Sensorial software evolution comprehension

Subtitle: Reinventing the World

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I certify that except where due acknowledgement has been given, the work presented in this thesis is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; and the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program.

Gianlorenzo Occhipinti
Lugano, Yesterday July 2022

To my beloved

Someone said . . .

Someone

Abstract

The comprehension of software evolution is essential for the understandability and maintainability of systems. However, the sheer quantity and complexity of the information generated during systems development make the comprehension process challenging. We present an approach, based on the concept of synesthesia (the production of a sense impression relating to one sense by stimulation of another sense), which represents the evolutionary process through an interactive visual depiction of the evolving software artifacts complemented by an auditive portrayal of the evolution. The approach is exemplified in SYN, a web application, which enables sensorial software evolution comprehension. We applied SYN on real-life systems and presented several insights and reflections.

Acknowledgements

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Chapter 1

Introduction

In 1971 Dijkstra, made an analogy between computer programming an art. It stated that is not important to learn how to compose a software, but instead, it is important to develop its own style and what will be their implications.

Software Understanding

- Section [Challenges of software understanding] - Section [Challenges of software maintainability] - Section [Software comprehension] - Section [Our approach] We present an approach, based on the concept of synesthesia (the production of a sense impression relating to one sense by stimulation of another sense), which represents the evolutionary process through an interactive visual depiction of the evolving software artifacts complemented by an auditive portrayal of the evolution.

Chapter 2

State of the art

2.1 Software visualization

Essential parts of software lifecycles are software maintenance and software evolution. Both activities require the comprehension of the system by the developer. Mayrhauser [37] defined *program comprehension* as a process that uses knowledge to acquire new knowledge. Generally, programmers possess two types of knowledge: general knowledge and software-specific knowledge, which represent their level of understanding of that software. Software comprehension aims to increase this specific knowledge of the system, and, to do that, it can leverage some software visualization techniques. Software visualization supports the understanding of software systems because it enables the visualization of the system's information (architecture, source code, behavior) with a 2D or 3D representation. Stasko et al.[11] conducted a study in 1998 that shows how visualization arguments human memory since it works as external cognitive aid and thus, improves thinking and analysis capabilities.

The earliest form of software visualization found in the literature was in the form of 2D diagrams. Haibt [12], in 1959, was one of the first to use them to visualize software systems. He provided a graphical outline of a program and its behavior with flowcharts. As shown in Figure **??**, they were 2D diagrams that described the execution of a program. He wrapped each statement in a box, representing the control flow with arrows. Ten years later, the effectiveness of flowcharts was confirmed by Knuth [20]. Unfortunately, at that time, most of the programs were affected by a lack of readability since they were not well documented. Therefore, it introduced a tool to generate visualizations from the software documentation automatically. Nassi and Schneiderman[27], in 1973, introduced the Nassi–Shneiderman diagram (NSD), able to represent the structure of a program. The diagram was divided into multiple sub-block, each with a given semantic based on its shape and position.

The 80s registered two main directions of software visualization. The first was the source code presentation. Hueras [13] and Waters [38] developed two techniques to format the source code with a prettyprinter. The second direction was the program behavior, used mainly for educational purposes. One of that period's most prominent visualization system was Balsa-II [3]. Around the end of the 80s, Müller et al. [26] released Rigi, a tool used to visualize large programs. It exploited the graph model, argumented with abstraction mechanisms, to represent systems components and relationships.

The 1990s recorded more interest in the field of software visualization. In 1992 Erik et al. [9] introduced a new technique to visualize line-oriented statistics. It was embodied in Seesoft, a software visualization system that allowed to analyze and visualize up to 50,000 lines of code simultaneously. On their visualization, each line was mapped to a thin row. Each row was associated with a color that described a statistic of interest. One year later, De pauw et al. [7] introduced Jinsight, a tool able to provide animated views of the behavior of object-oriented systems.

That period was favorable also for experimenting with novel research directions for visualization, such as 3D visualization and Virtual Reality. In 1998, Chuah and Erick [4] proposed three different techniques to visualize project data. They exploited the concept of glyphs, a graphical object that represents data through visual parameters. The first technique was the Timewhell glyph, used to visualize time-oriented information (number of lines of code, number of errors, number of added lines). The second technique was the 3D wheel glyph; it encoded the same attributes of the time wheel, and additionally, it used the height to encode time. Infobug glyph was the last technique, where each glyph was composed of four parts, each representing essential data of the system (time, code size, number of lines of code added/deleted/modified).

In the same year, Young and Munro [40] explored representations of software for program comprehension in VR. Finally, in 1999, Jacobson et al. [14] introduced what we now know as de facto the standard language to visualize the design of a system: UML.

Before the beginning of the 21st century, visualizing the evolution of a system was an unfeasible task due to the lack of data. However, thanks to the spread of version control systems and the open-source movement, this information became publicly accessible. As a result, many researchers focused their work on software evolution visualization.

Lanza [22] introduced the concept of the Evolution Matrix. It was a way to visualize the evolution of software without dealing with a large amount of complex data. Furthermore, that approach was agnostic to any particular programming language. The Evolution Matrix aimed to display the evolution of classes in object-oriented software systems. Each column represented a version of the software; each row represented a different version of the same class. Cells were filled with boxes whose size depended on evolutionary measurements. Thanks to this approach, he was able to infer some evolution patterns by just looking at the shape of the matrix.

Taylor and Munro [34], demonstrated that it is possible to use the data contained in a version control repository to visualize the evolution of a system. They also engineered Revision Tower, a tool that showed change information at the file level. Pinzger et al. [28] visualized the evolution of a software system through Kivat diagrams. RelVis, their tool, was able to depict a multivariate visualization of the evolution of a system. During the same year, Ratzinger et al. presented EvoLens [29], a visualization approach and tool to explore evolutionary data through structural and temporal views. During the same year, Langelier et al. [21] investigated the interpretation of a city metaphor [19] to add a new level of knowledge to the visual analysis.

D'Ambros and Lanza [5] introduced the concept of Discrete Time Figure. It was a visualization technique that embeded both historical and structural data in a simple figure. Furthermore, they defined an approach based on this technique. As a result, they were able to depict relationships between the histories of a system and bugs. They also presented the Evolution Radar [6], a novel approach to visualize module-level and file-level logical coupling information.

Steinbrückner and Lewerentz [33] described a three-staged visualization approach to visualize large software systems. The visualization was supported by a tool called Evo-Streets. Each stage of their approach was responsible for representing a different aspect of the system with

the city metaphor.

Wettel, in his thesis [39], revised the city metaphor to represent metrics meaningfully. In his work, he represented packages as districts and classes as buildings. This metaphor was applied in different contexts related to reverse engineering (program comprehension, software evolution, software quality) to demonstrate the metaphor's versatility. As a result, he found evidence that his approach works. However, he claims that the city metaphor brings visual and layout limitations (not all visualization techniques fit well with it). Under those circumstances, he preferred simplicity over accuracy, so he obtained a simple visual language that facilitates data comprehension. He conducted an experiment of the evidence that the city metaphor enables the creation of efficient software visualizations. His approach was implemented by a software visualization tool called CodeCity that supports the city metaphor.

Ens et al. [10] applied visual analytics methodologies to software repositories to help users comprehend co-evolution information. It enabled us to visulize, over time, how source and test files were developed together.

Kapec et al. [17] studied if it could ease the graph analysis with argumented reality. They made a prototype of a tool that provided a graph-based visualization of software, and then they studied some interaction methods to control it with augmented reality.

Schneider et al. [30] presented a tool, CuboidMatrix, that employed a space-time cube metaphor to visualize a software system. A Space-time cube is a well-known 3D representation of an evolving dynamic graph.

Merino et al. [25] aimed to augment software visualization with gamification. They introduced CityVR, a tool that displays a software system through the city metaphor with a 3D environment. Working with virtual reality, they scaled the city visualization to the physically available space in the room. Therefore, developers, to navigate the system, needed to walk.

Khaloo et al. [18] revised the idea of gamification with a 3D park-like environment. They mapped each class in the codebase with a facility. The wall structure depends on constituent parts of the class (like methods and signatues).

Alexandru et al. [1] proposed a method to visualize software structure and evolution simultaneously, with reduced accuracy and a fine-grained highlighting of changes in individual components.

2.2 Mining software repositories

Software repositories contain historical data about the evolution of a software system. Thanks to the spread of the git protocol, and consequently of GitHub, the largest code hosting website, Mining software repositories (MSR) became a popular research field.

In 2022, the number of GitHub repositories lays around 200 million. Even if it seems a promising source of data, Kalliamvakou et al. [16] raised some issues with its mining. They evidenced that a repository doens't always match with a project. A reason of this can be found in the fact that most repositories had had very few commits before becoming inactive. When they made their research, over the 70 percent of the GitHub projects were personal, and some of them weren't used for software development. Finally, the last perils that they raise, were related to GitHub features that are not properly used by software developers. To find actively developed repositories, they considered only projects with a good balance between number of commits, number of pull requests and number of contributors.

Spadini et al. [32] developed a Python framework, called PyDriller, that enables users to mine software repositories. They showed that their tool can be used to extract information about the evolution of a software system from any git repository.

2.3 Data sonification

External auditory representations of programs (known as program auralisation) is a researching field that is getting even more interest in the recent years.

One of the first attempts at program was described by Sonnenwald et al [31] They tried tp enhance the comprehension of complex applications by plating music and special sound effects. The prototype system that supported this approach was called InfoSound. This first approach, seen its adoption for the understanding of the program's behavior.

This approach was followed by many other researchers. To cite some of them, DiGiano and Baecker [8] made LogoMedia, a tool to associate non-speech audio with program events while the code is being developed. Jameson [15]] developed Sonnet, an audio-enhanced monitoring and debugging tool. Alty and Vickers [36] had a similar idea: using a structured musical framework, they was able to map the execution behavior of a program to locate and diagnose software errors.

Despite the usefulness of these tools, the adoption of a simple mapping lead them to have a limited musicality representations. Vickerts [35] evidenced the necessity of a multi-threaded environment to enhance the comprehension given by the musical representation. He proposed the adoption of an orchestral model of families of timbres, to enable programmers to distinguish between different activities of different threads.

The size and the complexity of systems can be a problem for the effectiveness of a visual representation of a software system. Having a large number of visual information, observers might find difficulty to focus only on the relevant aspects. Boccuzzo and Gall [2] supported software visualization with sonification. They used audio melodies to improve navigation and comprehension of their tool, CocoViz. Their ambient audio software exploration approach, exploited audio to intuitively describe the position of an entity in the space. Thanks to the adoption of surround sound techniques, the observers perceived the origin of an audio source so, it could adjust his navigation in the visualization. Each kind of entity played a different sound, based on a mapping criteria.

McIntosh et al. [24] explored the use of a parameter-based sonification, to produce a musical interpretation of the evolution of a software system. They technique mapped musical rests to inactive period of development and consonance and dissonance to interersting phenomena (like co-changing of components).

Mancino and Scanniello [23] presented an approach to transform source code metrics in a musical score that can be both visualized and played.

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