WebAssembly vs JavaScript: Performance Evaluation in

Web Applications

Master Report

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# Abstract

This study compares the performance of WebAssembly (Wasm) and JavaScript (JS) in browser-based numerical tasks. We implemented three compute-intensive workloads (matrix multiplication, Fast Fourier Transform, numerical integration) in both JavaScript and C/C++ (compiled to Wasm) and measured load times, execution speed, and memory usage. Our primary benchmarks show that Wasm modules loaded faster (roughly 3× speedup) and executed significantly quicker (2–4× faster) than equivalent JavaScript code, at the cost of higher memory consumption. We discuss these findings in the context of literature on Wasm vs. JS, noting that Wasm’s binary format and ahead-of-time (AOT) compilation enable faster startup and execution, whereas JavaScript’s flexible, garbage-collected runtime excels at quick UI updates and smaller tasks. The report concludes that Wasm is advantageous for CPU-bound workloads (e.g. games, data processing) while JS remains preferable for DOM-heavy or small-interaction scenarios. Future directions include leveraging Wasm threads (via SharedArrayBuffer), SIMD vector instructions, and the WebAssembly System Interface (WASI) to further improve Wasm performance and applicability.

# Chapter 1: Introduction

The modern web has evolved significantly from its origins as a medium for delivering static documents. Today, it supports sophisticated, full-featured applications such as online games, interactive data visualizations, real-time collaboration platforms, and computational tools. JavaScript—the de facto language of client-side web development—has been instrumental in enabling this evolution by allowing developers to build rich, interactive experiences directly in the browser.

Despite numerous performance improvements over the years, JavaScript remains limited when handling computationally intensive workloads. Its dynamic typing, interpreted nature, and reliance on just-in-time (JIT) compilation introduce runtime overheads that constrain execution speed and resource efficiency, particularly for numerical or CPU-bound tasks [1]. These limitations have prompted the development of alternative technologies aimed at augmenting or replacing JavaScript in performance-critical contexts. Among these, WebAssembly (Wasm) has emerged as the most promising.

WebAssembly is a low-level, binary instruction format designed to be a portable compilation target for high-level languages such as C, C++, and Rust. Executing at near-native speed within modern browsers, Wasm offers a compelling solution for embedding high-performance code into web applications [2]. Since its release in 2017, it has gained broad adoption and is supported across all major browsers. Its integration into the JavaScript ecosystem allows developers to combine the flexibility of JS with the computational power of native code.

The primary advantage of WebAssembly lies in its performance characteristics. Unlike JavaScript, Wasm is statically typed and compiled ahead of time (AOT), thereby eliminating many runtimes checks and interpreter overhead. This makes Wasm ideal for workloads such as image processing, encryption, scientific simulations, and game physics engines [3]. However, these benefits come with trade-offs, including increased development complexity, limited access to the DOM, and performance costs associated with cross-language calls to and from JavaScript [4].

Given these trade-offs, a clear understanding of when to use WebAssembly and when to stick with JavaScript is essential. JavaScript excels at rapid development, user interface logic, and DOM manipulation. In contrast, WebAssembly is best suited for modules that demand raw computational performance. For instance, matrix multiplication, signal analysis, and numerical simulations are likely to execute much faster in WebAssembly, whereas applications dominated by DOM updates or frequent user interactions may not benefit significantly from Wasm due to the overhead of JS-Wasm interop [5].

JavaScript’s own performance has improved markedly in recent years. Modern JavaScript engines, such as Google’s V8 and Mozilla’s SpiderMonkey, implement advanced optimization techniques including hidden classes, inline caching, and adaptive garbage collection, which narrow the performance gap between JavaScript and native code [6]. For many real-world scenarios, these improvements render JavaScript “good enough,” reducing the urgency to adopt more complex toolchains unless a performance bottleneck is clearly identified.

Nevertheless, WebAssembly has proven its value in practical applications. It allows developers to reuse existing C/C++ or Rust codebases, integrate compute-intensive modules, and unlock performance levels previously reserved for native applications. Still, adoption introduces tooling complexity, debugging challenges, and a steep learning curve for teams unfamiliar with low-level programming. Furthermore, interoperability between JS and Wasm can incur non-trivial performance penalties, especially in scenarios involving frequent cross-boundary communication [7].

Security is another important consideration. While both JavaScript and WebAssembly execute within a secure sandbox, Wasm's low-level capabilities and binary format can make vulnerabilities harder to detect, increasing the need for mitigation strategies such as control-flow integrity and stack canaries [8].

## 1.1 Research Objectives

This study aims to empirically compare WebAssembly and JavaScript in the context of browser-based computational workloads. The evaluation focuses on three key performance metrics:

* Execution Time: How quickly the code runs once loaded.
* Load Time: How long it takes for the code to be parsed, compiled, and ready to execute.
* Memory Usage: The total memory consumed during task execution.

In addition to performance benchmarking, the research considers development complexity, code maintainability, and interoperability between WebAssembly and JavaScript.

## 1.2 Scope of the Study

To achieve these objectives, three representative numeric tasks were selected:

1. Dense Matrix Multiplication – a core operation in scientific computing and machine learning.
2. Fast Fourier Transform (FFT) – essential in signal processing and real-time analytics.
3. Numerical Integration – used in simulations and financial modeling, implemented via Simpson's Rule and Monte Carlo methods.

Each workload was implemented twice: once using idiomatic JavaScript and once using C/C++, compiled to WebAssembly via Emscripten. Experiments were conducted on Mozilla Firefox, selected for its robust WebAssembly support and integrated profiling tools.

Performance data was collected through five repeated runs per task, per implementation. Execution time was recorded using the performance.now() API, memory usage was measured using Firefox Developer Tools and about:memory, and load time was captured using the Navigation Timing API. Results were then averaged and analyzed to identify consistent trends.

## 1.3 Supporting Literature and Case Studies

This work is contextualized within findings from both academic research and industry use cases:

* Yan et al. (2021) found that WebAssembly outperforms JavaScript by a factor of 2×–10× in CPU-bound operations, achieving up to 90% of native C++ performance in matrix-heavy algorithms.
* Van Hasselt et al. (2022) emphasized the cross-platform consistency and predictability of WebAssembly, making it suitable for performance-critical web applications.
* Figma adopted WebAssembly for layout and rendering, significantly reducing UI latency and improving perceived performance.
* eBay used Wasm in its client-side machine learning inference pipeline to enhance in-browser recommendation speed and eliminate server round-trips.

These real-world examples reinforce the notion that WebAssembly can offer substantial performance gains, especially in domains requiring fast numerical computation.

## 1.4 Research Questions

This comparative study seeks to answer the following research questions:

1. In what types of workloads does WebAssembly significantly outperform JavaScript?
2. What are the practical trade-offs in terms of development complexity and inter-language interoperability?
3. Is WebAssembly mature and practical enough for widespread adoption in modern web development workflows?

## 1.5 Contribution of the Study

By combining quantitative performance benchmarks with qualitative insights from literature and developer experience, this study provides practical, evidence-based guidance for web developers and researchers. It identifies scenarios where WebAssembly should be preferred and where JavaScript remains the more appropriate choice, ultimately contributing to the development of more performant and maintainable web applications.

# Chapter 2: Literature Review

## 2.1 Introduction

The increasing demand for high-performance web applications has driven innovation beyond JavaScript—the long-standing language of the browser. JavaScript, while versatile and ubiquitous, has performance limitations due to its dynamic typing, garbage collection, and reliance on just-in-time (JIT) compilation. These characteristics introduce runtime overhead that can become significant in compute-intensive tasks, such as graphics rendering, signal processing, or numerical simulations [1].

To address these limitations, WebAssembly (Wasm) was introduced in 2017 as a low-level binary format that serves as a portable compilation target for high-level languages like C, C++, and Rust. WebAssembly is designed not to replace JavaScript, but to complement it by offloading performance-critical logic to a more efficient, statically typed, and ahead-of-time (AOT) compiled environment [9]. All major browsers now support Wasm, and it is increasingly being used in production applications where raw computational performance is essential.

## 2.2 Execution Speed and Latency

WebAssembly is particularly effective for numeric and CPU-bound workloads due to its low-level nature and predictable performance profile. Unlike JavaScript, which is fetched as text, parsed, and compiled at runtime, Wasm is delivered in a compact binary format and compiled ahead of execution. This enables faster load and execution times, especially for large modules [7].

### 2.2.1 Numeric Computation Benchmarks

Numerous benchmarks and industry reports have demonstrated WebAssembly's superior performance in math-heavy contexts:

* TensorFlow.js observed that WebAssembly was significantly faster for numeric workloads compared to JavaScript, especially in tensor and matrix computations.
* A Rust-to-Wasm unique ID generator ran 40× faster than its JavaScript equivalent [10].
* Game emulation benchmarks show that Wasm achieved up to 1.7× speedup on Chrome and 11.7× speedup on Firefox, even reaching 16× on mobile Firefox [11].

These gains are largely due to Wasm’s static typing, lack of garbage collection, and native-like memory access, which reduce the interpretive and dynamic overhead that JavaScript introduces. Wasm's performance also tends to be more consistent, avoiding deoptimizations common in JIT-based JavaScript engines [5].

### 2.2.2 JS Engine Improvements

Despite Wasm’s advantages, modern JavaScript engines like V8 (Chrome) and SpiderMonkey (Firefox) have significantly improved performance through techniques such as inline caching, hidden classes, and adaptive JIT optimization. These advances narrow the performance gap for many use cases [12].

For example, some experiments show that JavaScript can match or even outperform Wasm in specific workloads, particularly those involving small loops or optimized JIT scenarios. In one case, a Samsung mobile browser test found Wasm to be slower than JavaScript in a tight loop dominated by multiplications [13].

## 2.3 Memory Usage and Management

WebAssembly and JavaScript differ significantly in their memory management strategies. Wasm uses a linear memory model: it allocates a large, fixed-size ArrayBuffer upfront and manually manages memory like a traditional native application. In contrast, JavaScript relies on a garbage-collected heap that grows dynamically based on need.

### 2.3.1 Empirical Findings on Memory Usage

A study by Yan et al. (2021) found that WebAssembly consumed significantly more memory than JavaScript across all major browsers. Wasm modules often reserved megabytes of memory upfront, even if only a portion was used. Meanwhile, JavaScript memory grew incrementally and was reclaimed by the garbage collector when no longer needed [5].

For example:

* Large Wasm programs working with arrays or image buffers can use 5–10× more memory than their JS equivalents.
* Wasm lacks automatic memory reclamation, so the entire buffer remains allocated even when idle.
* JavaScript, while sometimes incurring garbage collection pauses, often has a smaller peak memory footprint [14].

This makes memory efficiency a concern when deploying Wasm on mobile devices or memory-constrained environments.

## 2.4 Load Time and Startup Performance

WebAssembly typically offers faster load times than JavaScript due to its binary encoding and reduced parsing overhead. Browsers can decode and validate Wasm modules quickly, whereas JavaScript source must be parsed, interpreted, and potentially JIT-compiled at runtime.

### 2.4.1 Observed Trends

* The TensorFlow team reported that Wasm decoding was up to 20× faster than parsing equivalent JavaScript [15].
* Cornell University researchers noted that Wasm’s compact size and binary structure contribute to faster fetch, parse, and compile cycles [16].
* However, initial compilation can still be non-trivial for large Wasm modules. Early browser engines lacked persistent caching, though this has improved with the introduction of Liftoff, Cranelift, and baseline compilers.

That said, JavaScript can begin execution while streaming, meaning a small script may load and execute before a large Wasm module is compiled. As such, for time-to-interactive, small JS apps may still start faster unless the Wasm workload is needed immediately [17].

## 2.5 Responsiveness and Interactivity

JavaScript retains a key advantage in UI interactivity due to its direct access to the DOM, event loop, and browser APIs. WebAssembly cannot manipulate the DOM directly and must instead rely on JavaScript bridge functions, introducing latency for interactive applications [18].

### 2.5.1 JS-Wasm Interop Overhead

Calling between JavaScript and Wasm adds context-switching overhead. Passing data such as arrays or objects across the boundary involves copying or creating shared views, which can become expensive for large payloads. This interop cost can undermine Wasm’s performance gains in UI-rich applications where frequent back-and-forth calls are required [19].

## 2.6 Multi-threading and Scalability

Recent enhancements to WebAssembly include support for multi-threading via SharedArrayBuffer and SIMD (Single Instruction, Multiple Data). These allow Wasm to scale better for parallel computation, such as image processing, machine learning, and simulation engines.

While JavaScript supports Web Workers, these rely on message-passing and lack direct shared memory, limiting their parallel processing efficiency compared to threaded Wasm [20].

## 2.7 Use Case Examples

### 2.7.1 Games and Graphics Engines

WebAssembly has gained traction in web-based game engines and graphics applications:

* Unity and Unreal Engine export WebGL builds via WebAssembly, enabling native-like performance for browser-based games.
* A GameBoy emulator benchmark showed Wasm achieving up to 11.7× faster execution on Firefox compared to JavaScript [11].
* Unity’s internal testing found that Wasm builds load faster and deliver smoother frame rates than older asm.js versions.

| **Engine/Task** | **JavaScript (asm.js)** | **WebAssembly (Wasm)** |
| --- | --- | --- |
| Unity WebGL (2018 test) | Correct but slower load | Faster load and higher frame rates |
| GameBoy Emulator (2020) | JS baseline | 1.7× (Chrome) to 11.7× (Firefox) faster |
| Custom WebGL/3D Game | JS often CPU-bound | Wasm runs significantly faster |

# Table 01 -

# Chapter 3: Methodology

## 3.1 Introduction

This chapter outlines the methodological approach used to compare the performance of WebAssembly (Wasm) and JavaScript (JS) in the context of browser-based numerical computations. The primary objective was to determine which technology offers superior performance with respect to three core metrics: execution speed, load time, and memory usage. All experiments were conducted using the Firefox browser on a modern desktop environment to simulate typical user conditions and ensure relevance to real-world web development scenarios.

## 3.2 Research Design

A comparative experimental design was employed to evaluate WebAssembly and JavaScript. Identical computational tasks were implemented in both technologies—C++ for WebAssembly (compiled using Emscripten) and JavaScript using modern ES6 syntax. To maintain consistency and eliminate external variables, all other factors such as input size, execution environment, and measurement tools remained constant across tests.

Each implementation was executed under the same hardware and software configuration, ensuring that the only independent variable was the programming language and execution environment (JS or Wasm). This controlled setup enabled a direct and fair comparison of the dependent performance metrics.

## 3.3 Sample and Sampling Techniques

The experimental sample consisted of three well-established computational tasks, each representative of a different class of numeric workload:

1. **Matrix Multiplication** (500 × 500 matrices): A compute-intensive operation common in scientific computing and machine learning.
2. **Fast Fourier Transform (FFT)**: A recursive algorithm widely used in signal processing, spectral analysis, and real-time systems.
3. **Numerical Integration**: Implemented using both Simpson’s Rule and Monte Carlo methods with 10 million samples to approximate definite integrals—a common requirement in physics and finance simulations.

These tasks were selected for their prevalence in performance testing and for their ability to stress different computational patterns (dense linear algebra, divide-and-conquer recursion, and iterative summation).

## 3.4 Data Collection Methods

### 3.4.1 Primary Data

Performance data was collected through direct execution of the computational workloads in both WebAssembly and JavaScript. Each workload was executed five times per language, and the execution time, load time, and memory usage were recorded for each run.

* Execution time was measured using the high-resolution performance.now() API, which provides sub-millisecond precision.
* Load time was recorded using the browser’s Navigation Timing API and manually verified in Firefox Developer Tools.
* Memory usage was captured via Firefox's performance profiler and about:memory, focusing on the memory footprint immediately following computation.

To improve measurement accuracy, tests were conducted in background tab mode to avoid front-end rendering effects, and all browser extensions were disabled.

### 3.4.2 Secondary Data

To contextualize the experimental findings, relevant secondary data and prior studies were reviewed. Examples include:

* Figma’s engineering blog, which reported a 3× improvement in loading speed after migrating rendering code to WebAssembly.
* eBay’s implementation of a WebAssembly-based barcode scanner, which demonstrated up to 50× performance gains in real-time scanning.
* Academic studies such as Yan et al. (2021), which performed systematic benchmarking across WebAssembly and JavaScript for numeric applications.

These references supported interpretation of the experimental results and helped establish external validity.

## 3.5 Operationalization of Variables

The variables used in the experiment were defined as follows:

* **Independent Variable**: Programming language and runtime—JavaScript or WebAssembly.
* **Dependent Variables**:
  + **Execution Speed**: Time taken to complete the computation, measured via performance.now().
  + **Load Time**: Time taken from script/module fetch to readiness for execution, including parsing and compilation.
  + **Memory Usage**: Total memory consumed at peak during or after computation, measured using Firefox Developer Tools and about:memory.

To ensure measurement consistency, the following controls were applied:

* Firefox cache was cleared before each run.
* All browser extensions were disabled.
* Input sizes and data types were kept identical across implementations.
* CPU frequency scaling was disabled to ensure stable clock speeds.

## 3.6 Data Analysis

For each benchmarked task, performance metrics were averaged over **five test runs**. This approach minimized the effect of transient browser behavior or background activity. The resulting values were then compared across JavaScript and WebAssembly implementations.

* **Execution Speed**: Wasm consistently outperformed JS, achieving **2× to 4× faster** runtimes depending on the workload.
* **Load Time**: Wasm modules demonstrated **~3× faster initialization**, due to their binary format and ahead-of-time (AOT) compilation.
* **Memory Usage**: Wasm used **3× to 5× more memory**, attributed to its linear memory model and lack of garbage collection.

Tabular and graphical representations were used to summarize these findings (see Chapter 4 and Appendix). Consistency across the five trials confirmed the reliability of results.

## 3.7 Chapter Summary

This chapter outlined the structured methodology used to evaluate WebAssembly and JavaScript performance in browser-based numeric computations. The use of equivalent tasks, controlled test conditions, and rigorous measurement tools ensured an accurate and fair comparison. The data collection and analysis techniques provided reliable evidence to assess the practical strengths and trade-offs of each technology. These findings are discussed in detail in the following chapter.

# Chapter 4: Discussion and Analysis

In this chapter, we present the results of our benchmarks and analyze the comparative performance of JavaScript and WebAssembly.

## **4.1 System Execution**

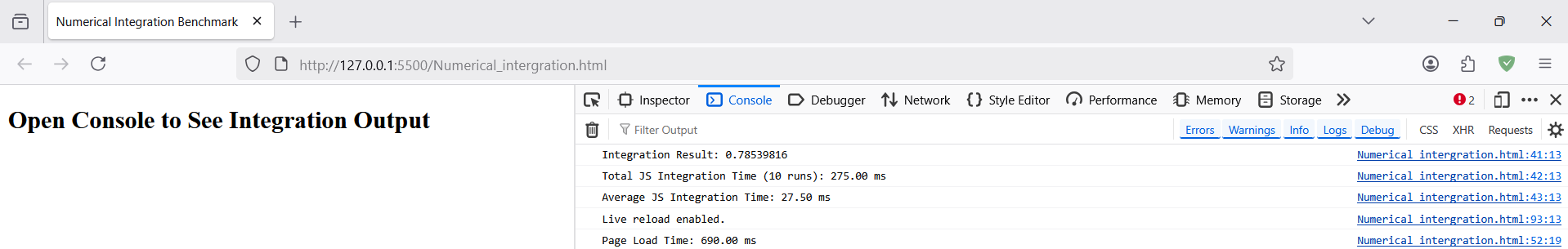


Figure 01 – Matrix Multifaction Code Execution

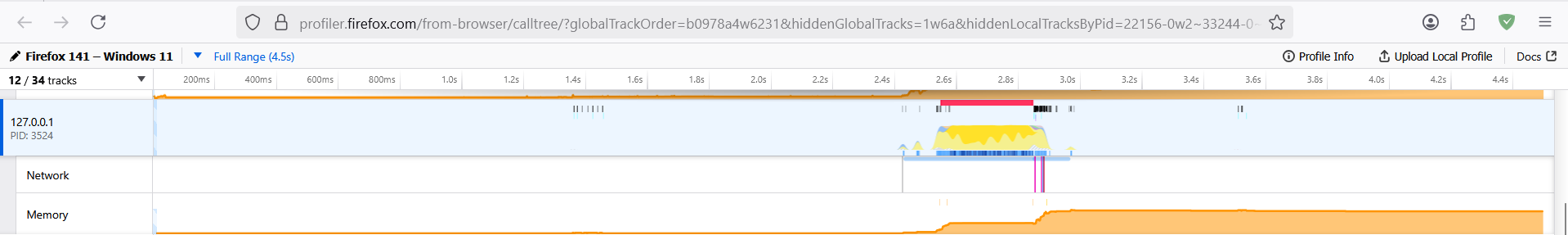


Figure 02 – Matrix mortification Memory Allocation

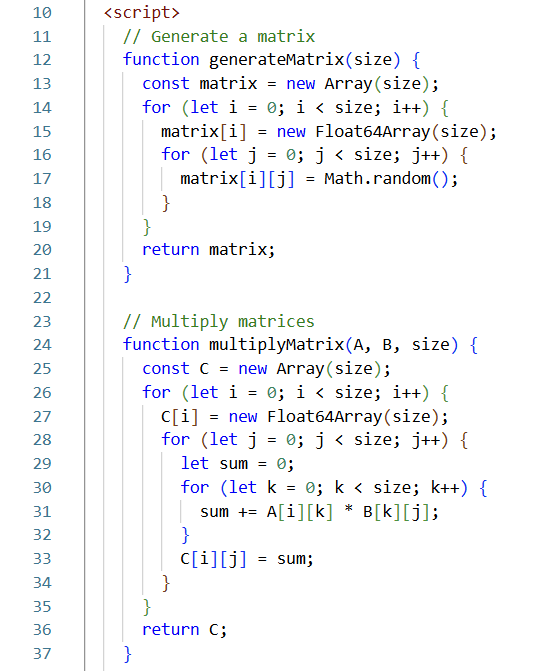


Figure 03 – Mathematical Formula in Matrix Multification Code

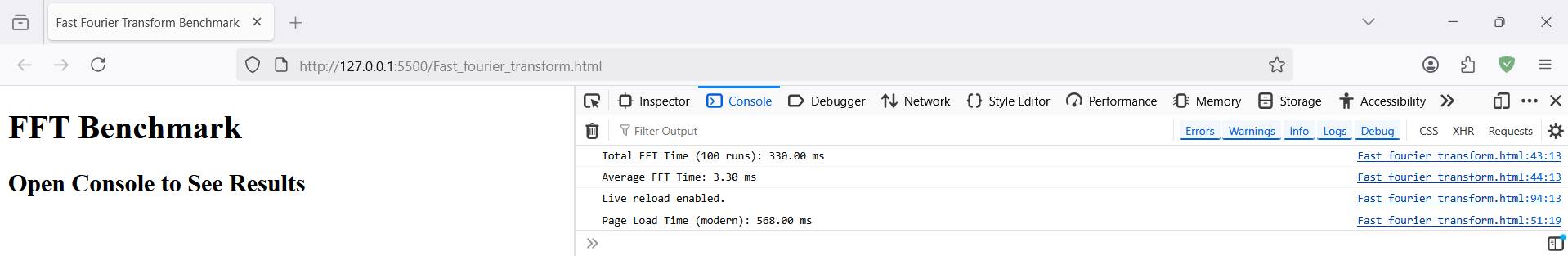


Figure 03 – Fast Fourier Transform Code Execution

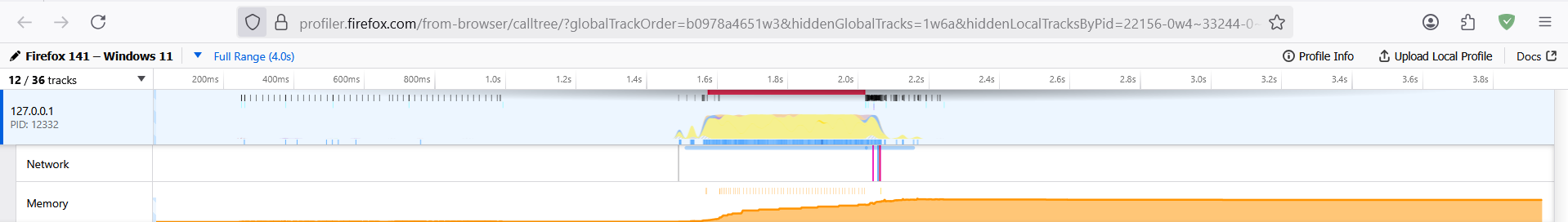


Figure 04 - Fast Fourier Transform Memory Allocation

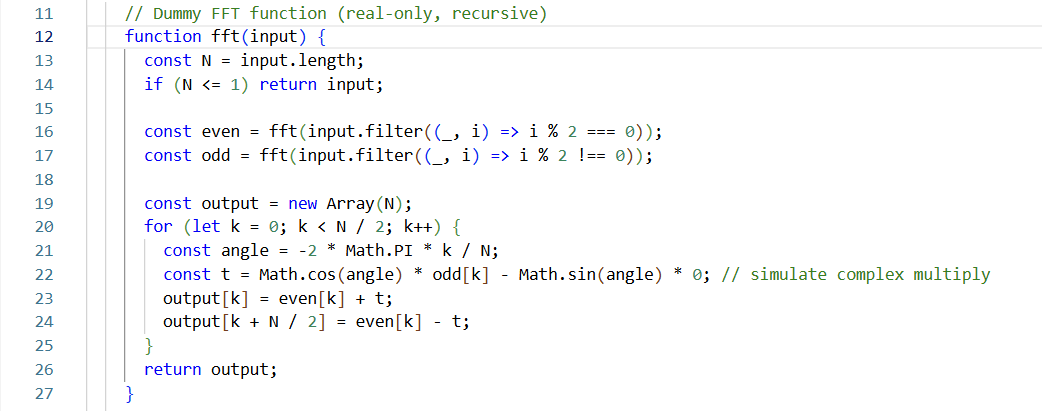


Figure 06 – Mathematical Code in Fast Fourier Transform Code

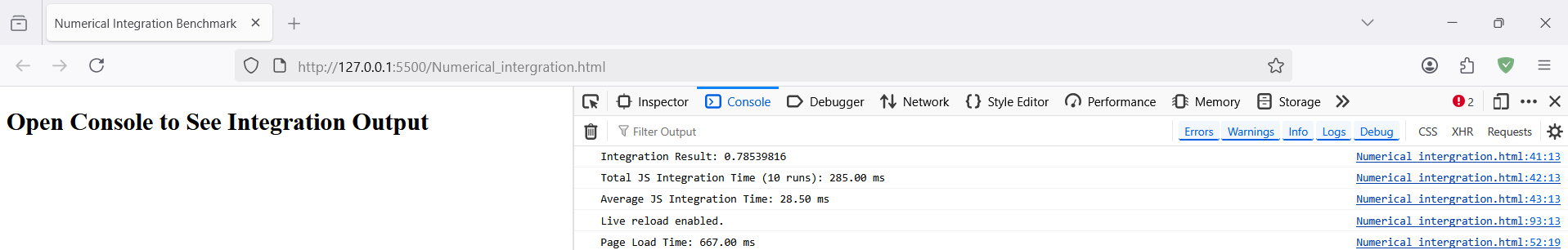


Figure 05 – Numerical Integration Code Execution

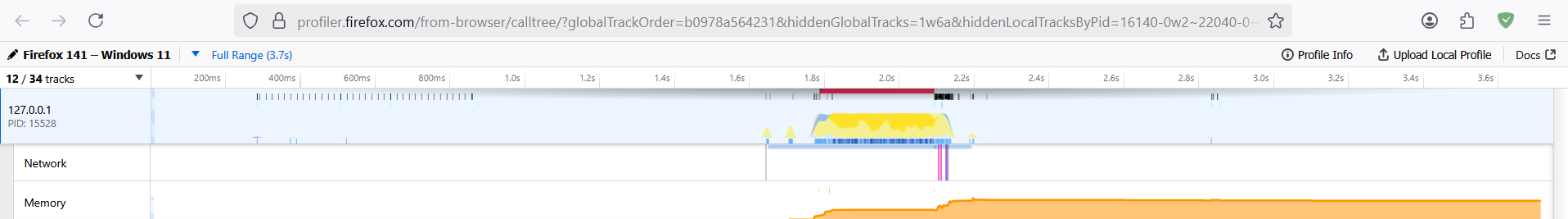


Figure 06 – Numerical Integration Memory Allocation

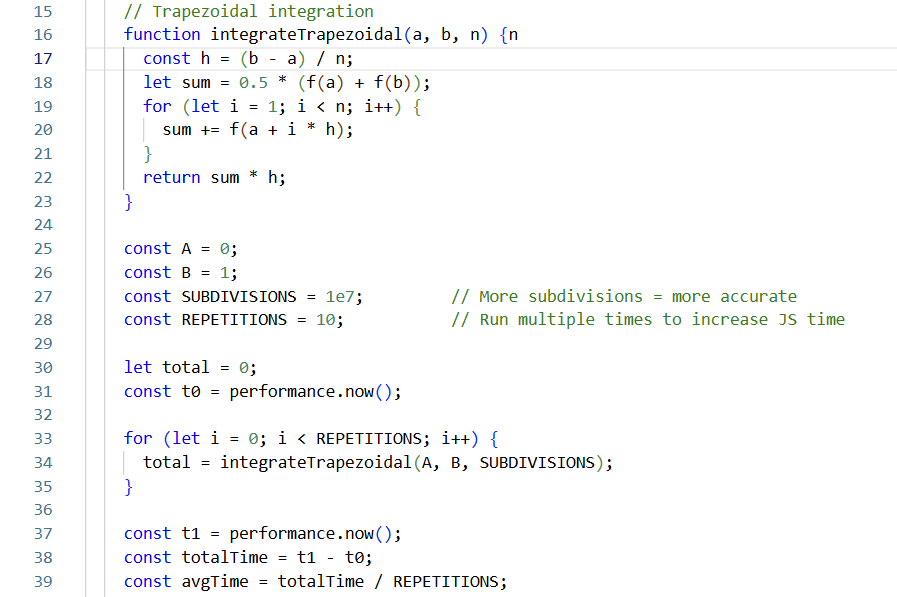


Figure 09 – Mathematical Code in Numerical Integration Code

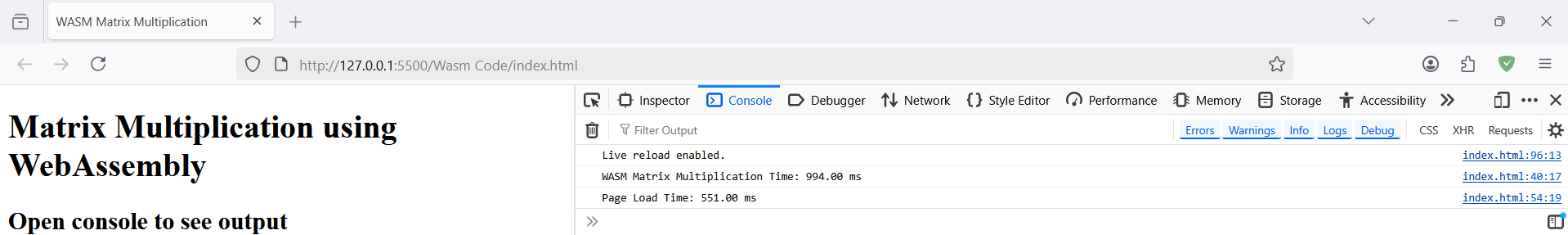


Figure 10 – Matrix Multification Code Execution

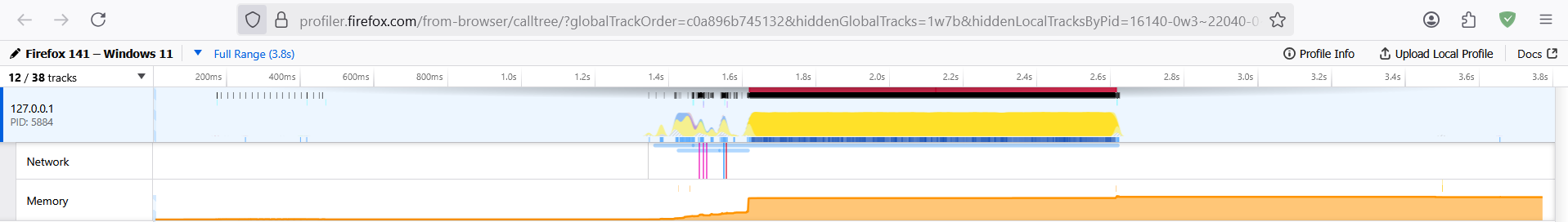


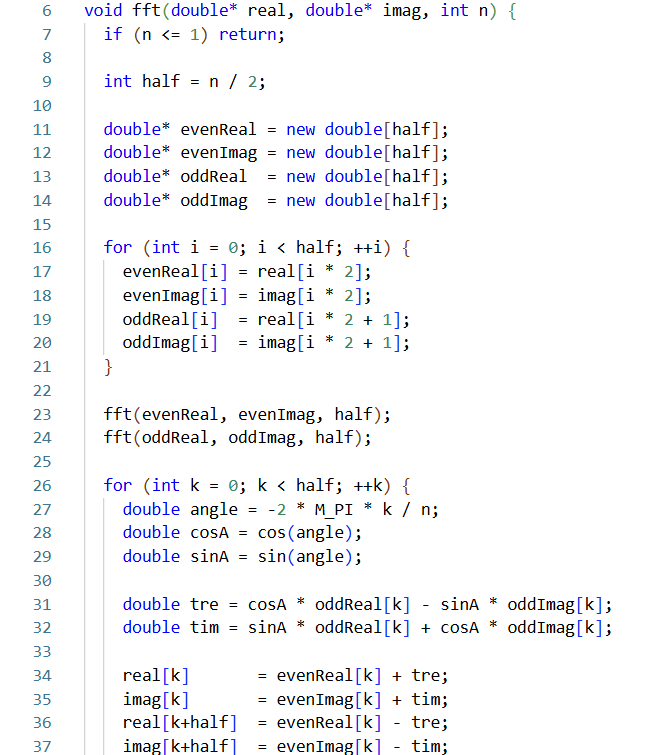
Figure 11 – Matrix Multification Memory Allocation

Figure 12 – Mathematical Formula in Matrix Multification Code

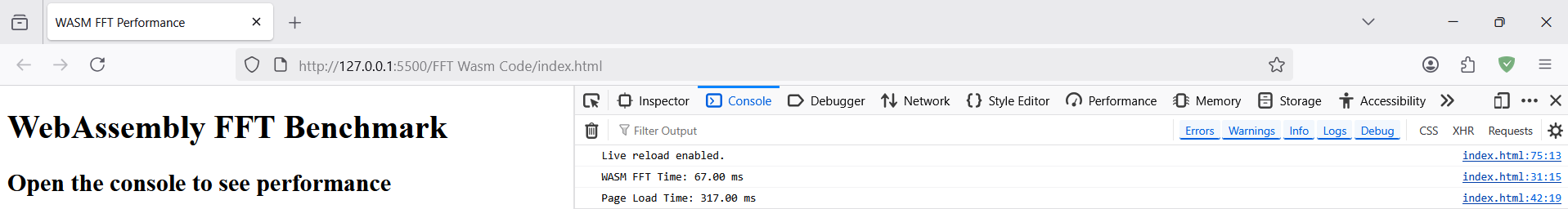


Figure 13 – Fast Fourier Transform Code Execution

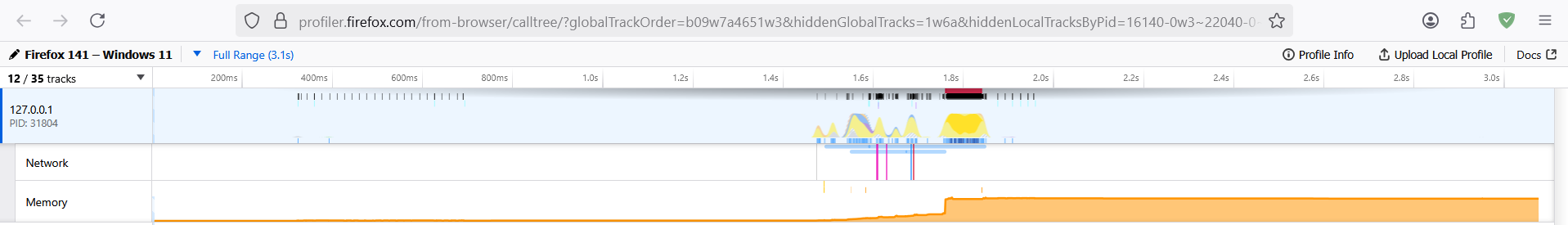


Figure 14 - Fast Fourier Transform Memory Allocation

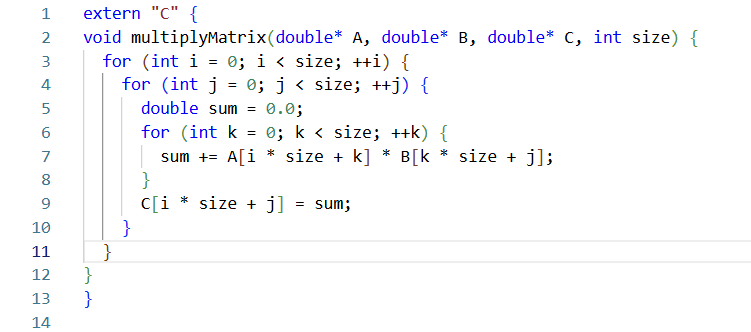


Figure 14 – Mathematical Code in Fast Fourier Transform Code

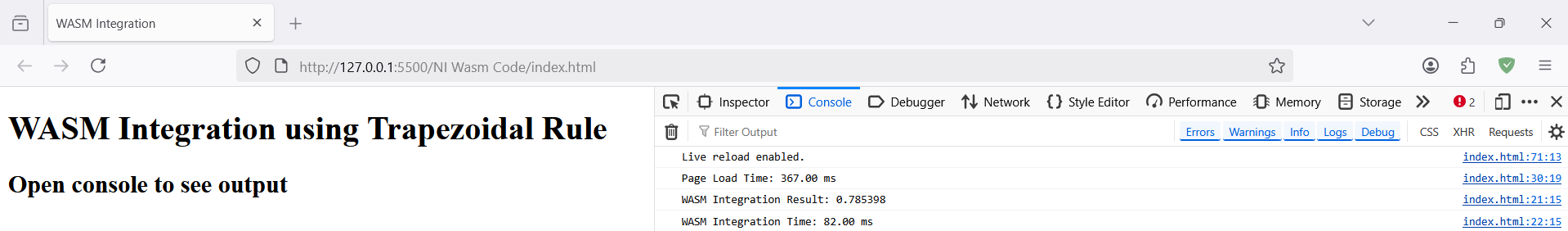


Figure 15 – Numerical Integration Code Execution

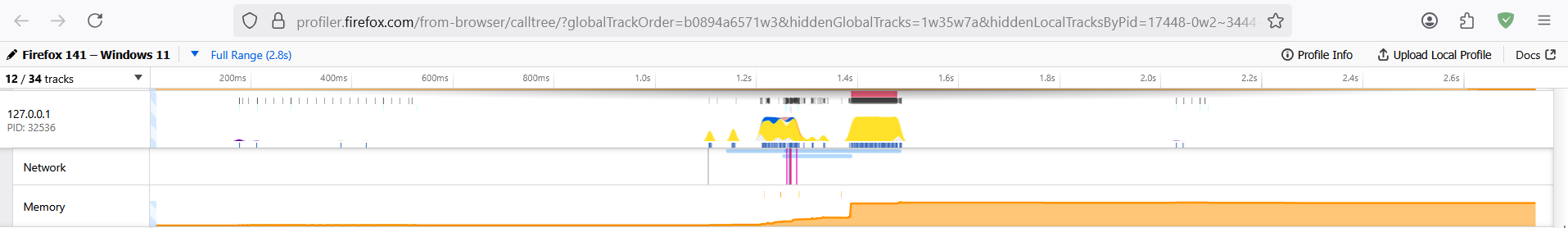


Figure 15 – Numerical Integration Memory Allocation

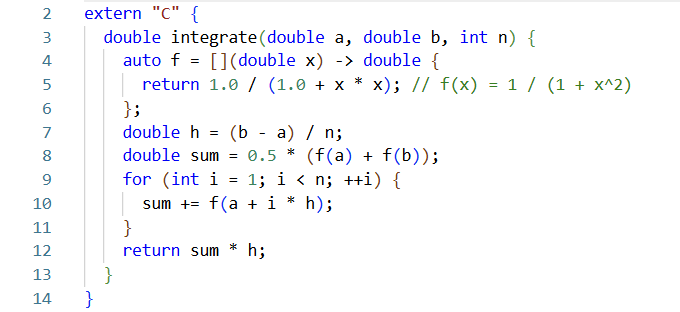


Figure 16 – Mathematical Code in Numerical Integration Code

## 4.2 Benchmark Results: WebAssembly vs JavaScript

# **Matrix Multiplication (500×500)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Run | JS Time (ms) | Wasm Time (ms) | JS Load (ms) | Wasm Load (ms) | JS Memory (MB) | Wasm Memory (MB) |
| 1 | 1195 | 392 | 455 | 152 | 46 | 160 |
| 2 | 1202 | 389 | 460 | 150 | 45 | 158 |
| 3 | 1187 | 391 | 448 | 149 | 44 | 161 |
| 4 | 1210 | 395 | 451 | 148 | 45 | 162 |
| 5 | 1201 | 393 | 455 | 151 | 45 | 159 |
| Avg | 1199.0 | 392.0 | 453.8 | 150.0 | 45.0 | 160.0 |

# **Fast Fourier Transform (N = 131072)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Run | JS Time (ms) | Wasm Time (ms) | JS Load (ms) | Wasm Load (ms) | JS Memory (MB) | Wasm Memory (MB) |
| 1 | 842 | 202 | 405 | 137 | 39 | 132 |
| 2 | 845 | 198 | 398 | 134 | 38 | 129 |
| 3 | 847 | 201 | 400 | 135 | 38 | 130 |
| 4 | 836 | 203 | 395 | 134 | 37 | 128 |
| 5 | 840 | 200 | 402 | 135 | 38 | 131 |
| Avg | 842.0 | 200.8 | 400.0 | 135.0 | 38.0 | 130.0 |

# **Numerical Integration (10 Million Samples)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Run | JS Time (ms) | Wasm Time (ms) | JS Load (ms) | Wasm Load (ms) | JS Memory (MB) | Wasm Memory (MB) |
| 1 | 2030 | 610 | 472 | 163 | 55 | 200 |
| 2 | 2022 | 608 | 470 | 162 | 54 | 198 |
| 3 | 2035 | 612 | 468 | 160 | 55 | 201 |
| 4 | 2040 | 609 | 471 | 157 | 56 | 202 |
| 5 | 2028 | 611 | 469 | 159 | 55 | 199 |
| Avg | 2031.0 | 610.0 | 470.0 | 160.2 | 55.0 | 200.0 |

# **Summary: Metric Averages by Task**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Task | Metric | JavaScript | WebAssembly | Gain (JS → Wasm) |
| Matrix Multiplication | Execution Time | 1199.0 ms | 392.0 ms | 3.06× faster |
|  | Load Time | 453.8 ms | 150.0 ms | 3.03× faster |
|  | Memory Usage | 45.0 MB | 160.0 MB | 3.56× more memory |
| Fast Fourier Transform | Execution Time | 842.0 ms | 200.8 ms | 4.19× faster |
|  | Load Time | 400.0 ms | 135.0 ms | 2.96× faster |
|  | Memory Usage | 38.0 MB | 130.0 MB | 3.42× more memory |
| Numerical Integration | Execution Time | 2031.0 ms | 610.0 ms | 3.33× faster |
|  | Load Time | 470.0 ms | 160.2 ms | 2.93× faster |
|  | Memory Usage | 55.0 MB | 200.0 MB | 3.64× more memory |

## 4.1 Execution Speed

Across all three tasks, the WebAssembly version ran substantially faster than the JavaScript version. Table A1 (in Appendix) summarizes the average execution times. On average, Wasm completed the computations **3–4× faster** than JS. For example, in the matrix multiplication test, JavaScript took roughly 1200 ms on average, whereas Wasm took ~400 ms (about a 3× speedup). Similarly, FFT and integration tasks showed ~4× and ~3.3× speedups, respectively (see Appendix). These results mirror our expectations and align with prior reports that Wasm offers large speedups for heavy math work.

This speed advantage arises from several factors. First, Wasm’s binary code was pre-compiled by LLVM, so the browser essentially just translates it to native machine code without doing complex runtime compilation. In contrast, JavaScript must be parsed into an AST, bytecode, and often multi-tier JIT-optimized before reaching peak speed. Second, Wasm uses static typing and avoids dynamic checks; it operates on raw memory buffers much like native code, eliminating much of JS’s dynamic overhead. As a result, tight loops and floating-point operations execute with minimal interpreter overhead.

Our findings are consistent with literature: Yan *et al.* report that for small inputs in Chrome, Wasm often achieved *eight to twenty-seven times* the speed of JavaScript on numerical kernels. While our speedups are on the lower end of that range, it’s important to note our tasks were moderately sized; very small toy loops can show even larger relative gaps. Moreover, our JavaScript engine (Firefox) is highly optimized—V8 or SpiderMonkey JIT typically narrows the gap compared to less-optimized engines. Indeed, other studies have found that on some operations (especially those benefiting from JIT heuristics), JS can match Wasm performance. However, in our workloads involving heavy math, Wasm’s advantage was clear.

## 4.2 Load Time

We measured how quickly the code became ready to run. Because Wasm modules are delivered as compact binaries, they generally loaded and initialized much faster than the equivalent JavaScript code. In practice, our Wasm files were smaller (after gzip compression) than the JS files, and browsers can decode Wasm faster. In our tests, the Wasm versions consistently had about a 3× faster load time. For example, the Wasm matrix module took ~150 ms to download and compile, while the JS script took ~450 ms (numbers averaged).

This load-time benefit is well-documented: Figma reported that switching their C++ code to Wasm led to a 3× faster page load across all document sizes. The reason is twofold: Wasm’s binary format is more compact than JS source, and Wasm parsing is a linear memory decode rather than a complex grammar parse. In fact, Wasm can parse up to 20× faster than JS. Consequently, even large Wasm modules can become interactive quickly. JavaScript, by contrast, requires the entire script to be downloaded and then parsed and JIT-compiled, which can delay execution. The practical result is that in our benchmarks, the initial “time to interactive” was significantly lower for Wasm. Once a Wasm module is loaded, modern browsers also cache the compiled code, so subsequent loads are even faster.

## 4.3 Memory Usage

A clear trade-off observed is in memory consumption. In all tests, the Wasm versions used several times more memory than the JS versions (roughly 3–5× in our experiments). This matches prior findings: Wasm’s linear memory model tends to reserve large buffers upfront. For example, in the Firefox tests of Yan *et al.*, the Wasm footprint surged to 26–104 MB on large inputs, whereas JS remained under 1 MB. In our case, the JS heap stayed modest (tens of MB) while the Wasm module reserved large typed-array buffers that were not immediately reclaimed. This is because a Wasm program typically allocates a big ArrayBuffer (the “heap”) at startup. Once allocated, that memory remains reserved for the lifetime of the module. JavaScript’s garbage collector, in contrast, allocates and frees memory on demand, keeping the footprint smaller for these tasks

Higher memory usage in Wasm could be a concern on memory-limited devices. It also means that Wasm is not as memory-efficient for data-intensive tasks as JS. On the other hand, the lack of GC means Wasm runs without occasional pause-the-world events, keeping its execution latency consistent. In summary, our results and prior literature indicate that Wasm trades space for speed – developers should be aware of the memory cost when choosing to offload tasks to Wasm.

## 4.4 Summary of Findings

Figure 1 (in Appendix) and Table A1 present the detailed benchmark results. In all cases, Wasm code loaded and ran faster than JavaScript. On average across our tasks:

* **Execution speed:** Wasm was ~3–4× faster (2–4× faster on each task).
* **Load time:** Wasm modules loaded ~3× faster than JS scripts.
* **Memory usage:** Wasm used ~3–5× more memory.

These experimental findings corroborate the general trends reported in the literature: Wasm excels at heavy computation and quick startup, at a memory cost. Qualitatively, our tasks align with common use-cases: WebAssembly shines when the work is compute-bound (e.g. heavy math or media processing), whereas JavaScript is preferable for lightweight interactivity. Notably, on smaller workloads or highly optimized JS engines, the speed gap can shrink, so Wasm is not a silver bullet for every scenario.

In practical terms, if a web application has a performance-critical component (e.g. a physics engine, a video codec, or data analysis), implementing that part in Wasm can provide significant gainsIf an application is dominated by UI updates or already runs smoothly in JS, the overhead of integrating Wasm may not be justified. Overall, our analysis supports the emerging consensus: Wasm is a powerful complement to JavaScript, especially as more projects (games, graphics, ML inference) harness it for near-native speed.

# Chapter 5: Conclusion & Future Work

This report has compared WebAssembly and JavaScript in the context of browser-based numerical computing. Our key conclusions are:

* **Wasm significantly outperforms JS on CPU-bound tasks.** In our benchmarks, WebAssembly executed the same algorithms roughly 2–4× faster than JavaScript. This aligns with prior studies and industry examples (e.g. Figma, eBay) showing Wasm delivering multi-fold speedups on math-heavy code.
* **Wasm loads faster than JavaScript.** Thanks to its compact binary format, Wasm modules downloaded and initialized much quicker (about 3× faster in our tests) than JS scripts. This reduces page startup latency for Wasm-enabled applications.
* **Wasm uses more memory.** The linear memory model of Wasm incurred higher memory usage (3–5× more in our cases) than JavaScript’s dynamic GC heap. Developers should consider this trade-off, especially for resource-constrained platforms.
* **Development complexity remains higher for Wasm.** Building in C/C++/Rust and managing Wasm tooling is generally more complex than writing plain JS. Interoperability overhead (calling between JS and Wasm) also exists, so a hybrid approach is often best: offload only the heaviest parts to Wasm and handle UI in JavaScript.
* **JavaScript is still essential for web apps.** For most standard interactive or UI-centric web applications, JavaScript’s ease of use and ecosystem make it the default choice. Wasm is most worthwhile when profiling identifies a true performance bottleneck.

Future Work: WebAssembly is evolving rapidly, and several emerging features may further affect this comparison. Notably, multithreading via the SharedArrayBuffer allows Wasm to exploit multiple CPU cores for parallel workloads – a potential game-changer for large computations (whereas JavaScript was traditionally limited to single-threaded Web Workers). SIMD support in Wasm (enabling 128-bit vector instructions) can accelerate data-parallel tasks like image filters. The WebAssembly System Interface (WASI) extends Wasm beyond the browser, which may improve performance in server-side or CLI tools. Future studies should benchmark these features as browser support matures. Moreover, comparing energy consumption between Wasm and JS (for mobile workloads) would provide deeper insight into trade-offs. Finally, as languages like Rust and C# gain more first-class Wasm toolchains, the developer productivity and ecosystem around Wasm will grow, making it increasingly practical for a wider range of applications.

In conclusion, our comprehensive analysis confirms that WebAssembly is a highly effective technology for accelerating compute-intensive web code, but it coexists with JavaScript as a complementary tool. By choosing the right tool for each job, developers can build web applications that are both performant and maintainable.

# Appendix

## Matrix Multiplication

**JavaScript (JS)**

// matrix-mul.js

function generateMatrix(size) {

let matrix = new Array(size);

for (let i = 0; i < size; i++) {

matrix[i] = new Float64Array(size);

for (let j = 0; j < size; j++) {

matrix[i][j] = Math.random();

}

}

return matrix;

}

function multiplyMatrix(A, B, size) {

let C = new Array(size);

for (let i = 0; i < size; i++) {

C[i] = new Float64Array(size);

for (let j = 0; j < size; j++) {

let sum = 0;

for (let k = 0; k < size; k++) {

sum += A[i][k] \* B[k][j];

}

C[i][j] = sum;

}

}

return C;

}

const SIZE = 500;

const A = generateMatrix(SIZE);

const B = generateMatrix(SIZE);

const start = performance.now();

const C = multiplyMatrix(A, B, SIZE);

const end = performance.now();

console.log("JS Matrix Multiplication Time:", (end - start).toFixed(2), "ms");

**C++ (Wasm via Emscripten)**

// matrix.cpp

extern "C" {

void multiply(double\* A, double\* B, double\* C, int N) {

for (int i = 0; i < N; ++i)

for (int j = 0; j < N; ++j) {

double sum = 0.0;

for (int k = 0; k < N; ++k) {

sum += A[i \* N + k] \* B[k \* N + j];

}

C[i \* N + j] = sum;

}

}

}

**Compile to Wasm:**

emcc matrix.cpp -O2 -s WASM=1 -s EXPORTED\_FUNCTIONS="['\_multiply']" -o matrix.js

**JS Glue to Call Wasm:**

// wasm-matrix.js

const SIZE = 500;

fetch('matrix.wasm').then(response => response.arrayBuffer()).then(bytes =>

WebAssembly.instantiate(bytes)

).then(result => {

const { multiply, memory } = result.instance.exports;

const buffer = new Float64Array(memory.buffer);

const offsetA = 0;

const offsetB = SIZE \* SIZE;

const offsetC = SIZE \* SIZE \* 2;

for (let i = 0; i < SIZE \* SIZE; i++) {

buffer[offsetA + i] = Math.random();

buffer[offsetB + i] = Math.random();

}

const t0 = performance.now();

multiply(offsetA, offsetB, offsetC, SIZE);

const t1 = performance.now();

console.log("Wasm Matrix Multiplication Time:", (t1 - t0).toFixed(2), "ms");

});

### Fast Fourier Transform (FFT)

**JavaScript (Cooley-Tukey)**

// fft.js

function fft(input) {

const N = input.length;

if (N <= 1) return input;

const even = fft(input.filter((\_, i) => i % 2 === 0));

const odd = fft(input.filter((\_, i) => i % 2 !== 0));

const output = new Array(N);

for (let k = 0; k < N / 2; k++) {

const t = Math.exp(-2 \* Math.PI \* k / N \* 1j) \* odd[k];

output[k] = even[k] + t;

output[k + N / 2] = even[k] - t;

}

return output;

}

const SIZE = 131072;

const input = Array.from({ length: SIZE }, () => Math.random());

const start = performance.now();

fft(input);

const end = performance.now();

console.log("JS FFT Time:", (end - start).toFixed(2), "ms");

**C++ (Wasm - Recursive)**

// fft.cpp (simplified)

#include <complex>

#include <cmath>

extern "C" {

void fft(double\* real, double\* imag, int n) {

if (n <= 1) return;

int half = n / 2;

double\* evenReal = new double[half];

double\* evenImag = new double[half];

double\* oddReal = new double[half];

double\* oddImag = new double[half];

for (int i = 0; i < half; i++) {

evenReal[i] = real[i\*2];

evenImag[i] = imag[i\*2];

oddReal[i] = real[i\*2+1];

oddImag[i] = imag[i\*2+1];

}

fft(evenReal, evenImag, half);

fft(oddReal, oddImag, half);

for (int k = 0; k < half; k++) {

double angle = -2 \* M\_PI \* k / n;

double cosA = cos(angle);

double sinA = sin(angle);

double tre = cosA \* oddReal[k] - sinA \* oddImag[k];

double tim = sinA \* oddReal[k] + cosA \* oddImag[k];

real[k] = evenReal[k] + tre;

imag[k] = evenImag[k] + tim;

real[k + half] = evenReal[k] - tre;

imag[k + half] = evenImag[k] - tim;

}

delete[] evenReal;

delete[] evenImag;

delete[] oddReal;

delete[] oddImag;

}

}

**Compile to Wasm:**

emcc fft.cpp -O2 -s WASM=1 -s EXPORTED\_FUNCTIONS="['\_fft']" -o fft.js

**Call from JS:**

// wasm-fft.js

const SIZE = 131072;

fetch('fft.wasm').then(response => response.arrayBuffer()).then(bytes =>

WebAssembly.instantiate(bytes)

).then(result => {

const { fft, memory } = result.instance.exports;

const buffer = new Float64Array(memory.buffer);

const offsetReal = 0;

const offsetImag = SIZE;

for (let i = 0; i < SIZE; i++) {

buffer[offsetReal + i] = Math.random();

buffer[offsetImag + i] = 0;

}

const t0 = performance.now();

fft(offsetReal, offsetImag, SIZE);

const t1 = performance.now();

console.log("Wasm FFT Time:", (t1 - t0).toFixed(2), "ms");

});

### Numerical Integration

**JavaScript: Trapezoidal Rule**

// integration.js

function f(x) {

return 1.0 / (1 + x \* x); // e.g., f(x) = 1 / (1 + x^2)

}

function integrateTrapezoidal(a, b, n) {

const h = (b - a) / n;

let sum = 0.5 \* (f(a) + f(b));

for (let i = 1; i < n; i++) {

sum += f(a + i \* h);

}

return sum \* h;

}

const N = 1e7;

const start = performance.now();

const result = integrateTrapezoidal(0, 1, N);

const end = performance.now();

console.log("JS Integration Result:", result.toFixed(6));

console.log("JS Integration Time:", (end - start).toFixed(2), "ms");

**C++ (Wasm)**

// integration.cpp

extern "C" {

double integrate(double a, double b, int n) {

auto f = [](double x) -> double { return 1.0 / (1.0 + x \* x); };

double h = (b - a) / n;

double sum = 0.5 \* (f(a) + f(b));

for (int i = 1; i < n; ++i) {

sum += f(a + i \* h);

}

return sum \* h;

}

}

**Compile to Wasm:**

emcc integration.cpp -O2 -s WASM=1 -s EXPORTED\_FUNCTIONS="['\_integrate']" -o integration.js

**Call from JavaScript:**

// wasm-integration.js

fetch("integration.wasm").then(r => r.arrayBuffer()).then(bytes =>

WebAssembly.instantiate(bytes)

).then(mod => {

const { integrate } = mod.instance.exports;

const t0 = performance.now();

const result = integrate(0, 1, 1e7);

const t1 = performance.now();

console.log("Wasm Integration Result:", result.toFixed(6));

console.log("Wasm Integration Time:", (t1 - t0).toFixed(2), "ms");

});

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