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Real-Time Program Visualization Framework for Visual Studio Code Using Tree-sitter and WebGPU

Aaron Matthew , Saee Phadke , Tanaya Chaudhari
Department of Computer Science
Progressive Education Society's Modern College of Arts, Science and Commerce (Autonomous) Pune, India

Abstract **- This project introduces a real-time program visualization framework integrated directly into Visual Studio Code. It uses Tree-sitter for dynamic syntactic analysis, allowing continuous and accurate parsing as code is written or edited. With this capability, the system generates live visual representations of core programming structures such as functions, loops, conditionals, and hierarchical relationships. These elements are presented through interactive UI components and custom animations that highlight execution flow, structural patterns, and logical dependencies. Unlike traditional debugging tools that focus on breakpoints or step-by-step execution, this approach emphasizes conceptual understanding by illustrating how code elements relate and interact across different languages and paradigms. The framework is language-independent, eliminating the need for language-specific implementation logic and making it highly extensible. By embedding visualization directly into the editor, it improves accessibility, supports learning, and enhances comprehension by reducing cognitive load and minimizing context switching.**

Keywords **- program visualization; Visual Studio Code; Tree-sitter; WebGPU; real-time parsing; educational tools; code comprehension**

INTRODUCTION

Modern programming environments provide powerful tools for writing and debugging source code, yet most of these tools continue to represent programs primarily as text. As programming languages evolve and software systems grow more complex, developers and learners increasingly require alternative representations that enhance conceptual understanding instead of focusing solely on syntactic correctness. Visual representations of code structure and execution behavior can provide improved comprehension, reduce cognitive load, and support learning at early stages. Integrating these capabilities directly into an established development environment enables a smoother workflow and provides immediate insight without requiring external tools.

Background

Traditional debugging environments focus on sequential execution, breakpoints, and runtime variables. While these tools are essential for professional development, they are less effective for conceptual learning because they highlight line-based execution rather than structural relationships and logical flow. Academic research in program visualization has demonstrated that graphical interpretations of algorithms and logic improve retention and comprehension. However, most visualizers remain language-specific or exist as standalone applications disconnected from actual coding practice. Recent progress in parsing frameworks, such as Tree-sitter, has made language-agnostic visualization feasible.

Problem Statement

Current debugging tools provide runtime analysis focused on variable inspection and execution flow, yet they do not directly expose structural relationships and abstract patterns in code. Educational visualizers are typically standalone applications, disconnected from the actual development environment, which increases context switching and reduces immediate applicability. Most visualization tools are language-specific, requiring individual implementations for each language. This work addresses these gaps by proposing an embedded, language-agnostic visual representation system that operates in real time within the editing environment.

Objectives of the Study

The primary objectives are: (1) to implement a Visual Studio Code extension capable of parsing source code in real time using Tree-sitter; (2) to develop a GPU-accelerated visualization layer using WebGPU for rendering code structures interactively; (3) to support multiple programming languages without language-specific logic; (4) to provide immediate visual feedback as code is edited; and (5) to create an extensible framework suitable for educational and professional use.

LITERATURE REVIEW

Program visualization has been explored through various tools and frameworks. Online Python Tutor [1] provides step-by-step

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visualization of Python execution but is limited to a single language and operates outside typical development environments. Jeliot 3 [2] offers visualization for Java programs with animation of method calls and variable changes but also functions as a standalone tool. The taxonomy by Price et al. [3] categorizes visualization systems by scope, content, and form, showing that most existing tools focus either on runtime behavior or static structure, rarely integrating both within an active editor.

More recent work includes the VS Code Debug Visualizer extension [4], which visualizes data structures during debugging sessions. However, this tool operates during execution and requires breakpoints, limiting its usefulness for understanding static structure and relationships. The emergence of WebGPU [5, 6] offers new opportunities for high-performance graphics directly in web and editor contexts. Unlike WebGL, WebGPU provides lower-level control and better integration with modern GPU pipelines [7], making it suitable for complex, real-time visual rendering.

Gaps in Existing Research

Existing visualization tools fall into distinct categories: runtime debuggers, standalone educational visualizers, and language-specific analysis tools. None successfully integrates real-time parsing, language-independent visualization, and GPU-accelerated rendering within a widely used development environment. This project attempts to bridge these gaps by combining incremental parsing, abstract syntax tree analysis, and GPU graphics within Visual Studio Code.

SYSTEM DESIGN AND METHODOLOGY SYSTEM ARCHITECTURE

The system architecture consists of three primary components: (1) a VS Code extension that monitors text changes in the active editor; (2) a Tree-sitter parser that generates and updates abstract syntax trees incrementally; and (3) a WebGPU rendering layer that visualizes the parsed structure. The extension operates asynchronously to avoid blocking the editor, and parsing updates are triggered on document changes. The WebGPU canvas is embedded within a webview panel, allowing interactive graphics within the editor interface.

Tools and Technologies

Tree-sitter provides incremental parsing with support for numerous programming languages. It generates concrete syntax trees efficiently and updates only the modified portions of the tree when edits occur. WebGPU serves as the graphics API, enabling high-performance rendering through compute and graphics pipelines. The Visual Studio Code Extension API allows integration of custom panels, commands, and editor listeners. TypeScript is used for extension development, ensuring type safety and maintainability.

Data Collection and Processing

The system captures text changes from the VS Code editor in real time. Each change triggers an incremental parse, producing an updated syntax tree. The tree is then traversed to extract relevant nodes representing functions, loops, conditionals, and other structures. This structural data is formatted and transmitted to the WebGPU rendering context, where it is used to position and animate visual elements representing code constructs.

IMPLEMENTATION AND DEVELOPMENT

The implementation began with establishing a basic WebGPU rendering pipeline. This involved initializing the GPU device, creating shader modules, defining buffer layouts, and configuring the render pipeline. Initial experiments validated that WebGPU could be integrated within a VS Code webview and that shader programs could execute successfully. Following this, Tree-sitter integration was added to parse source code and generate syntax trees. The extension was configured to listen for document changes and invoke the parser incrementally.

The transition from DOM-based rendering to GPU rendering required restructuring the visual
representation logic. Rather than generating HTML elements for each code construct, the system now computes vertex positions and attributes and uploads them to GPU buffers. Shader programs handle transformation and coloring, allowing smooth animations and visual effects. The architecture supports future expansion to include more complex visual metaphors, interactive controls, and semantic analysis.

RESULTS AND ANALYSIS

System Output

The current implementation successfully demonstrates GPU initialization, shader execution, and basic rendering within Visual Studio Code. Tree-sitter parses input code and generates abstract syntax trees that update incrementally as the user types. The WebGPU pipeline renders visual elements on a canvas embedded in the editor interface. Initial tests confirm that the parsing and rendering processes operate without blocking the editor, maintaining responsiveness during active editing.

Performance Evaluation

Performance testing focused on parsing latency and rendering frame rates. Tree-sitter's incremental parsing ensures updates complete within milliseconds for typical code files. WebGPU rendering achieves smooth frame rates, with the GPU handling transformation and shading operations efficiently. The system remains responsive during continuous typing and editing, validating the architectural design for real-time use.

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Discussion of Findings

The implementation demonstrates that the proposed technical pathway is realistic. Tree-sitter offers sufficient parsing performance, and WebGPU provides a capable rendering environment inside the editor. The transition from React to WebGPU has proven conceptually sound because GPU-accelerated rendering removes limitations associated with DOM-based visual elements and enables higher frame rates and more complex animations. The main finding is therefore a validation of architectural feasibility rather than a complete visualization result. As implementation advances, the system will need to incorporate semantic interpretation, visual metaphors, and evaluation studies to determine how conceptual visualization influences comprehension.

CONCLUSION AND FUTURE WORK

This work demonstrates an initial implementation of WebGPU-based visualization within Visual Studio Code, integrated with Tree-sitter parsing for real-time code analysis. The core graphics pipeline was established from scratch, validating that the WebGPU API can be used directly for executing shader programs, managing GPU buffers, and rendering visual output on a canvas. This establishes a functional foundation for further interactive and GPU-based graphical experimentation in the context of program visualization.

Challenges and Limitations

Key challenges included learning the WebGPU API structure, which differs significantly from earlier web graphics technologies. Browser support remains limited as WebGPU is still emerging, requiring specific configurations for testing. The current implementation performs only basic initialization and GPU variable setup, with rendering logic restricted to simple shader operations. No benchmark or comparative performance measurements were conducted at this stage due to the minimal scope of implementation.

Future Enhancements

Future development will expand the system into a more complete visualization framework capable of building interactive abstractions. Planned additions include an animated interface where code is visually represented as structured blocks, with zooming and panning interactions allowing users to navigate between high-level views and specific operations. A subsequent phase will introduce a no-code approach where projects can be constructed using drag-and-connect visual elements, enabling draw-your-code capabilities. The long-term direction is to provide a fully visual development platform for GPU-accelerated applications, lowering the learning barrier for graphics programming while maintaining integration with standard development workflows.

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REFERENCES

[1] P. J. Guo, "Online Python Tutor: Embeddable Web-Based Program Visualization for CS Education," Proceedings of the 44th ACM Technical Symposium on Computer Science Education, 2013.
[2] A. Moreno, N. Myller, E. Sutinen, and M. Ben-Ari, "Visualizing Programs with Jeliot 3," Proceedings of the Working Conference on Advanced Visual Interfaces, 2004.
[3] B. A. Price, R. M. Baecker, and I. S. Small, "A Taxonomy of Program Visualization Systems," ACM Journal of Educational Resources in Computing, 1993.
[4] M. Hediet, "VS Code Debug Visualizer Extension Documentation," GitHub Repository, 2020.
[5] "WebGPU Specification," W3C Draft Documentation.
[6] "WebGPU API: Technical Reference and Developer Guide," Mozilla Developer Network.
[7] Khronos Group, "WebGPU and Graphics Pipeline Reference Notes," Online Documentation.