The Code-Map Metaphor
A Review of Its Use Within Software Visualisations

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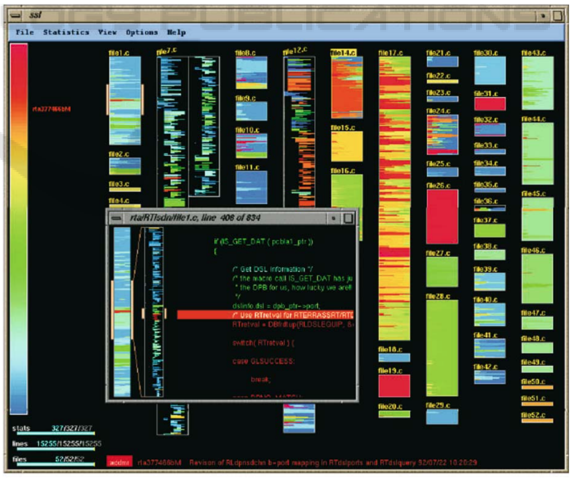
Abstract: Software developers can use software visualisations employing the code-map metaphor to discover and correlate facts spread over a large code base. This work presents an extensive review of the use of the code-map metaphor for software visualisation. The review analyses a set of 29 publications, which together describe 21 software development tools that use visualisations employing the code-map metaphor. The review follows a task oriented framework to guide the analysis of the literature in terms of the task, audience, target, medium, representation, and evidence dimensions based on the code- map metaphor. Although the literature indicates that software visualisations based on the code-map metaphor are perceived by the research community to be helpful across all aspects of the software develop process, the main finding of our review is that there is a lack of quantitative evidence to support this perception. Thus, the effectiveness of visualisations incorporating the code-map metaphor is still unclear. The majority of the software visualisations analysed in this study, however, do provide qualitative observations regarding their usage in various scenarios. These are summarised and presented in this review as we believe the observations can be used as motivation for future empirical evaluations.

1 INTRODUCTION

Software visualisation (*softvis*), a sub-field of information visualisation, is "*the art and science of generating visual representations of the various aspects of software (e.g. source code) and its development process*" (Diehl, 2007). Moreover, the goal of softvis is to help stakeholders to comprehend software systems and to improve the productivity of the software development process (Diehl, 2007). Researchers in softvis are concerned with visualising the structure, behaviour, and evolution of software; where structure refers to the static aspects of a software system, behaviour to the dynamic aspects of a software system, and evolution to the development process of a software system.

SeeSoft (Eick et al., 1992) is a prominent example of a software visualisation. The original publication has over 800 citations. SeeSoft was pioneered by Eick et al. in the 1990s to visualise the evolution of large and complex software systems. Figure 1 shows a screenshot of the SeeSoft system, visualising several files containing over five thousand lines of code. Colour is used to show code age, where red depicts recently modified code and blue depicts code that has been unchanged for a long time. The smaller window shows the source code corresponding to the current region in focus. Several facts about the code base are shown including an overview of the relative sizes of all files in the code base as well as their structure. Marcus et al. (Marcus et al., 2003a) suggest that SeeSoft is so successfully because it in-



```
if (IS_GET_DAT ( pcbla1_ptr ))
{

        /* Get DSL information */
        /* the macro call IS_GET_DAT has ju
         * the DPB for us, how lucky we are!!
         */
        dslinfo.dsl = dpb_ptr->port;
        /* Use RTretval for RTERRASSRT/RTE
        RTretval = DBfrdtup(RLDSLEQUIP, &

        switch( RTretval ) {

        case GLSUCCESS:

                break;
```

rla377466bM Revison of RLdpnsdchn b-port mapping in RTdslports and RTdslquery 92/07/22 10:20:29

Figure 1: SeeSoft - Visualising program code changes.

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corporates a natural and direct mapping from the visual metaphor to the source code and back, leading to a natural navigation between the representations. This makes the visual representation easy to understand, yielding high levels of trust on the part of the user.

Many visualisations have been developed that are based on the SeeSoft representation and several terms have been used to describe these types of visualisations, including dense layouts for text, pixel oriented views, and zoomed out views. However, none of the above terms are able to include all visualisations based on the SeeSoft representation, therefore, we will be using the term **code-map metaphor**. We define the code-map metaphor as the *mapping of source code to a zoomed out representation, either by the use of pixels, pixel lines, or a scaled down representation of text, in order to allow stakeholders to comprehend various statistics collected at the level of detail of individual lines of code*. We feel that this term best describes the original intent of these software visualisations as they encode source code to a zoomed out representation that maintains the spatial relationships between source code elements and visually encodes key metrics describing the characteristics of these source code elements.

To the best of our knowledge, there has been no dedicated effort to identify and synthesise the softvis literature relating to software visualisations employing the code-map metaphor. Therefore, to fill this gap, this work reports the design, execution, and findings of a review that identifies, selects, and summarises a comprehensive set of literature on software visualisations, that employ the code-map metaphor. The primary research question this review aims to answer is: *How is the code-map metaphor employed by existing software visualisations and what evidence exists of its usefulness?* The review follows a task oriented framework to guide the analysis of the literature in terms of the task, audience, target, medium, representation, and evidence dimensions (Maletic et al., 2002; Schots and Werner, 2014) of softvis. The main contribution of this study is an extensive analysis of the code-map metaphor, in terms of real world applicability, limitations, and perceived usability. We believe that the findings from this review can provide important benefits to researchers and practitioners from the softvis community.

The remainder of this paper is structured as follows. Section 2 presents previous overviews, reviews, surveys, and systematic mapping studies in the field of softvis. Section 3 describes the method used to identify relevant literature corresponding to software visualisations employing the code-map metaphor, as well as the methodology used to extract data from the literature. Section 4 presents a synthesis of the analysed software visualisations. Section 5 presents a discussion of the findings presented in Section 4. Finally, Section 6 reiterates the most important aspects of this study, as well as implications for future work.

2 RELATED WORK

This study presents a review of the code-map metaphor and software visualisations that employ it. We are interested in synthesising previous research to provide insight into how various software visualisations have employed the code-map metaphor, as well as investigating existing evidence in regards to its usefulness and usability. To the best of our knowledge, this is the first review that focuses exclusively on software visualisations employing the code-map metaphor.

A large body of literature exists in the field of visualisation in order to guide researchers and tool developers. For example (Munzner and Maguire, 2015; Ward et al., 2015; Telea, 2015) provide a synthesis view of the infovis field. Moreover, there have been several review (Müller and Zeckzer, 2015; Shahin et al., 2014; Sharafi, 2011), overview (Diehl, 2007; Teyseyre and Campo, 2009; Petre and Quincey, 2006), and survey (Ghanam and Carpendale, 2008; Caserta and Zendra, 2011) studies in the field of softvis. These either focus on sofvis as a whole or specific areas, such as software architecture visualisation (Shahin et al., 2014). In order to place this study into the broader context of softvis literature, we present a brief overview of a subset of these studies.

Petre and De Quincey (Petre and Quincey, 2006) provide an overview of the softvis field in regards to what software development tasks are supported by software visualisations and what aspects of a software system are visualised. The overview study does not mention the code-map metaphor. However, the authors do state that one of the main challenges of software visualisation is to identify the most appropriate visualisation technique for a given software development task. This claim is considered in our study by the use of the task oriented framework (Maletic et al., 2002), which is described further in Section 3.

Shahin et al. (Shahin et al., 2014) conducted a systematic review of software visualisation techniques for software architecture. The authors analysed 57 studies and were able to categorise them based on the type of visualisation technique that was employed. Out of the 57 studies, 26 employed graph-based visualisations, 22 employed notation based visualisations, 5 employed matrix based visualisations, and 4 employed metaphor based visualisations. The metaphor based visualisations do not include any software visualisation tools incorporating the code-map metaphor. We believe that this supports the assumption that the code-map metaphor is not suitable for software architecture visualisations, due to the fact that software architecture visualisations typically do not include information at the source code level of detail and are more tailored toward managers and system architects rather than software developers.

The survey study on software architecture visualisation by Carpendale and Ghanam (Ghanam and Carpendale, 2008), emphasises the importance of evaluation. They found that most software architecture visualisation tools failed in evaluating how their utilisation directly influenced the targeted audience. Additionally, the authors state that it is not sufficient to rely on guesses to decide whether a specific metaphor should be used or not, but that there is a need to study how effective and expressive an abstract or a real metaphor is. This claim is taken into account in this review by the use of the extended task oriented framework (Schots and Werner, 2014), which is described further in Section 3.

Caserta and Zendra (Caserta and Zendra, 2011) present a survey on 2D and 3D based visualization techniques representing the static aspects of software. The authors find that visualisations of the static aspects of software can be split into two main categories: visualisations that show evolution and visualisations that give a picture of the software at a specific point in time. Additionally, visualisations belonging to these categories can be further categorised based on their level of abstraction: source code level, middle level (consisting of package, class and method level), and architectural level. Several tools included in the survey are categorised as belonging to the source code level of abstraction category, including SeeSoft (Eick et al., 1992) and SV3D (Marcus et al., 2003a).

3 RESEARCH METHOD

A systematic literature review is a widely used research method and is a means of identifying, evaluating, and interpreting all available research relevant to a particular topic of interest. For this review, we followed Kitchenham and Charters guidelines (Kitchenham and Charters, 2007). These guidelines involve three main phases: defining a review protocol, conducting the review, and reporting the review. The protocol used in this study was inspired by (Shahin et al., 2014) and is composed of the following components: research questions, literature search, and study selection. These steps are detailed in the following subsections.

3.1 Research Questions

To answer our main research question (how is the code-map metaphor employed by existing software visualisations and what evidence exists of its usefulness?), a task oriented framework was used to guide our analysis of the literature we reviewed. The task oriented framework was originally proposed by Maletic et al. (Maletic et al., 2002) and is intended to be used for the characterisation and classification of software visualisations. The framework makes use of five dimensions which reflect the task, audience, target, medium, and representation of a software visualisation. However, the applicability of a software visualisation to a specific task is not clearly emphasized in the dimensions of the framework. The software visualisation literature (Ghanam and Carpendale, 2008; Petre and Quincey, 2006) emphasises the importance of evaluation in order to identify the most appropriate visualisation technique for a given software development task. In order to overcome this limitation, Schots and Werner (Schots and Werner, 2014) extended the task oriented framework to include a dimension capturing the evidence that a visualisation is *worthwhile* for a specific task.

To improve support for mapping information to each dimension, Schots and Werner (Schots and Werner, 2014) include a comprehensive set of questions that relate to each dimension. These questions were modified to fit this study and are presented in Table 1. The modified task oriented framework utilised by this study makes use of the following 6 dimensions and associated questions.

Task (why): This dimension is used to answer the question of why a particular software visualisation is needed. More specifically, in this study the dimension is used to determine the main motivation for employing the code-map metaphor (SQ:1.1) and the main goal of a visualisation (SQ:1.2). Additionally, we are also interested in which software engineering activities the visualisations employing the code-map metaphor support (SQ:1.3).

Audience (who): Software visualisations can be tailored toward users with different skills and different information needs. In order to extract this information this dimension attempts to answer which stakeholders the software visualisations target (SQ:2.1).

Target (what): The target dimension defines which aspects of a software system's source code are

Table 1: Research questions derived from (Schots and Werner, 2014, Table 1).

Dimensions	Research questions
Task	SQ1.1: What is the main motivation for using the metaphor? SQ1.2: What is the main goal of using the metaphor? SQ1.3: Which software engineering activities are supported?
Audience	SQ2.1: For which users are the visualisations intended?
Target	SQ3.1: Which aspects of the source code are visually represented? SQ3.2: Do these aspects represent the structure, behaviour, or evolution of a software system?
Representation	SQ4.1: How is source code mapped to the visual representation? SQ4.2: How are the various properties of source code mapped to the metaphor?
Medium	SQ5.1: Which medium is used to display the visualisation? SQ5.2: Which resources can be used to interact with the visualisation?
Evidence	SQ6.1: Which methods are used for assessing the quality of the visualisation(s) employing the metaphor? SQ6.2: Which aspects of the visualisation(s) are evaluated? SQ6.3: What are the results and outcomes of the conducted evaluation(s)?

visualised (SQ:3.1) and attempts to categorise these aspects in regards to the structure, behaviour, and evolution categories of softvis (SQ:3.2).

Representation (how): The effectiveness of a visualisation can be measured based on its ability to clearly and accurately represent information. For this study this dimension asks how source code (SQ:4.1) and the various properties (SQ:4.2) of the code are mapped to the visual representation of the metaphor.

Medium (where): The medium dimension aims to extract what type of display medium is used by the software visualisation (SQ:5.1), which can include paper, single monitors, multiple monitors, virtual reality headsets, and mobile devices. This dimension also attempts to gain insight into which resources can be used to interact with the software visualisations (SQ:5.2).

Evidence (worthwhile): The evidence dimension is used to determine if the software visualisations employing the code-map metaphor are effective in helping their target users. Moreover, the dimension aims to answer which evaluation methods were used (SQ:6.1), which aspects of the visualisation were evaluated (SQ:6.2), and what the outcomes of these evaluations were (SQ:6.3).

3.2 Literature Search

The process of extracting relevant literature for this review was composed of three steps. Step one consisted of analysing the literature presented in Table 2, in order to extract relevant publications related to the code-map metaphor. Step two consisted of searching the proceedings of the publication venues (known for including softvis research) presented in Table 3 using the query term *"SeeSoft"*. This query term was constructed after examining the publications extracted from step one. The reasoning behind the query term was that many of the extracted publications used the terms "SeeSoft like represented" or "a view similar to SeeSoft" when describing visualisation systems. Finally, step three consisted of manually analysing related work sections from the publications extracted in step one and step two in order to extract any further publications related to the code-map metaphor.

Table 2: Literature search phase 1.

Reference	Type	Extracted
(Munzner and Maguire, 2015)	Book	2
(Ward et al., 2015)	Book	1
(Telea, 2015)	Book	1
(Diehl, 2007)	Book	9
(Müller and Zeckzer, 2015)	Review	1
(Shahin et al., 2014)	Review	0
(Sharafi, 2011)	Review	0
(Teyseyre and Campo, 2009)	Overview	5
(Petre and Quincey, 2006)	Overview	0
(Ghanam and Carpendale, 2008)	Survey	1
(Caserta and Zendra, 2011)	Survey	4

Table 3: Literature search phase 2.

Venue	Years	Papers	Extracted
VISSOFT	02, 05, 07, 11, 13 - 15	161	16
SOFTVIS	03, 05, 06, 10	145	20
EuroVIs	2015 - 2016	130	0
InfoVis	2013 - 2016	136	0
ICPC	03, 11, 14, 15	153	1

3.3 Study Selection

The publications extracted from the literature search were analysed in order to determine if these were relevant for this work. For a publication to be included in the review, the study had to be peer-reviewed and present a visualisation which employed the code-map metaphor. In total, 29 publications describing 21 software visualisations were extracted and are listed in Table 4. For the remainder of this study, the names of the individual visualisations are used rather than references to the publications, as several visualisations are described in multiple publications. To the best of our knowledge, we have included all software visualisations that employ the code-map metaphor.

Table 4: Extracted visualisations.

Name	References
SeeSoft	(Eick et al., 1992) (Ball and Eick, 1996)
SeeSlice	(Ball and Eick, 1994) (Ball and Eick, 1996)
Almost	(Reiss, 1999)
Aspect Browser	(Griswold et al., 2001) (Shonle et al., 2004)
Aspect Miner	(Hannemann and Kiczales, 2001)
Bee/Hive	(Reiss, 2001a) (Reiss, 2001b)
Tarantula	(Jones et al., 2002)
SV3D	(Xie et al., 2005) (Maletic et al., 2003) (Marcus et al., 2003a) (Marcus et al., 2003b)
Augur	(Froehlich and Dourish, 2004)
Gammatella	(Orso et al., 2004)
MicroPrints	(Ducasse et al., 2005) (Robbes et al., 2005)
Visual Code Navigator	(Lommerse et al., 2005)
War Room Command Console	(O'Reilly et al., 2005)
CVSscan	(Voinea et al., 2005)
Code Thumbnails	(De Line et al., 2006)
SOLIDFX	(Telea and Voinea, 2008)
Code Bubbles	(Reiss and Tarvo, 2013) (Bragdon et al., 2010)
Decluvi	(Islam et al., 2010)
MosaiCode	(Maletic et al., 2011)
Chronos	(Servant and Jones, 2013)
SpiderSense	(Reddy et al., 2015)

4 RESULTS

This section will describe the results of analysing the 21 selected visualisations using the extended task-oriented framework. For each dimension of the task oriented framework that this study uses, the selected publications were the only sources of information. Due to space constraints, only some of the analysed visualisations are mentioned throughout the description of the findings.

4.1 Task

SQ1.1: What is the main motivation for using the metaphor? Examining the source code of a software system is often the only reliable method for gaining insight into the system's structure, behaviour, and evolution. During the maintenance of a software system, software developers can face several challenges. One of the challenges consisting of making changes to an existing code base, either to extend the functionality of the system of simply just to remove a bug. However, due to the volume of code that is present in a typical software system, developers can find it difficult to relate aspects from the structure, behaviour, or evolution of the corresponding system back to the code.

In general, the main motivation for producing software visualisations employing the code-map metaphor was the need for a direct mapping from a visual representation to the source code and back. The direct mapping is needed in order to support the encoding of specific properties and relationship, in order to make developers aware of promising locations within the code to motivate further exploration.

SeeSoft, one of the first tools employing the code-map metaphor, was motivated by the fact that a new scalable technique was needed for visualising program text. *SeeSlice*, *Almost*, *Aspect Browser*, *Augur*, *Gammatella*, and *CSVscan* were motivated by the lack of adequate tools for a number of different software development tasks including exploring program slices, inspecting the behaviour of a system, presenting search query results, and supporting the distributed process of software development. The motivation of *SV3D* is described as overcoming the limitations of *SeeSoft* by exploring new mediums and representations to facilitate code understanding.

SQ1.2: What is the main goal of using the metaphor? The main goal of using the code-map metaphor is to provide developers with a "big picture" view of a code base, while still being able to understand information collected at the source code level of detail. This information can include execution traces, search query results, code ownership, and code age. Keeping the main goal in mind, the analysed software visualisations also support specific goals, depending on which aspects of a system's source code are represented. *SeeSoft* aims to allow developers, managers, and testers to gain insight into the overall structure of a software system. *Almost* aims to link the execution history of a software system back to the corresponding lines of code. *Tarantula* aims to help developers in locating faults in a program by illuminating possible faulty statements. *Augur* aims to enrich source code with information corresponding to development activities in order to coordinate collaborative development work.

SQ1.3: Which software engineering activities are supported? All of the analysed software visualisations employing the code-map metaphor support the comprehension of one or more aspects of a software system. This comprehension process in turn supports a number of software development activities including specification, design, implementation, validation, and maintenance (Laplante, 2007). In general, software visualisations employing the code map metaphor can support all presented activities, except specification. However, the visualisations are mainly tailored towards supporting software maintenance.

Table 5: SE activities & targeted stakeholders.

	Specification	Design	Development	Validation	Maintanance	Total		Architects	Developers	Managers	Testers
SeeSoft		🟩		🟩	🟩	3			🟩	🟩	🟩
SeeSlice					🟩	1			🟩		
Almost					🟩	1			🟩		
A. Browser					🟩	1			🟩		
A. Miner					🟩	1			🟩		
Bee/Hive					🟩	1			🟩		
Tarantula				🟩	🟩	2			🟩		🟩
SV3D				🟩	🟩	2			🟩		🟩
Augur					🟩	1			🟩		
Gammatella					🟩	1			🟩		
MicroPrints			🟩		🟩	2			🟩		
VCN					🟩	1		🟩	🟩		
WRCC			🟩		🟩	2			🟩		🟩
CVSscan					🟩	1			🟩	🟩	🟩
C. Thumbnails			🟩		🟩	2			🟩		
SolidFX					🟩	1			🟩		
Code Bubbles			🟩		🟩	2			🟩		
Decluvi					🟩	1			🟩		
MosaiCode					🟩	1		🟩	🟩	🟩	
Chronos					🟩	1			🟩		
Spider Sense				🟩	🟩	2			🟩		
Total	0	1	4	3	21			2	21	3	5

Table 5 depicts which of the software engineering activities are supported by the analysed software visualisations. All visualisations address the maintenance activity, while only a minority address software design, development, and validation. A number of the analysed visualisations, including *WRCC*, *Tarantula*, and *MicroPrints*, aim to support multiple actives. The authors of *SeeSoft* mention support for designing code and describe how the the code-map metaphor can be used to determine which subsystems of a software system would benefit most from an object oriented design. The authors of *Code Thumbnails* mainly focus on using the code-map metaphor to facilitate source code navigation. However, the tool is incorporated into an integrated development environment. Therefore, we assume that it supports the tasks of writing code. *Almost* utilises the code-map metaphor for linking execution history to the corresponding lines of code in order for developers to quickly gather enough knowledge about the system to make small to medium changes. *Gammatella* and *Tarantula* address the activity of verifying code by using the code-map metaphor for visualising program faults. This is done be examining the results of test cases and encoding the corresponding lines of code with the colour green (passing tests) or red (failing tests).

4.2 Audience

SQ2.1: For which users are the visualisations intended? The analysed visualisations are targeted towards four types of users: software architects, developers, managers, and testers. Many of the visualisations including *Tarantula*, *VCN*, and *CSVscan* mention that the targeted users are maintainers. We assume these to be similar to developers, therefore, the visualisations which target maintainers are included in the developer category. Table 5 depicts the targeted users for each of the analysed software visualisations. All visualisations target software developers/maintainers, where only 2 mention support for software architects, 3 mention support for software project managers, and 5 mention support for software testers. An interesting finding was that none of the analysed visualisations were targeted towards students and/or instructors. Furthermore, none of the analysed visualisations mention if they are tailored towards novice or experienced users. This is an important aspect, as experienced programmers will have drastically different information needs compared to novices.

4.3 Target

SQ3.1: Which aspects of the source code are visually represented? The main data represented is the source code of a software system. However, visualisations employing the code-map metaphor aim to visually encode at least one other aspect within the code, depending on the task at hand. These aspects range from code-age to test execution data, to developer activity. For example, the authors of *SeeSoft* include several different examples where colour is used to encode either execution traces, code structure, code ownership, code age, code evolution or query results. *Augur* displays code structure and developer activity simultaneously. *Aspect Miner* and *Aspect Browser* both use the code-map metaphor as a means of displaying the results of queries on a global view of a code base. These queries consist of regular expressions used to locate specific code fragments.

SQ3.2: Do these aspects represent the structure, behaviour, or evolution of a software system? To better understand the use of the code-map metaphor we categorised the visualisations that were analysed for this review according to whether they visualised structure, behaviour, and evolution. The code-map metaphor can be used to visualise all three, byt many visualisations focus on a subset. Figure 2 depicts the result of our classification. *SeeSoft* and *Sv3D* correspond to the structure, behaviour, and evolution of a software system. *Aspect Browser*, *Aspect Miner*, and *Code Thumbnails* are mainly concerned with visualising the static structure of a software system. *SeeSlice* and *MicroPrints* visually represent aspects corresponding to the static structure and dynamic behaviour of a system.

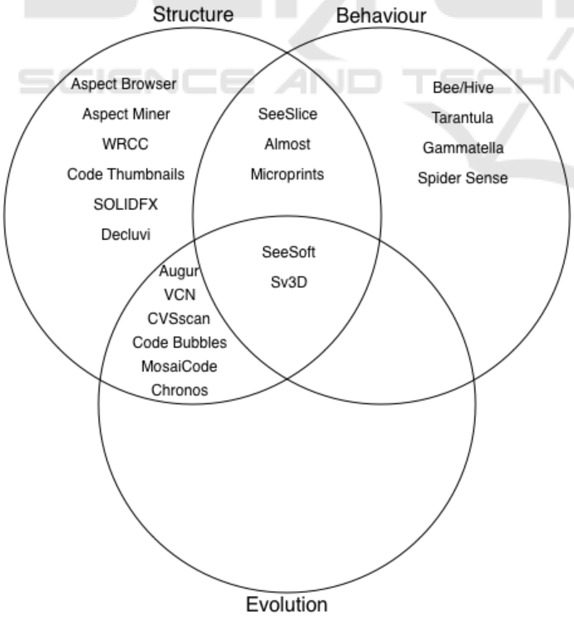

Figure 2: Classification of analysed visualisations.

4.4 Representation

SQ4.1: How is source code mapped to the visual representation? There are three main approaches to mapping source code to a code-map representation. The first approach maps each line of code to a pixel line, as seen in Figures 3 and 4 . Figure 3 uses the actual layout of the code, including indentation and spacing. Visualisations that utilise this mapping include *SeeSoft*, *Augur*, and *Tarantula*. Figure 4 ignores the layout of the code and maps each line of code to a new line in the visual representation, as seen in *Aspect Browser* and *Aspect Miner*. The second approach (Figures 5 and 6) maps each line of code to a pixel (2D) or cuboid (3D). Both the 2D and 3D representation can be seen in SV3D. The third approach (Figure 7) is similar to the first approach, however, it utilises a scaled down font representation instead of pixel lines. This approach also takes the original layout of the code into consideration and can be seen in *Code Thumbnails*. The most commonly used approach for mapping lines of code to a display medium is the pixel line approach depicted in Figure 3.

Figure 3: Pixel line 1.

Figure 4: Pixel line 2.

Figure 5: Pixel (2D).

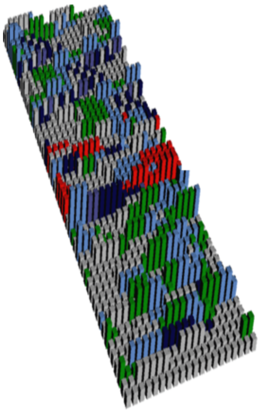

Figure 6: Pixel (3D).

SQ4.2: How are the various properties of source code mapped to the metaphor? Colour is an important attribute and is used in most tools as a

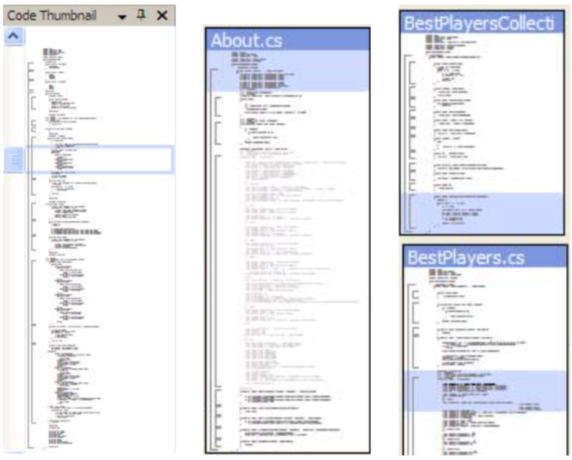

Figure 7: Scaled font.

means for encoding additional information. *Aspect Browser* and *Aspect Miner* use colour to encode the results of queries in order to make developers aware which lines of code correspond to the queries. *Tarantula* uses colour to show which lines of code contain faults. *Augur* uses colour to depict developer activity (Figure 3) and *SeeSoft* uses colour to encode code age (Figure 1). Several of the analysed software visualisations use other means such as lines, shapes, and annotations to display additional information. The code-map display in *Augur* is annotated with information in two extra columns that run down the left-hand side of each module block (Figure 3). The leftmost column indicates developer activity, while the other shows code structure by indicating line type (block comments, method definitions, and method separators). Juxtaposing these columns allows developers to see at a glance whether recent activity has added whole new methods or modified existing ones. *Code Thumbnails* uses brackets drawn to the left of the code-map to convey the nesting structure of the code (Figure 7).

4.5 Medium

SQ5.1: Which medium is used to display the visualisation? The medium of choice used to display visualisations employing the code-map metaphor is a standard computer display (in cases where authors do not explicitly state this we feel it is safe to assume). Some authors (e.g *SeeSoft*) include additional information regarding the display medium supported by the visualisations, however, this information is mostly limited to the make and model of the display and the supported resolution. No approaches mentioned the use of virtual reality or mobile devices, which is expected as most were created before these were widely available.

SQ5.2: Which resources can be used to interact with the visualisation? While most of the analysed software visualisations employing the code-map metaphor include information regarding the interactions the visualisations support (e.g zooming, scaling), all fail to provide information in regards to which interaction devices are supported. Therefore, we assume that all analysed visualisations support a standard computer mouse and keyboard. No approaches mention support for other devices such as virtual reality headsets or motion capture devices.

4.6 Evidence

SQ6.1: Which methods are used for assessing the quality of the visualisation(s) employing the metaphor? Table 6 summarises the description of evaluation for visualisation included in this study. 14 of the 21 analysed visualisations did not include any information on whether some type of evaluation was performed other than providing a simple use case demonstrating how the visualisation can be used. The authors of *Tarantula*, *Code Bubbles*, and *SolidFX* did conduct a quantitative evaluation. However, the evaluations measured the effectiveness of an algorithm rather than the effectiveness of the code-map visualisation. Therefore, this information was excluded in our study as we focus exclusively on the code-map metaphor. The papers describing *SeeSoft* and *SeeSlice* provide an informal evaluation, describing user experiences posthoc. The papers describing *Aspect Browser*, *Augur*, and *CSVscan* provide observational evaluations, which present observations the authors gathered of users using their tools to complete various software development tasks. The paper describing *Code Thumbnails* provides a quantitative evaluation regarding the usage of the code-map metaphor in the context of using spatial memory to navigate source code. Additionally, the authors of *Code Thumbnails* include user feedback through a formal satisfaction questionnaire.

SQ6.2: Which aspects of the visualisation(s) are evaluated? Of the papers which provided information regarding some form of evaluation, all except *Augur* and *Code Thumbnails* were concerned with observing and evaluating the usage of the tools as a whole and not of the utilised code-map metaphor. Table 6 includes information on which aspects of the visualisations, presented in Section 3, were evaluated. The authors of *SeeSoft* provided informal usage experience of the tool in the context of exploring unfamiliar code, assigning code ownership to developers, changing the design of a code base, examining developer activities, diffing versions of a code base, and profiling a code base to find execution hotspots. The authors of *SeeSlice* provided an informal usage experience of the tools ability to present developers with dynamic code slices. Papers describing *Aspect Browser*, *Visual Code Navigator*, and *Code Thumbnails* provided insight to how each tool can be used to explore, re-factor, and modify an existing code base. Furthermore, the paper describing *Code Thumbnails* was the only paper to present quantitative results. These results correspond to how the code-map metaphor can be used as a navigational aid to facilitate between and within file navigation.

Table 6: Evaluation type information.

	Demonstration	Qualatative	Quanatative	Whole tool	Code-map	Participants
SeeSoft	🟩	🟩		🟩		1-?[2]
SeeSlice	🟩	🟩		🟩		1-?[2]
Almost	🟩					0
A. Browser	🟩	🟩		🟩		1
A. Miner	🟩					0
Bee/Hive	🟩					0
Tarantula	🟩					0
SV3D	🟩					0
Augur	🟩	🟩		🟩	🟩	4
Gammatella	🟩					0
MicroPrints	🟩					0
VCN	🟩	🟩		🟩		3
WRCC	🟩					0
CVSscan	🟩	🟩		🟩		2
C. Thumbnails	🟩	🟩	🟩	🟩	🟩	11
SolidFX	🟩	🟩		🟩		8
Code Bubbles	🟩					0
Decluvi	🟩					0
MosaiCode	🟩					0
Chronos	🟩					0
Spider Sense	🟩					0
Total	21	8	1	7	2	

SQ6.3: What are the results and outcomes of the conducted evaluation(s)? The authors of *SeeSoft* and *SeeSlice* state that by being able to visually see the structure and change history of a code base or multiple files within the code base, developers are able to use the tool to drive code discovery and exploration. Additionally, when using the code-map metaphor to encode developer activity, it can be used as a means to assign the ownership of source code files or fragments within a code base to the developers responsible for the majority of changes. Moreover, the authors of *SeeSoft* note that the reaction of developers and managers using the tool had been enthusiastic and many stated that they wished that it had been available for recent work.

The authors of *Aspect Browser* observed that the code-map metaphor influenced and aided the completion of tasks in regards to software evolution. Also, the processes and strategies developed around the use of the metaphor were successful in minimising the introduction of bugs and produced a running system with a minimum of debugging. The authors of *Augur* presented observations on how the tool allowed developers to gain insight into the coding and development practises of distributed team members. Additionally, developers using the tool were interested and engaged, as a participant from the observational study noted that an interesting aspect one can comprehend from the code-map metaphor, in the context of software evolution, is the growth of a project over time. The literature describing *Code Thumbnails* presented quantitative results regarding the usage of the code-map metaphor for search and spatial memory tasks, as well as for usage during code base re-factoring. Although developers were able to use standard navigational features in the quantitative evaluation study, it was clear that all participants frequently used the code-map features for navigation, searching, and selection. Even under time pressure, participants found that the code map was easy to learn and helpful.

In summary, the observations and results presented here suggest that the code-map metaphor is useful for providing developers with an overview of a code base or several files within a code base. Developers are able to use software visualisations employing the metaphor for several tasks including code discovery, tracking and gaining insight into developer activities, comparing different versions of a system or files, and navigating a large code base. However, there is a lack of quantitative evidence to support these claims. Therefore, the effectiveness of the code-map metaphor remains in question.

5 DISCUSSION

In this section we discuss the limitations of the evaluations carried out by the authors of the analysed software visualisations employing the code-map metaphor. Additionally, shortcomings of the metaphor, derived from the analysed literature, are also presented.

5.1 Evaluation

The lack of empirical studies is a shortcoming not only of software visualisation research, but also of software engineering and computer science in general (Diehl, 2007). Quantitative evaluations involving human participants are time consuming. The authors of

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[1] The number of participants was not explicitly stated.

Augur support this claim by stating that effective evaluation cannot be conducted in a laboratory, as true validation requires longer-term deployment and an analysis of the impact of a system on software development practises. Therefore, Diehl (Diehl, 2007) recommends that at least qualitative evaluations should be performed during the design of visualisation tools or posthoc. While the majority of software visualisations analysed in this study do present some form of qualitative evaluation (informal, formal, and observational), the evaluations have several limitations in terms of the methodology used for evaluating the usability code-map metaphor. These limitations are discussed below.

An important aspect for evaluating the usability of a software visualisation is the number of participants incorporated in the study, as well as the method used to collect observations of the usability of the tools. Figure 6 shows the number of participants each analysed software visualisation used during qualitative and quantitative evaluations. There is no consensus among the evaluations on the number of participants needed in order to provide reliable support. The authors of *SeeSoft* and *SeeSlice* do not explicitly state the number of users that took part in their studies, therefore, we assume there to have been at least one. *Aspect browser* provides observations based on one user, *CSVscan* provides observations based on 2 users, while the remaining tools provide results based on at least 3 users. Nelson (Nielsen, 2000) considers that at least 15 participants are needed to discover all usability issues. However, Nielson (Nielsen, 2000) also proposes that the best results come from testing no more than 5 users and running many small tests. For quantitative studies Nielson (Nielsen, 2006) suggests that 20 participants typically offer a reasonably tight confidence interval. Bridging these findings with our study, the reader will find that from all of the analysed software visualisation tools, none meet the requirements specified by Nielson. Therefore, in order to provide a consensus among the number of participants future evaluations should consider incorporating, we suggest using the numbers provided by Nielson's research.

Regarding the method used to collect observations of the usability of a tool, the authors of *SeeSoft* and *SeeSlice* present the experiences of developers and managers using the tools, but it is unclear how these experience reports were obtained. The authors of *CSVscan* use a silent observer to record both user actions and findings during tool usage. The authors of the paper on *Aspect Browser* use a method similar to the think-aloud protocol (Nielsen, 2012). When using a think-aloud protocol, test participants are asked to use a system while continuously verbalising their thoughts as they move through the user interface. The main benefits of using the protocol include that there is no special equipment needed, it can be used at any stage in the development life-cycle, and the protocol is easy to learn. While the authors of *Aspect Browser* observe the activities of a single developer we believe, however, that the method used to obtain these observations can be considered a step in the right direction. Thus, for future evaluations we suggest using a think-aloud protocol (Nielsen, 2012).

5.2 Limitations

Regarding the limitations of the code map metaphor, publications corresponding to *SV3D* and *SeeSoft* include this information. We were able to extract 4 main limitations from these publications. The first is that the 2D line representation limits the number of attributes that can be visualised, as well as the type of relationships and hierarchies that can be shown. *SV3D* tries to tackle this limitation by using 3D instead of 2D. The second limitation mentioned in the literature is that the metaphor includes little support for multiple abstraction levels. This limitation is supported by the fact that most of the analysed tools for this study include multiple views or multiple visualisation in a single view. The third limitation is that the metaphor limits the usage of the available 2D space, as the space is used to depict multiple files using a zoomed out representation. However we believe that this aspect cannot be considered a limitation, as the main goal of the code-map metaphor is to present as many files as possible to provide developers with an overview of a code base. There is a limit to the number of lines of code that can be visualised at a single point in time, but this is due to the limitations of available screen real estate. Finally, the fourth limitation is that there is a lack of mechanisms that offer flexibility to stakeholders in customising their visualisations.

6 CONCLUSION

In this work we provide an extensive review of the code-map metaphor and analyse 21 software visualisations, all of which employ the metaphor. Using an extended task oriented framework, we were able to extract information regarding the task, audience, target, medium, representation, and evidence dimensions.

In summary the code-map metaphor, first proposed by Eick et al. (Eick et al., 1992) in the early nineties in a tool named *SeeSoft*, is widely perceived to be useful for software development. This is due to the fact that the metaphor uses a natural and direct mapping from the visual representation to the source code and back, which leads to a natural navigation between multiple representations (Marcus et al., 2003a). This yields high levels of trust on behalf of the user, which is supported by qualitative observation from several of the analysed tools. However, to date, little to no quantitative data exists in the literature that supports the claim that the use of the metaphor can facilitate the process of software development.

The authors of *Code Thumbnails* provide quantitative evidence that if present, a code-map visualisation feature will be used by developers for the tasks of code exploration, navigation, and selection. Additionally, developers using *Code Thumbnails* were also starting to form a cognitive map of the code base. We believe that this is an interesting and important finding as it provides initial evidence that the code-map metaphor is useful for exploring and navigating large code bases, as observations from the usage of *Aspect Browser* support this claim. Using these findings, we believe that a worthwhile direction for future work could be investigating the use of the code-map metaphor in integrated development environments, extending the work of *Code Thumbnails*. Furthermore, various source code editors, such as *Sublime Text*[3] include a code-map of the currently focused document. However, to date, no empirical evidence, other than the results described in *Code Thumbnails*, has been found to provide information about the usefulness of this approach.

A large amount of information relating to software developer activities and static characteristics of source code can be obtained from source code repositories, as it is already available in most revision control systems. We believe that visualisations employing the code-map metaphor should be able to provide most of the above stated information to the user using a layering mechanism similar to that of an online map (e.g. Google maps). Depending on the task at hand, this would allow developers to switch between viewing different types of information dynamically and provide a way to tailor the visualisation to help complete a specific task or answer a specific question.

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[2] https://www.sublimetext.com/

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