Efficient Implementation and Evaluation of Profilers in JavaScript-based Interpreters

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Introduction:

Profilers are essential tools in software development, providing crucial insights into program execution behavior and performance. This research focuses on implementing and evaluating efficient profiling techniques within a JavaScript-based interpreter for an original language. The single-threaded nature of JavaScript presents unique challenges, necessitating innovative approaches to profiling.

Research Objectives:

1. Implement and compare different profiling techniques in a JavaScript-based interpreter.
2. Overcome JavaScript's single-threaded limitations in statistical profiling.
3. Analyze trade-offs between accuracy and overhead for different profiling methods.

Methodology: Three profiling approaches were implemented and evaluated:

1. Event-based Profiler:

- Records start and end times of each function call.
- Provides accurate execution time measurements.
- Implements function entry and exit event capturing.

2. Statistical Profiler (Promise-based):

- Uses setInterval to queue sampling tasks every 1ms in the Task Queue.
- Implements frequent checkpoints in the program evaluation using await new Promise(...).
- At each checkpoint:
    - Program evaluation is temporarily paused.
    - Checks if a sampling task is in the Task Queue.
    - If present, records the currently executing function.
    - If not, resumes program evaluation.
- Challenges:
    - High overhead due to frequent pausing and resuming of program evaluation.
    - Potential for missing short-lived functions between checkpoints.

3. Statistical Profiler (Worker Thread-based):

- Utilizes Web Workers to create a separate thread for profiling.
- Main thread: Runs the program evaluation.
- Worker thread: Handles profiling tasks.
- Implementation details:
    - Creates a SharedArrayBuffer for inter-thread communication.
    - Main thread updates the SharedArrayBuffer with current function information.
    - Worker thread uses setInterval to sample the SharedArrayBuffer every 1ms.
    - Samples are processed to generate a statistical profile of function execution times.
- Advantages:

    - Minimal interruption to the main program execution.
    - Consistent sampling interval, independent of program complexity.
    - Lower overhead compared to the Promise-based approach.
- Challenges:
    - Potential for slight inaccuracies due to the statistical nature of sampling.
    - Requires careful synchronization between threads to ensure data consistency.

Evaluation: Profilers were tested using programs with different numbers of function calls

Results:

1. Overhead Comparison:

Figure 1 shows the overhead of the Promise-based Statistical Profiler. As evident from the graph, this approach introduces significant overhead, making it impractical for most scenarios.

Figure1: Overhead of Promise-based Statistical Profiler

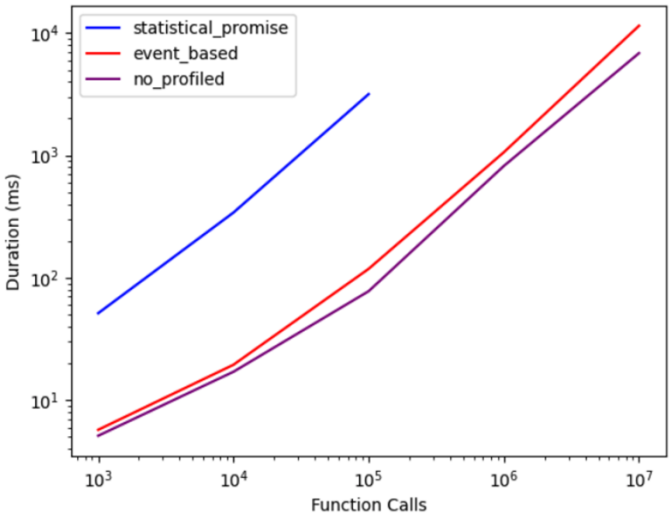
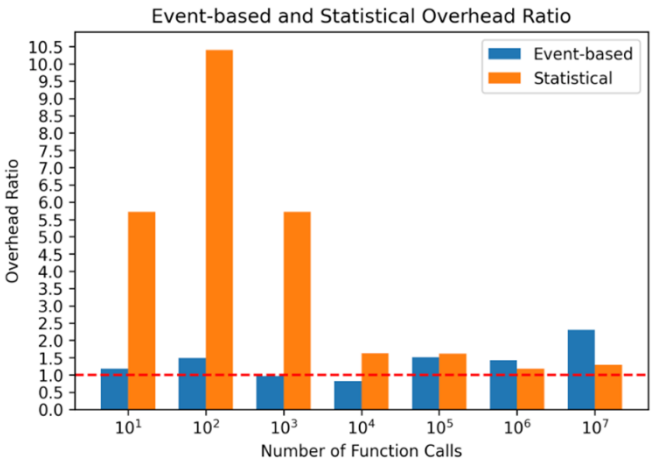


Figure 2 compares the overhead of the Event-based Profiler and the Worker Thread-based Statistical Profiler.

Figure 2: Overhead Comparison of Event-based and Worker Thread-based Statistical Profilers



Key observations from Figure 2:

- Event-based Profiler: Lower overhead for <10^5 function calls, but increases linearly with the number of calls.
- Worker Thread-based Statistical Profiler: Higher but constant overhead, becoming more efficient for ≥10^5 function calls.

2. Accuracy:
    - Event-based Profiler: Higher accuracy for individual functions.
    - Statistical Profiler (Worker Thread): Good overall estimate, potentially missing very short-lived functions.
3. Scalability:
    - Worker Thread-based Statistical Profiler showed better scalability for large programs.

Conclusion:

- The Promise-based Statistical Profiler, proves impractical due to excessive overhead.
- For <10^5 function calls: Event-based Profiler is preferable (higher accuracy, lower overhead).
- For ≥10^5 function calls: Worker Thread-based Statistical Profiler offers better balance between accuracy and performance.
- Web Workers and SharedArrayBuffer effectively overcome JavaScript's single-threaded limitations in statistical profiling.

These findings provide valuable insights for choosing appropriate profiling strategies in JavaScript-based language implementations.

Future Work:

- Extend profiling techniques to other scripting languages (e.g., Python, Ruby).
- Integrate static analysis with dynamic profiling.

Related Work:

This research builds upon and extends the concepts from various existing profiling tools. Some notable related works include:

- gprof:
    - A popular profiling tool for C, C++, and Fortran programs
    - Uses a combination of statistical sampling and call graph analysis
- Valgrind:
    - A comprehensive suite of debugging and profiling tools
    - Operates at the machine code level, allowing for detailed analysis
- Python cProfile:
    - A built-in profiling module for Python
    - Offers function-level statistics including call counts and execution times