NanoLog: A Nanosecond Scale Logging System

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Overview

- **Implemented a fast C++ Logging System**
  - **12.5ns** median latency at **60M** log msgs/sec
  - 10-100x faster than existing systems such as Log4j2 and spdlog
  - Maintains printf-like semantics
- **Shifts work out of the runtime hot-path**
  - Extraction of static information at compile-time
  - Compacted binary output at runtime
  - Defers formatting to an offline process
- **Benefits and Costs**
  - Allows detailed logs in low latency systems
  - Comes at the cost of 1MB of RAM per thread, one core, and disk bandwidth

Why *Fast Logging*?

- **Cornerstone of debugging**
  - Affords visibility application state
  - Helps in root cause analysis after execution

- **Problem: Logging is slow**
  - Application response times are getting faster (microseconds)
  - Logging is not (100-1000’s of nanoseconds)
  - Example: RAMCloud response time= 5µs, but log time= 1µs

What makes logging slow?

```
1473057128.133777014 src/LogCleaner.cc:826 in TombstoneRatioBalancer
NOTICE: Using tombstone ratio balancer with ratio = 0.400000
```

- **Compute: Complex Formatting**
  - Loggers need to provide context (i.e. file location, time, severity, etc)
  - The message above has **7 arguments** and takes **850ns** to compute

- **Output Bandwidth: Disk IO**
  - On a 250MB/s disk, the **129 byte** message above takes **500ns** to output!

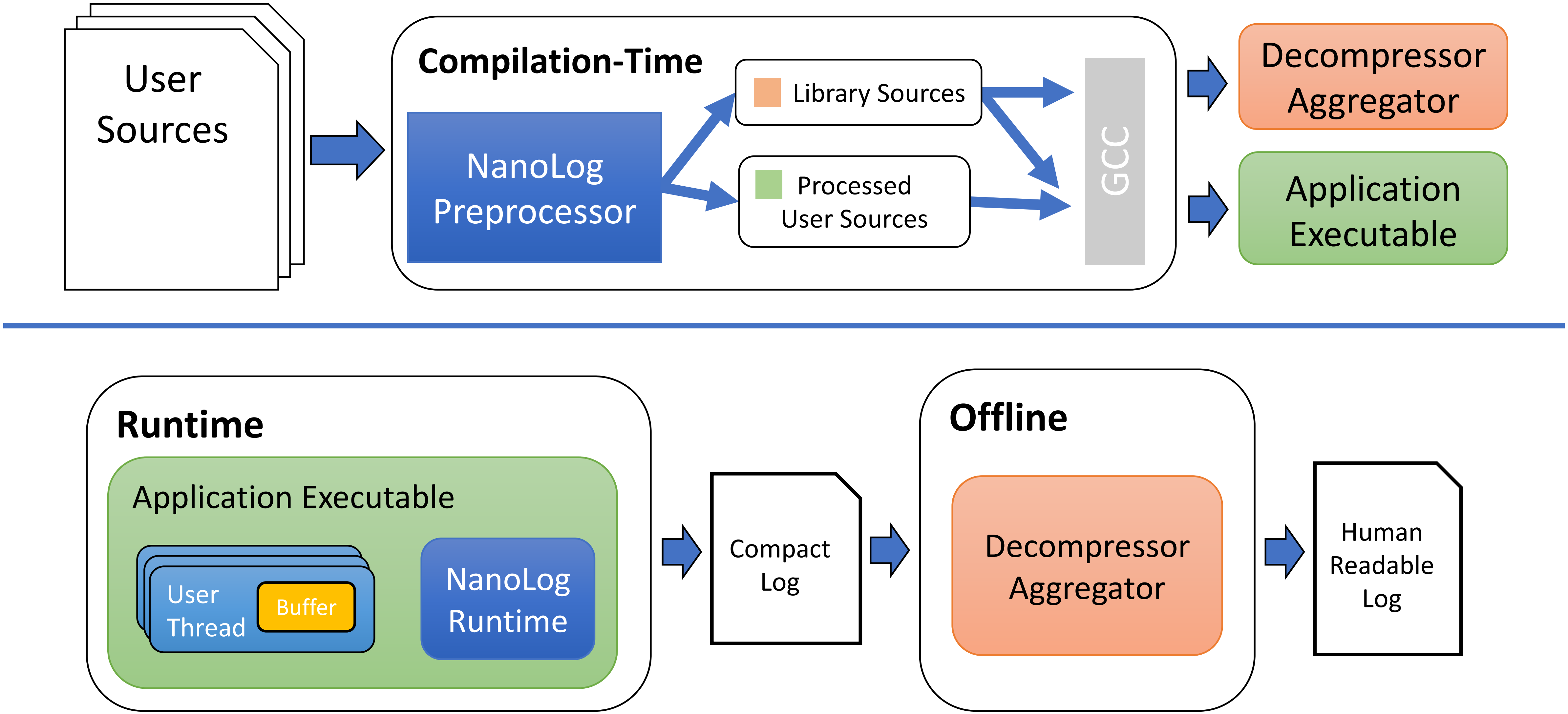
Solutions

```
1473057128.133777014 src/LogCleaner.cc:826 in TombstoneRatioBalancer
NOTICE: Using tombstone ratio balancer with ratio = 0.400000
```

- **Compute: Raw Data Output**
  - Most logs in production are not consumed by humans
  - Save computation by deferring formatting to an *offline* process
  - Side benefit: more efficient for analysis engines

- **IO: Extracting Static Information**
  - Static Info in message: file location, line #, function, severity, format string.
  - Replace with identifier and compact remaining dynamic information

NanoLog System Architecture



Compile-time Optimizations

User Source (main.cc)

```
#include "NanoLog.h"

main() {
  NANO_LOG("Hello World %d", rand());
}
```

(a) Extract static log info

NanoLog Library (StaticInfo.cc)

```
// Maps Log Instance to Id
extern int uniqueId_main_cc_4 = 0;

void compact0(in, out) {...}

void decompress0(in) {
  const char* fmtString = "Hello World %d";
  const char* filename  = "main.cc";
  const int   linenum   = 4;
  enum        severity  = "DEFAULT"

  ...
}
```

(b) Inject optimized log code

Post-Processed User Source (main.ii)

```
#include "NanoLog.h"

# 1 "generated.h"
inline void
record_main_4(const char *str, int arg1) {
  extern int uniqueId_main_cc_4;

  NanoLog::push(uniqueId_main_cc_4);
  NanoLog::push(time());
  NanoLog::push(arg1);
}

# 2 "main.cc"
main() {
  record_main_4(
          "Hello World %d", rand());
}
```

compile

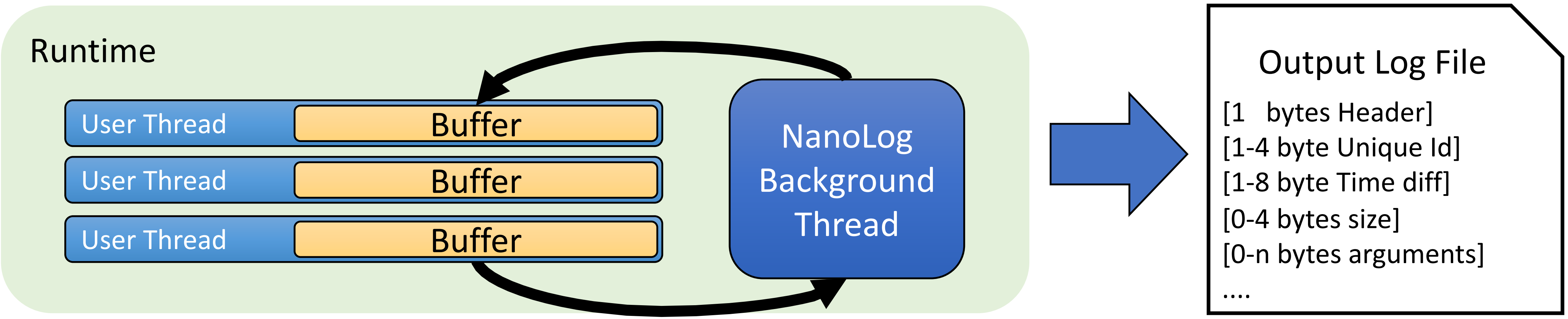
Decompressor Executable

compile

Application Executable

Fast Runtime Architecture

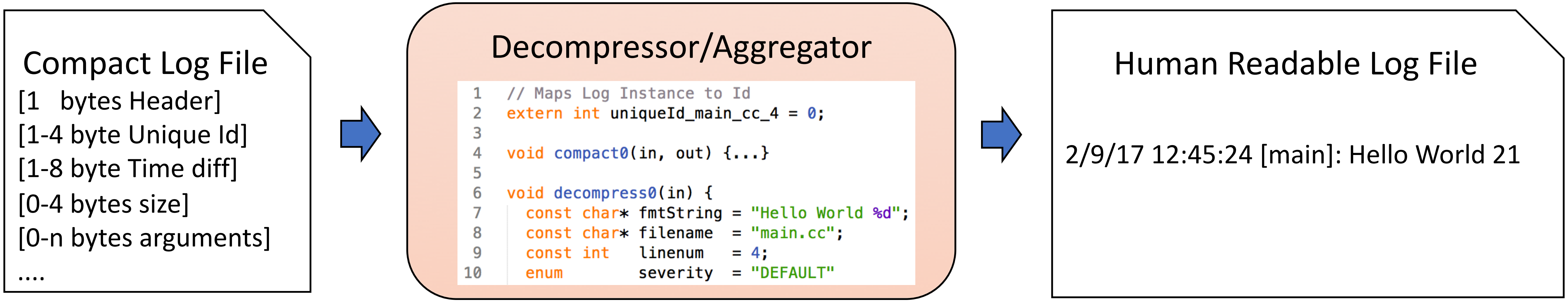
- **Isolate the Threads**
  - Use per-thread buffers to lower synchronization
  - Don’t notify the background thread; let it poll for data
- **Minimize Output Cost**
  - Caller pushes data *uncompressed* to save on compute
  - IO Thread needs to save on both IO and compute times.
    - Use only rudimentary compaction (deltas + smallest byte representations)



Decompressor/Aggregator

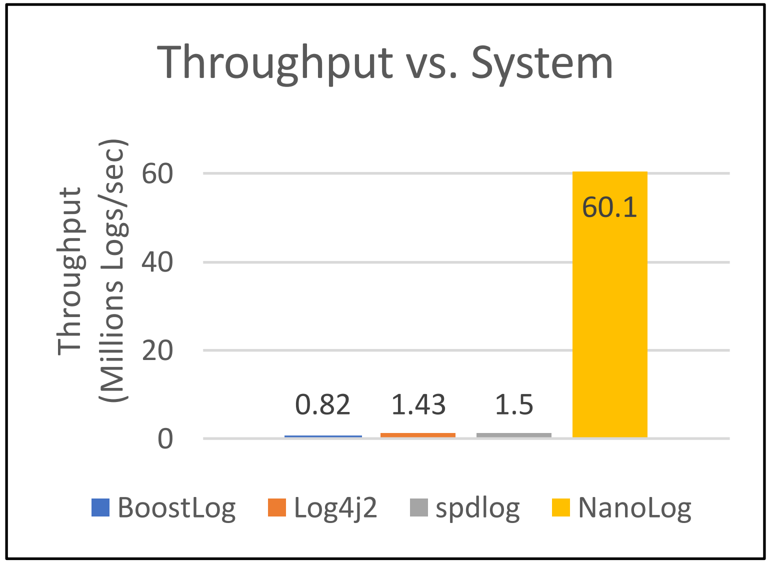
- **Offline process to decompress log**
  - Recombines the static + dynamic data to produce a human-readable file

- **Future Work**
  - Query/Aggregate in compacted format



Benchmarks

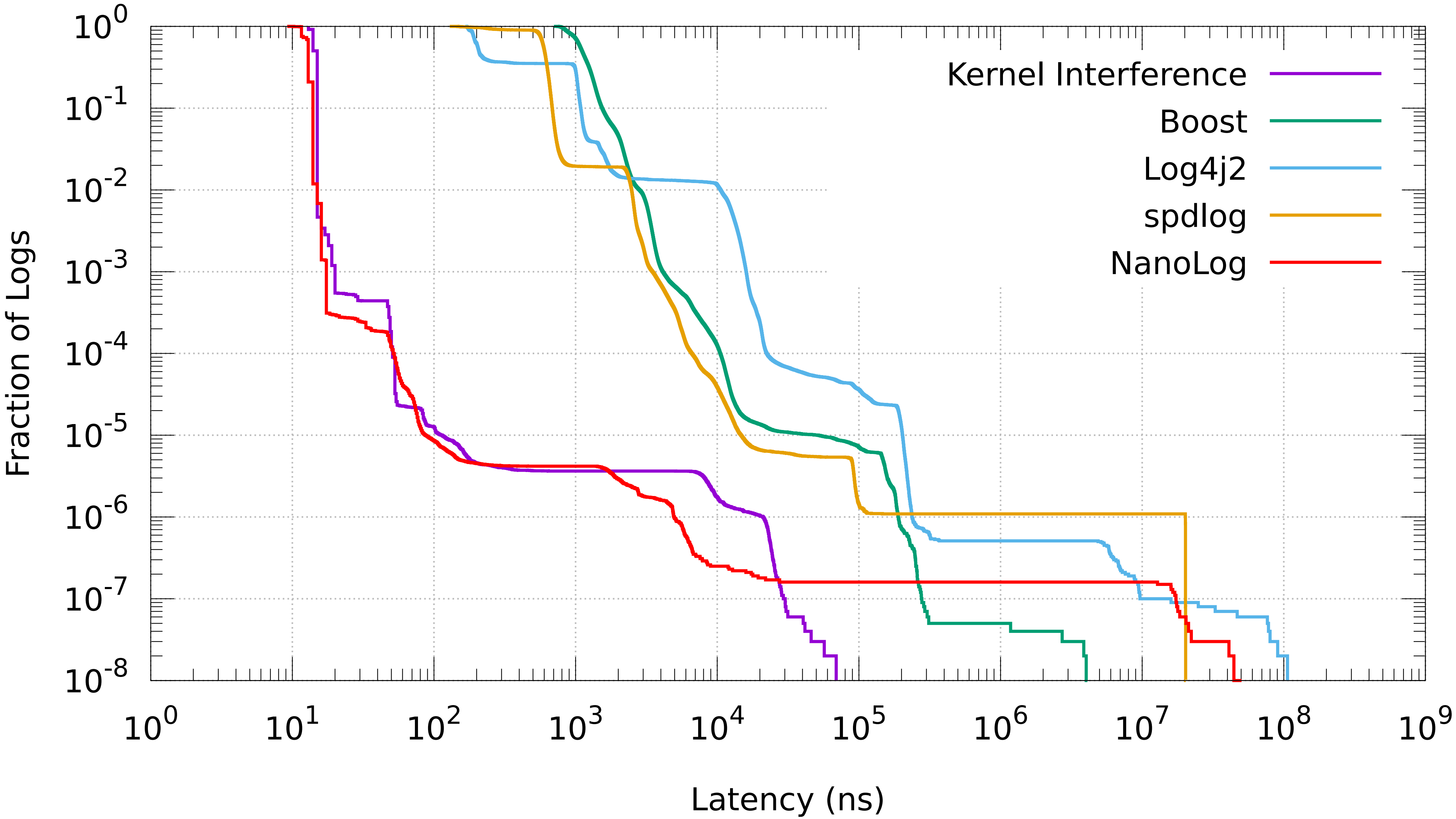
- **System Setup**
  - Processor: Quad-Core Intel Xeon X3470 @ 2.93GHz
  - Memory: 24GB DDR3 @ 1333Mhz
  - Disk: 120GB Crucial M4 over SATAII (~250MB/s)
- **Test Setup**
  - 100M iterations of log messages, back to back
  - Log Message: "{time} {severity}: {56-byte message}"



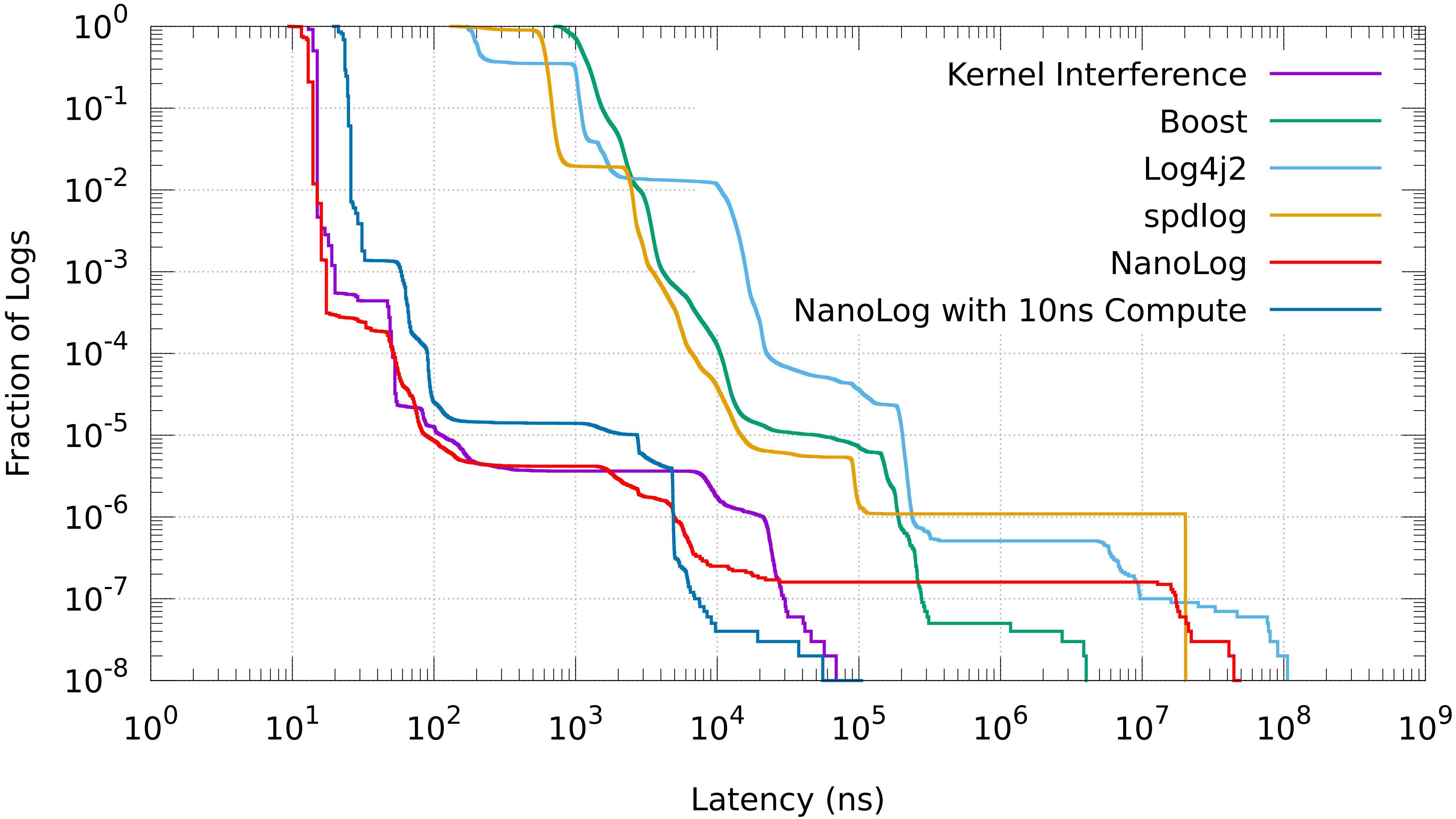
- **Overall Results**

Zero Arguments	Boost v1.55	Log4j2	Spdlog	NanoLog
Throughput (Log/s)	0.82M	1.43M	1.50M	60.1M
Average Latency (ns)	1110 ns	697ns	668 ns	16.5ns

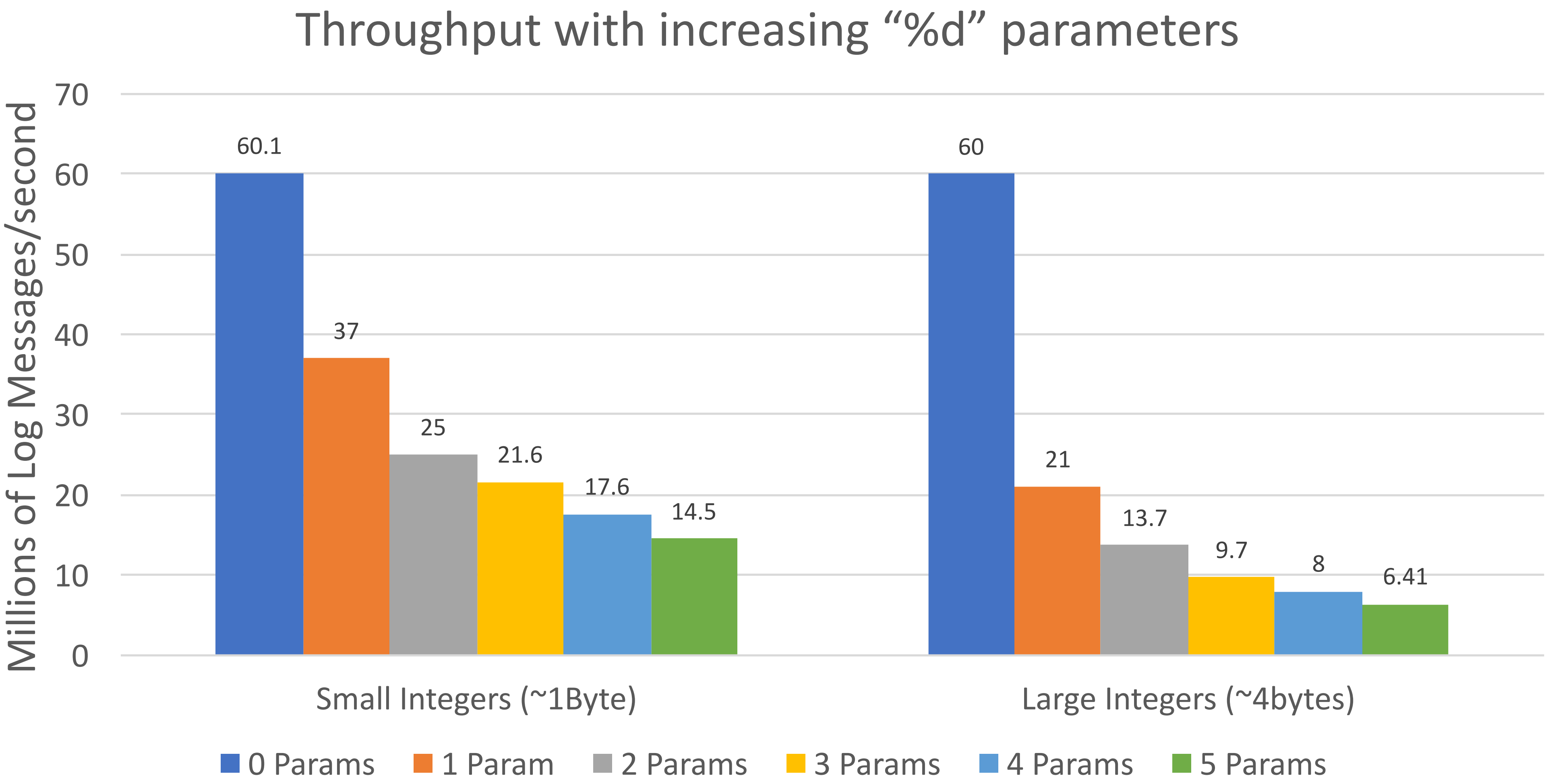
Tail Latencies



Tail Latency (+ NanoLog Compute)



Increasing Parameters



Limitations/Future Work

- **Better Compression?**
  - Is there a better way to compact the output, but in a performant way?
- **Fully featured decompressor/aggregator**
  - Operating on the compact representation is more efficient.
  - Iterating over a compact log message takes about 100ns vs. 1.3µs to output
- **Resource Utilization**
  - Currently the system requires 1MB per user thread, a full core to compact, and the full bandwidth of a SATA SSD to main low latency. How does this change with new hardware?

NanoLog System Summary

- **Compile-Time Preprocessor**
  - Extract static information from log messages at compile time
    - File name, line #, function name, etc
  - Catalogs static info and assigns a unique ID to each log statement
  - Code Injection to record only an identifier + parameter arguments

- **Runtime Library**
  - Producer/Consumer Log output
  - Simple compaction (taking deltas/compacting integers)

- **Offline Decompressor/Aggregator**
  - Recombine static information for human consumption (if necessary)
  - Offline Search/Grep/Aggregate in compressed format

Questions