

PerfVis: Pervasive Visualization in Immersive Augmented Reality for Performance Awareness

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ABSTRACT

Developers are usually unaware of the impact of code changes to the performance of software systems. Although developers can analyze the performance of a system by executing, for instance, a performance test to compare the performance of two consecutive versions of the system, changing from a programming task to a testing task would disrupt the development flow. In this paper, we propose the use of a city visualization that dynamically provides developers with a pervasive view of the continuous performance of a system. We use an immersive augmented reality device (Microsoft HoloLens) to display our visualization and extend the integrated development environment on a computer screen to use the physical space. We report on technical details of the design and implementation of our visualization tool, and discuss early feedback that we collected of its usability. Our investigation explores a new visual metaphor to support the exploration and analysis of possibly very large and multidimensional performance data. Our initial result indicates that the city metaphor can be adequate to analyze dynamic performance data on a large and non-trivial software system.

CCS CONCEPTS

• **General and reference** → **Performance**; • **Human-centered computing** → **Visualization design and evaluation methods**; *Mobile devices*; • **Software and its engineering** → **Software maintenance tools**;

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1 INTRODUCTION

Among the many questions that arise during software development, programmers often formulate questions about the performance of

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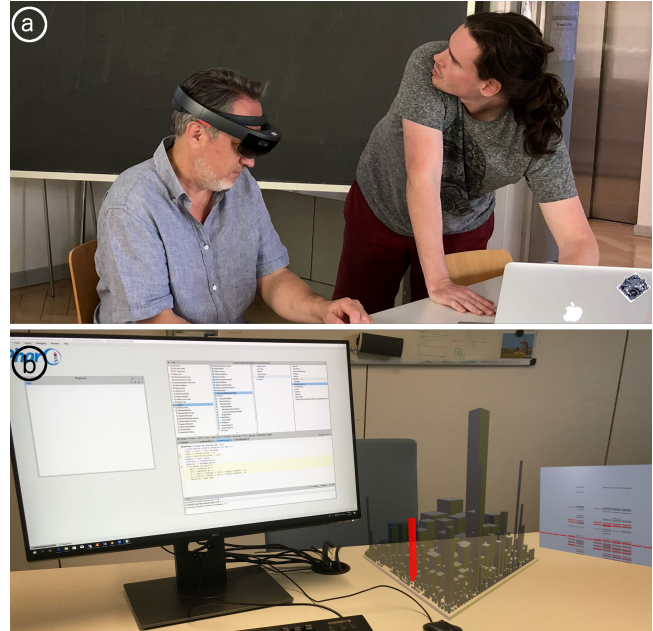


Figure 1: Pervasive visualization displayed in immersive augmented reality: (a) a developer wears a Microsoft HoloLens device (b) for performance visualizations using the city metaphor and a scatter plot.

software systems [1, 5]. They ask, for instance, “what is the software doing when performance issues arise?” [15], and “where is most of the time being spent?” [16]. Since developers introduce multiple changes to the source code during the implementation of a software system, being aware of the impact of a code change task to the performance of a software system is an important concern for developers [5]. Tools such as profilers and performance tests allow developers to analyze the performance of only a single version of a system at a time, and force developers to change to a different task (interrupting their flow). Our intuition is that developers would benefit from analyzing the live performance of an evolving system as its source code changes. We expect that such an analysis would help them identify changes that severely decrease the performance of a system. We conjecture that a pervasive tool, (*i.e.*, a tool that is omnipresent at all times during the implementation of a software system) can make developers aware of important changes in the performance of a system without disrupting the implementation flow. Using a visualization approach, developers could obtain such a pervasive view of the live performance of

a system, however, we observe that developers can be reluctant to sacrifice space in their integrated development environment (IDE). Consequently, we formulate the following research question:

RQ: How can visualization support developers in the analysis of the impact of source code changes to the performance of a system?

This paper presents an initial step toward answering our general research question. To increase developer awareness of the impact of changes to the source code in the performance of software systems we present *PerfVis*, a pervasive visualization tool displaying in immersive augmented reality. *PerfVis* provides an omnipresent overview of the system that takes advantage of visualization techniques to make developers aware of the impact of changes introduced to the source code in the live performance of a software system.

The main contribution of the paper is threefold: (i) a discussion of design choices, (ii) lessons learned from building the tool, and (iii) insights from observing its use. We also contribute to the reproducibility of our research by making the implementation of *PerfVis* publicly available¹.

2 RELATED WORK

A number of 3D visualization tools have been proposed to support software development concerns. *Seelt 3D* [17] uses a 3D scatter plot visualization to represent software metrics collected from Java source code to support developers on software comprehension tasks. *SynchroVis* [19] employs a visualization based on the 3D city metaphor that displays the structure and metrics of software systems, as well as program traces and synchronization aspects (e.g., semaphores/wait) to support the analysis of the behavior of concurrent software systems. These tools display the 3D visualization on a standard computer screen and focus on performance data collected using static analysis. In contrast, we propose the visualization to be displayed in immersive augmented reality and focus on live performance data collected using dynamic analysis.

There are some visualization tools that use virtual reality to support software comprehension tasks. *Code Park* [4] proposes an immersive visualization of software metrics and source code; an evaluation showed that the visualization displayed in virtual reality excels at usability and significantly helps in code understanding. *ExplorViz* [3] introduces a visualization of software landscapes to support software comprehension tasks. *CityVR* [10] gamifies software implementations using a 3D city visualization displayed in virtual reality to boost developer engagement. In contrast, we propose the use of immersive augmented reality to improve the awareness of the impact of changes on the source code to the performance of software systems. Moreover, some of these tools focus on various static software metrics, as opposed to our tool that includes the visualization of dynamic live performance data.

Several existing performance visualizations focus on the analysis of static performance data. *JOVE* [15] is a visualization tool for monitoring the performance of Java programs. Using the visualization, developers can obtain details on demand to identify routines and threads in which the application spends much time.

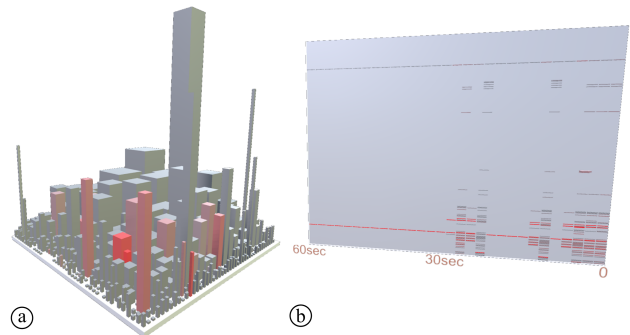


Figure 2: A detailed view of the (a) dynamic city visualization and (b) the complementary scatter plot that maintains the history of the overall performance of the system for a configurable interval of time.

Another tool [2] includes the visualization of the structure of parallel software systems. The visualization uses an execution graph to simplify the analysis of the complex run-time behavior. Moreta and Telea [13] present a visualization of the behavior of the memory allocator in C programs to optimize functionality, decrease fragmentation, and improve response time. Another tool [14] facilitates the visualization of software performance in real-time, using the city metaphor to show the structure and performance of a program. The buildings in the city represent the classes in the system, and the heights of the buildings represent the number of times the methods of a class are called during execution. All these tools support the analysis of various aspects of software performance through visualizations displayed on a standard computer screen. In contrast, we rely on immersive augmented reality to display our visualization.

A few software visualizations chose augmented reality as a display medium. One study [8] evaluated a city visualization displayed in immersive augmented reality to support software comprehension tasks. Another study [18] used the city metaphor in augmented reality to support the analysis of software evolution. In contrast, we propose a city-based visualization using immersive augmented reality to support software performance tasks, which is an innovative and not-yet explored approach.

3 PERFVIS OVERVIEW

PerfVis is a tool to visualize software performance through immersive augmented reality. We characterize the context of *PerfVis* using a taxonomy proposed by Maletic *et al.* [6] and Merino *et al.* [12].

PerfVis provides visualization in *immersive augmented reality* to support the *programmer* audience in system performance tasks. The visualization shows *static data* of the structure of the system and *dynamic data* of the live performance of the system.

3.1 Design

Medium: Immersive Augmented Reality. Most visualizations that support performance analysis tasks are displayed on a computer screen. They require developers to either use an application outside their development environment, or use a plug-in in their environment that sacrifices some valuable screen space. Amongst the few visualizations that use a different medium most are displayed in immersive virtual reality [9]. These visualizations require

¹<http://scg.unibe.ch/research/perfvis>

that developers completely change their development environment, and isolate themselves wearing a headset. As opposed to these approaches, we argue that a medium that disrupts as little as possible the development flow can significantly increase the usability of visualizations. The medium used to display a software visualization can impact its effectiveness and efficiency [7]. Consequently, we chose immersive augmented reality to display PerfVis, because (i) developers can use the visualization as a complement to their usual development environment without much disruption (*i.e.*, developers are required to wear a headset, but not to modify the rest of their environment), and (ii) visualizations in immersive augmented reality are inherently displayed in 3D, which provides an extra dimension to encode performance data of a software system.

Apparatus: HoloLens. We choose Microsoft HoloLens to render our visualization in immersive augmented reality. HoloLens is an untethered head-mounted stereoscopic display, featuring two stereoscopic displays with 1268×720 pixel resolution, 60 Hz content refresh rate, and a 30° H and 17.5° V field of view. Interaction is possible through head tracking, gesture input, and voice support.

Technique: City Visualization and Scatter plot. In a previous study [12], we observed that most visualizations to support developers in monitoring performance used pixel-based techniques. These visualizations usually attempt to provide an overview of a significant amount of data to promote the detection of visual patterns that may signal anomalies in the performance of software systems. Instead, we adopt lightweight visualization techniques that involve less cognitive effort to make developers aware of the performance of a system. Our visualization includes two views: (i) a city visualization that provides a pervasive overview of the structure and performance and (ii) a scatter plot that displays the history of the performance of a software system in the past.

City visualization. We opted to represent a metric of the performance of the software system using the color of buildings. The visualization is always on and indicates the system performance collected during a short time frame. In consequence, a glimpse at the city can make developers aware of the current overall status of the performance, and a detail of the classes that are involved. Figure 2 (a) shows a visualized software city. Each building represents a class in the software system. Buildings are grouped into districts according to their packages. Each building can be configured to represent software metrics using three properties: (i) height, (ii) footprint (*e.g.*, squared base), and (iii) color. We consequently configured the city in the following manner: each building's (i) height encodes the number of methods of the represented class, (ii) footprint (*i.e.*, squared base) encodes the number of attributes of the represented class, and (iii) color encodes the number of times that methods of the class are called during execution.

Scatter plot. The scatter plot helps developers analyze changes in the dynamic city visualization that might be overlooked. Figure 2 (b) shows the scatter plot to the right of the city visualization. The *X*-axis encodes time, and the *Y*-axis encodes the classes in the system. Each mark represents a class that was involved in the execution of the system at a point in time. The color of a mark encodes the number of times methods of a class were called. The more intense the red, the more often a class was called. Each row in the scatter plot represents the evolution of the number of times the methods

of a class are called along time. Each column is a snapshot of the performance of the whole system at a point in time.

Interaction: Selection and Navigation. Developers can interact with PerfVis through: (i) *Selection.* Through head movements, users can point and select elements in the visualization. When the pointer hovers over a building in the city visualization or a mark in the scatter plot, the name of the corresponding class is displayed. Users select buildings by performing an *airtap* gesture.² Once a building is selected, that building and the mark that represent the same class are simultaneously highlighted with a yellow background. Similarly, when selecting a mark in the scatter plot, the building and mark that represent the same class are highlighted. Using this feature, developers relate the information they get from one visualization to the elements in the complementary visualization. (ii) *Navigation.* To gain an overview of the whole system, the user can move around and inspect the city from different angles. This way the user can compare metrics between different buildings.

3.2 Implementation

The landscape of the city visualization is generated using CodeCity³ for Moose 5.⁴ The color animation of the city and the scatter plot are implemented in Unity⁵ using the MixedRealityToolkit-Unity⁶ library. The performance data are collected using the Spy2⁷ profiler for Pharo Smalltalk, and streamed to the HoloLens through the network.

4 DISCUSSION

We revisit our research question: *How can visualization support developers in the analysis of the impact of source code changes to the performance of a system?* We have presented a design and publicly available implementation of a visualization tool that uses immersive augmented reality to support developers in the analysis of software performance. We now discuss lessons learned during the development process, and early feedback on the usability of PerfVis.

4.1 Lessons Learned

Scale. PerfVis aims to give developers an overview of the live performance of a software system with the least disruption possible to the integrated development environment. We tested PerfVis visualizations at various scales. We observed that the visualization had to be scaled to be large enough to give an overview of the complete system, but also small enough to be used as a complement to a computer screen.

Text. We learned that the position, rotation, and scale of text can greatly impact usability when navigation is done by head movements. In an early prototype, we chose to display the names of classes on top of their corresponding building, however, we found that depending on the position of the user and the size of the building, the text on top of a building might be difficult to read, and also that text on top of a building might be occluded by neighboring buildings. We addressed these issues by positioning the text in

²<https://docs.microsoft.com/en-us/hololens/>

³<http://smalltalkhub.com/#!/~RichardWettel/CodeCity>

⁴<http://www.moosetechnology.org/>

⁵Version 2017.3.0b8 (64-bit)

⁶<https://github.com/Microsoft/MixedRealityToolkit-Unity>

⁷<https://github.com/ObjectProfile/Spy2>

relation to the position of the camera. Specifically, we placed the text at the top left corner of the user's field of view. Benefits of this approach are that (i) text is never occluded, (ii) text always faces the user, and (iii) no movement of the head and only little movement of the eyes is required to read the text.

History. A live visualization has the benefit that it can provide developers online feedback of the performance of the system, however, changes in the visual properties of the visualization can take a very short time. Then the city visualization can be good at making developers aware of an important change in the performance but might not be good for analyzing details of the context of the change since it provides developers too little time to react. To help developers get details on demand we included a companion lightweight visualization (*i.e.*, scatter plot). We observed some usability issues. For instance, (i) marks in the scatter plot can be too small and difficult to select, and (ii) the size of the buffer presented in the scatter plot has to ensure a good performance (too many marks would slow down the visualization tool). To address the former issue we included a type of selection that involves only head movement (marks are selected when hovering over them for one second). We also addressed the latter issue by making the definition of the size of the buffer configurable.

4.2 Early Feedback on Usability

We demonstrated the tool to a group of Computer Science students to discuss our design choices and obtain impressions. Their feedback allowed us to iterate several times on the design of the various components of the visualization tool. Certainly, the positive impressions of developers who used our visualization tool do not represent a solid proof of its benefits, however, they represent a basis to design a suitable evaluation [11].

Visualization Techniques. Developers who used PerfVis noticed that the city visualization and the scatter plot complement each other. The former, being a space-filling technique, can be scaled down to a small size, and so provide developers an omnipresent overview of the performance of the whole system; and once the attention of a developer is caught, the latter can be used to provide details on demand of the history of the performance of a system. Some developers who used early prototypes of PerfVis observed that the city visualization was too big, and so only part of it was visible through the narrow field of view of the immersive augmented reality device that we used (HoloLens). We then scaled the visualization to be visible even when the developer is looking at the computer screen.

Interactions. Interactions such as navigation and selection represent key features that promote usability. In particular, developers who used PerfVis found it difficult to stabilize their head when pointing at small elements in the visualization to select them (through airtap). Some of the developers also said that the highlighting feature of selected elements in the city and scatter plot visualizations did not have a good contrast, and it was hard to see. Several developers suggested including more interactions to the scatter plot visualization. Specifically, they said that features to pause and rewind would help them in the analysis of the performance of the system in a past time.

5 CONCLUSION AND FUTURE WORK

We introduced *PerfVis*, a visualization tool displayed in immersive augmented reality that supports developers in the analysis of software performance. We elaborated on design choices and discussed implementation details, lessons learned, and early impressions of developers who used prototypes of our visualization tool. In the future, we plan to conduct a thorough evaluation of *PerfVis* to identify strengths and improvement opportunities.

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REFERENCES

- [1] Juan-Pablo Sandoval Alcocer, Alexandre Bergel, Stéphane Ducasse, and Marcus Denker. 2013. Performance evolution blueprint: Understanding the impact of software evolution on performance. In *Proc. of VISSOFT*. IEEE, 1–9.
- [2] Wolfgang Blochinger, Michael Kaufmann, and Martin Siebenhaller. 2005. Visualizing structural properties of irregular parallel computations. In *Proc. of SOFTVIS*. ACM, 125–134.
- [3] Florian Fittkau, Alexander Krause, and Wilhelm Hasselbring. 2017. Software landscape and application visualization for system comprehension with ExplorViz. *Information and Software Technology* 87 (2017), 259–277.
- [4] Pooya Khaloo, Mehran Maghoubi, Eugene Taranta, David Bettner, and Joseph Laviola. 2017. Code Park: A new 3D code visualization tool. In *Proc. of VISSOFT*. IEEE, 43–53.
- [5] Thomas D. LaToza and Brad A. Myers. 2010. Hard-to-answer questions about code. In *Proc. of PLATEAU*. ACM, Article 8, 6 pages.
- [6] Jonathan I. Maletic, Andrian Marcus, and Michael Collard. 2002. A task oriented view of software visualization. In *Proc. of VISSOFT*. IEEE, 32–40.
- [7] Leonel Merino. 2018. *The Medium of Visualization for Software Comprehension*. PhD thesis. University of Bern.
- [8] Leonel Merino, Alexandre Bergel, and Oscar Nierstrasz. 2018. Overcoming issues of 3D software visualization through immersive augmented reality. In *Proc. of VISSOFT*. IEEE, 54–64.
- [9] Leonel Merino, Johannes Fuchs, Michael Blumenschein, Craig Anslow, Mohammad Ghafari, Oscar Nierstrasz, Michael Behrisch, and Daniel Keim. 2017. On the impact of the medium in the effectiveness of 3D software visualization. In *Proc. of VISSOFT*. IEEE, 11–21.
- [10] Leonel Merino, Mohammad Ghafari, Craig Anslow, and Oscar Nierstrasz. 2017. CityVR: Gameful software visualization. In *Proc. of ICSME (TD Track)*. IEEE, 633–637.
- [11] Leonel Merino, Mohammad Ghafari, Craig Anslow, and Oscar Nierstrasz. 2018. A systematic literature review of software visualization evaluation. *Journal of Systems and Software* 144 (2018), 165–180.
- [12] Leonel Merino, Mohammad Ghafari, and Oscar Nierstrasz. 2017. Towards actionable visualization for software developers. *Journal of Software: Evolution and Process* 30, 2 (2017), e1923.
- [13] Sergio Moreta and Alexandru Telea. 2007. Visualizing dynamic memory allocations. In *Proc. of VISSOFT*. IEEE, 31–38.
- [14] K. Ogami, R. G. Kula, H. Hata, T. Ishio, and K. Matsumoto. 2017. Using high-rising cities to visualize performance in real-time. In *Proc. of VISSOFT*. IEEE, 33–42.
- [15] Steven P. Reiss and Manos Renieris. 2005. JOVE: Java as it happens. In *Proc. of SOFTVIS*. ACM, 115–124.
- [16] Michael D. Shah and Samuel Z. Guyer. 2016. An interactive microarray call-graph visualization. In *Proc. of VISSOFT*. IEEE, 86–90.
- [17] Bonita Sharif, Grace Jetty, Jairo Aponte, and Esteban Parra. 2013. An empirical study assessing the effect of SeeIT 3D on comprehension. In *Proc. of VISSOFT*. IEEE, 1–10.
- [18] Rodrigo Souza, Bruno Silva, Thiago Mendes, and Manoel Mendonça. 2012. SkyscrapAR: An augmented reality visualization for software evolution. In *Proc. of WBVS*. SBC, 17–24.
- [19] Jan Waller, Christian Wulf, Florian Fittkau, Philipp Dohring, and Wilhelm Hasselbring. 2013. Synchrovis: 3D visualization of monitoring traces in the city metaphor for analyzing concurrency. In *Proc. of VISSOFT*. IEEE, 1–4.