the molecules to change java file events, and used the colors to represent the author of the change. The sectors were mapped to the changed java file, its package or the author.

To guide our evaluation, we considered a study that reports typical questions asked by developers and project managers in the context of software collaboration (Sillito et al., 2006). We were able to answer 16 of these (out of 27 questions presented in this study) about the jEdit using the metaphor with the configuration described. However, due to page limitations we will only present five of them. The other questions require other sources of information that our tool is not yet extracting.

Who is working on what?

This is a typical question asked by software managers and technical leaders. In big teams, the manager knows which feature or bug developers are coding using a tool like Bugzilla or Jira. However, it is difficult to track what artifacts the developers are working on (e.g packages they are changing).

To reach this goal, we narrowed some information to give a more accurate answer. We adapted the question to: Who has been working in the last 5 months on what package?. Thus, we configured the timeline to represent 5 months (March 08, 2012 - August 08, 2012) the oldest (inner guideline) to the newest date (outer guideline) respectively. The molecules are associated to the change of a java file and its color with the author of the change. The sectors are using java package as their pooler. We do not consider the splitter or angle property for this analysis.

Figure 5 presents the visualization of the EVOWAVE metaphor within the described set-up for jEdit. The authors who have been working on the last 5 months are listed in the bottom-right area of the figure with their respective colors. By analyzing the timeline paths, it is possible to have a perception about the time of the contributions. However, EVOWAVE still provides a tooltip box, which gives more precise time information when the user interacts with the visualization. In addition, EVOWAVE uses the sectors to show the packages developers are working on during the selected period.

This visualization allows us to understand what happened during this period of time. Then we can start to explore it in order to do some interpretations. For example: the author Hisateru Tanaka (brown color) has contributed to all the changed classes in the last 5 months in the same window. Maybe it is important to understand what changes he made in the past that had many impacts; the org/gjt/sp/jedit/ sector (top-center) had many changes (in terms of commits) performed by different authors. As a possible side effect, bugs can appear later if these authors are not synchronized about their tasks. Therefore, a code review should be performed in this package to disclaim any possibility of architecture violations.

How much work has people done?

In 14 years of development it is hard to obtain how much work each collaborator has done. Work done may have several interpretations. For example, one may consider the number of commits as a metric to evaluate the quantity of work; others may use the number of lines of code. The timeline could be mapped to any period inside the 14 years. For this question, we decided to visualize the whole period, as shown in Figure 6. The orientation was set-up from the oldest (inner guideline) to the newest date (outer guideline). The molecules are associated to the change of a java file and their colors with the author of the change. The sectors are also the authors. Again, we do not need to use the splitter or angle visual properties on this analysis.

Figure 6 shows EVOWAVE in action for the described period and configuration. All the developers who worked in the project are listed in the sectors. The number of molecules in each sector represents the

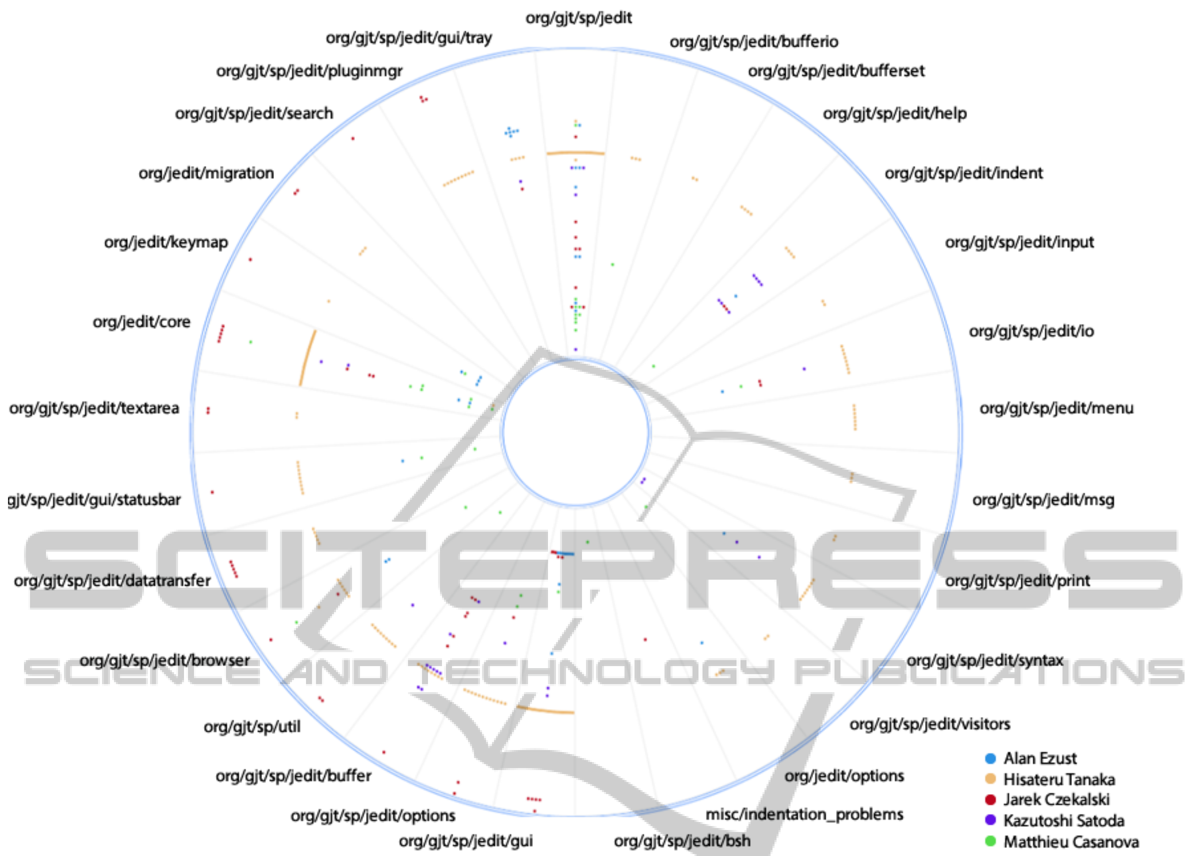

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Figure 5: EVOWAVE showing who is working on that.

amount of work. More precise information can be obtained by using some of the EVOWAVE mechanisms of interaction (e.g. hold the mouse over the sector while pressing the keyboard modifier key shift).

Using this visualization, it is also possible to clearly see that Slava Pestov (black color) was the founder of the project. In the middle of the project he left it. Matthieu Casanova and Alan Ezust were the two main code contributors after the founder while Jazub Roztocill, Damien Radtke and Sebastian Schuberth gave small contributions before leaving the project. Many questions can be raised, such as: Did those three developers have enough knowledge about the system to make those changes?. What were the decisions made by them?. It is important to recovery these answers as soon as possible because they may not return to the project or be available for questioning.

What classes have been changed?

During the software development it is important to make track of the classes that are being modified. The majority of the version control systems clients have this feature. However, when there are many commits they do not provide a big picture of the changes. They only allow us to see what classes were changed commit by commit. To reach the goal of this task, we established a timeline of one month (August, 2012). The orientation was set-up from the oldest (inner guideline) to the newest date (outer guideline). The molecules are associated to the change of a java file and their color with the author of the change. The sectors are the classes changed and no splitter or angle property was used.

Figure 7 shows an EVOWAVE visualization for the described period and configuration. All the classes changed in August, 2012 are displayed in the sectors. The authors who made those changes are listed in the bottom-right corner. Jarek Czekalski was the author who most changed the system in the last month. During one window he changed a lot of classes in different packages. The changes Matthieu Casanova made do not seem have a direct impact on the changes of Jarek Czekalski because they changed different artifacts in different periods.

Who has the knowledge to do the code review?

This is also a hard question to answer since many fac-

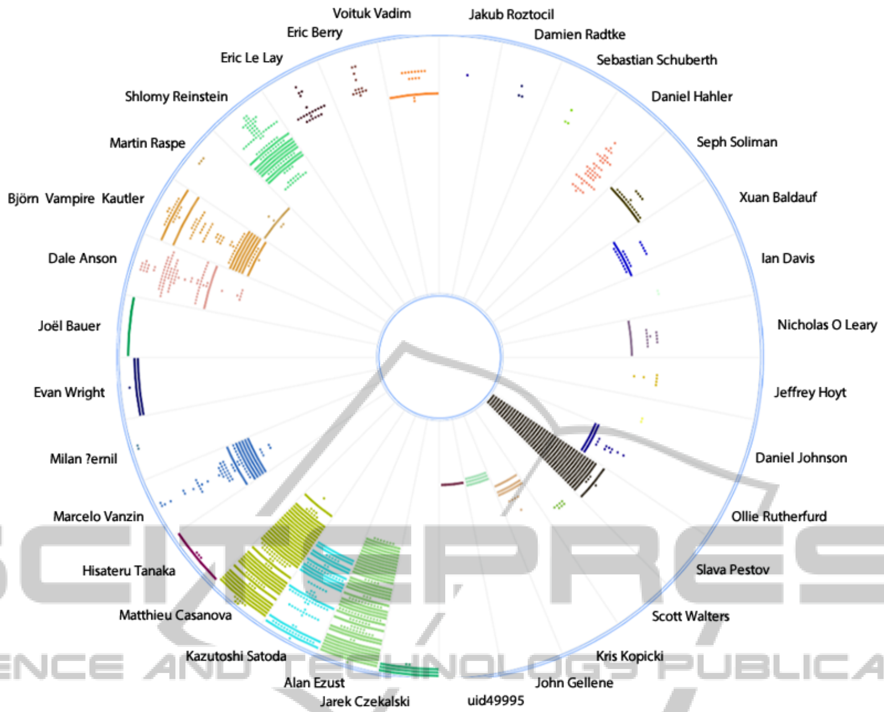

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Figure 6: EVOWAVE showing how much work has people done.

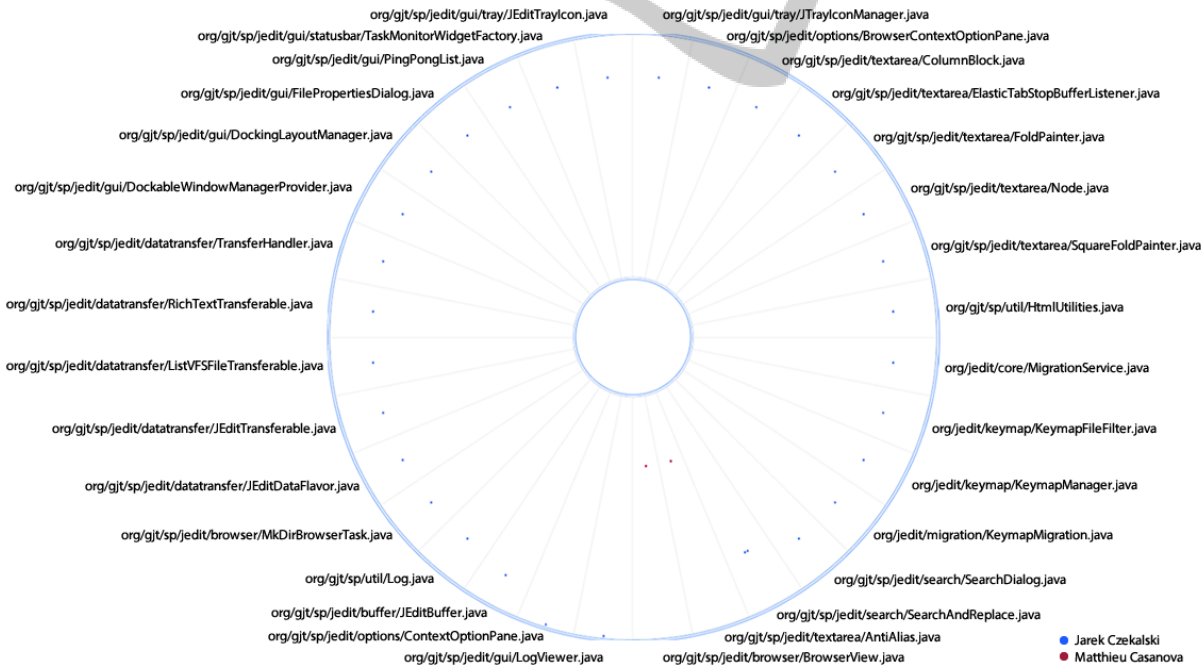

Figure 7: EVOWAVE showing what classes have been changed.

tors involved (e.g. business knowledge, architectural knowledge). However, it is possible to assume that the author who made a lot of changes in some artifact during a long period of time has knowledge about it. We set a timeline from 2006 to 2012 because this was the period that the project received many contributions. The orientation is from 2006 (inner guideline) to 2012 (outer guideline). The molecules are associated to the

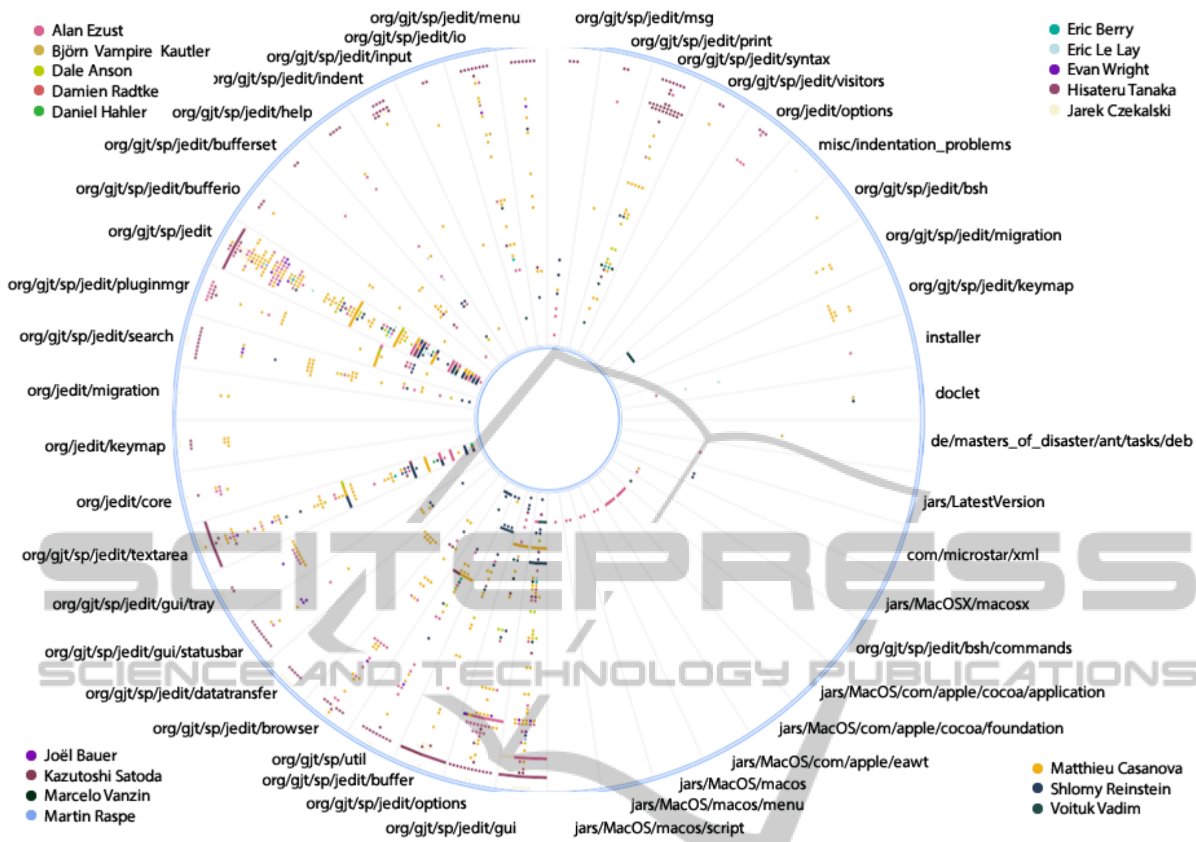

Figure 8: EVOWAVE showing who has the knowledge to do the code review.

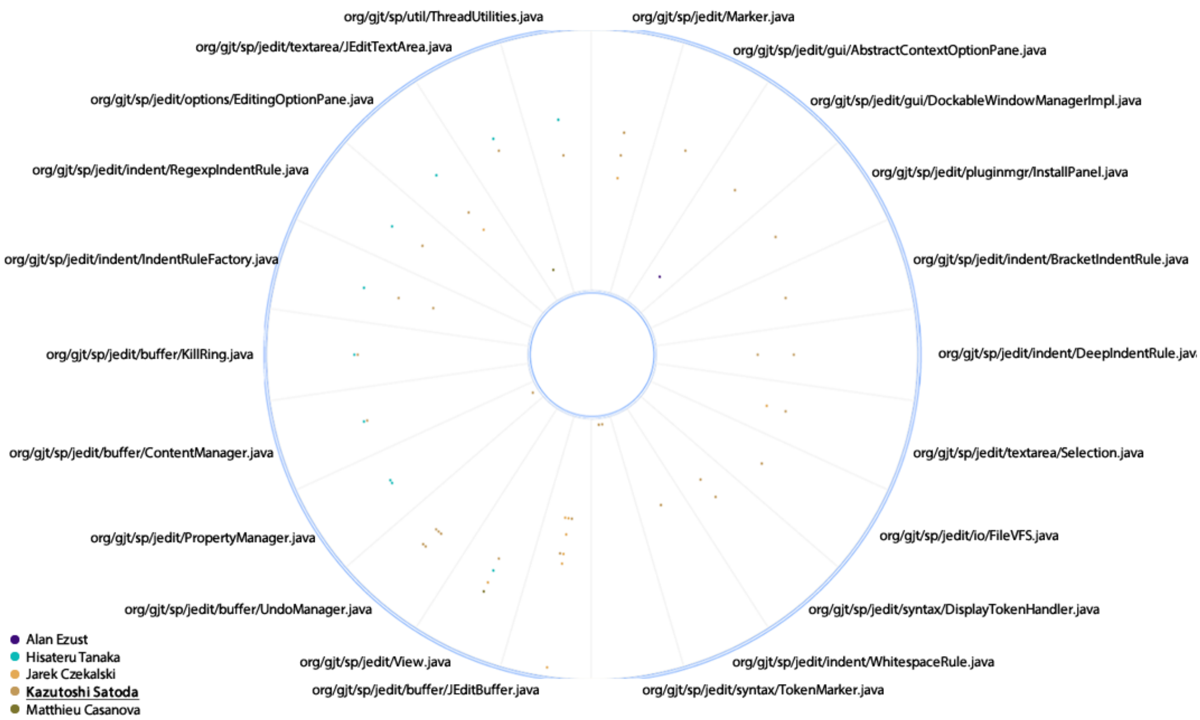

Figure 9: EVOWAVE showing who is working on the same classes as Kazutoshi Satoda and in what java files.

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change in a java file and its color with the author of the change. The sectors are using the java package as their pooler.

Figure 8 shows an EVOWAVE visualization for the described period and configuration. The visualization depicts the contributors on the corners with their respective color. Some of them can be identified as the owner (i.e. most contributions) of some packages. Alan Ezust, for example, is the most indicated person to do the code review of the MacOS code (packages jars/MacOS/com/apple at the bottom-right quadrant). He mainly contributed to previous features as can be seen in the bottom-right packages. Another example is the package with the most number of commits (org/gjt/sp/jedit). Even though many people changed this package, the EVOWAVE shows that Matthieu Casanova (yellow color) had a considerable number of commits during the whole period. Therefore, he may be indicated to do the code review.

Who is working on the same classes as I am and for which work item?

Developers and managers may ask this question. Developers may want to know the collaborators that are changing similar artifact, while managers may want to control the conflicts between the tasks. To answer this question, we set up the timeline for the last 5 months (March 08, 2012 - August 08, 2012) and set Kazutoshi Satoda as the developer who wants to know who is working in the same artifacts. The orientation was set-up from the oldest (inner guideline) to the newest date (outer guideline). The molecules are associated to the change of a java file and its color with the author of the change. The sectors use the java package as their pooler.

Figure 9 presents the visualization of the EVOWAVE metaphor within the described set up. The authors who are working on the same classes are displayed in the bottom-left corner. All the classes that were changed in the last 5 months by Kazutoshi Satoda are listed as sectors.

6 CONCLUSION

In this paper we presented a new software visualization metaphor for visually extracting information about software evolution. EVOWAVE can reduce the amount of work needed to analyze software artifacts such as source code files and version control system data, in order to answer questions that developers are interested in. To evaluate the applicability of our proposed visualization approach, we conducted an exploratory study, aiming to answer five questions about the jEdits collaboration evolution system.

6.1 Limitations

EVOWAVE has some known limitations. The color palette of the molecules could be too extensive leading to a difficult eye distinction between some of them. To overcome this limitation we can select all molecules for a specific color in order to identify witch one has the same color. Beyond that, it is possible to adjust the color palette to a better set of colors.

The collection of more data about the software evolution needs to be improved. The tool collects source code and version control system logs from git repositories as well as issues information from bug tracking systems. We believe more information will help developers and managers to answer many questions about the software evolution from different perspectives

6.2 Future Work

We plan to perform a controlled experiment in order to evaluate the effectiveness and correctness of this approach with participants from industry.

We are extending the prototype with more extraction capabilities in order to obtain different types of information (e.g. concerns) and extract more metrics to visualize them over time.

We intend to explore other domains beside software collaboration. For this we will be performing other exploratory studies to evaluate the usefulness of this metaphor in other domains and searching for a correlation among them. This exploration is important to retrieve cross-domain information that can lead us to a better knowledge about the software evolution.

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