GOAT

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Abstract. **Keywords:** golang,concurrency,testing,debugging

1 Introduction

ST: Intro to Go

ST: - Go is statically typed language
- Its concurrency originates from CSP Hoar [7]
- goroutines, channels, scheduler, serialization features such as mutex, waitgroups, condvars

ST: Motivating for Go debugging

ST: In traditional shared-memory concurrent languages such as Java/C/C++, threads interact with each other via shared memory. Processes in CSP-based languages such as Erlang communicate through mailbox (asynchronous) message passing. Go brings all these features together into one language and encourages developers to *share memory through communication* for safe and straightforward concurrency and parallelism. The visibility guarantee of memory writes is specified in the memory model[2] under synchronization constraints (*happens-before* partial order [10]). The language is equipped with a rich vocabulary of *serialization* features to facilitate the memory model constraints; they include synchronous and asynchronous communication (either unbuffered or buffered channels), memory protection, and custom barriers for efficient synchronization. This conflation of features has, unfortunately, greatly exacerbated the complexity of Go debugging. In fact, the popularity of Go has outpaced its debugging support [1, 20, 23]. There are some encouraging developments in support of debugging, such as a data race checker [21] that has now become a standard feature of Go, and has helped catch many a bug. However, the support for "traditional concurrency debugging" such as detecting atomicity violations and Go-specific bug-hunting support for Go idioms (e.g., misuse of channels and locks) remain insufficiently addressed.

ST: What we have done

ST: While good work has been proposed to address debugging concurrent aspect of Go, here are some limitations that they have:
- State explosion problem for static analysis
- Concurrency features and modern concepts of Go (such as Select) prevent tools for accurate translation/conversion/abstraction to reflect target program behavior (e.g. dingo-hunter (the static analyzer) is unable to translate real-world applications into MiGo (the behavioral type system) for checking channel safety and program liveness. Even for GoKer, it failed (crashed) to analyze on 29 bugs)
- Tools are too focused on a specific class of bug (symptom or cause).
We introduce a framework that provides a comprehensive model of execution automatically. This model hepls with in-depth information about dynamic behavior of written code Debugger can observe, perceive and compare the model against the mental model at the time of development. **Automatic Accurate** and **Comprehensive Perturb scheduler**

2 Background

3 GOAT Design

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4 Benchmark

GoBench

Results

Discussion

5 Related Work

Go comes with a few dynamic tools for analysis and debugging its programs. For example, the *race detector* [21] which is basically a wrapper around ThreadSanitizer [15], tracks memory accesses and detect races that happened during execution. A few other facilities for code coverage measurement, profiling, and tracing are provided to deliver insight into the testing quality and performance behavior. However, there is still a considerable gap for debugging concurrency. Several research groups have recently proposed and developed a range of *static* (source-level) or *dynamic* (execution-level) theories and tools towards filling this gap. Ng and Yoshida [14] first proposed a static tool to detect global deadlock in Go programs using choreography synthesis. Later, Stadtmuller et al. [16] proposed a static trace-based global detection approach based on forkable regular

expressions. Lange et al. proposed more static verification frameworks for checking channel safety, and liveness [11], and behavioral model checking [12]. Both methods approximate Go programs with session types and behavioral contracts extracted from their SSA intermediate representation. The mentioned work has limitations for handling dynamic (e.g., in-loop) goroutine or channel creation. They also do not scale and are impractical in real-world programs due to the state explosion problem. Besides, similar to other static analysis methods, they often suffer from false positives due to conservative constraints.

Zhao et al. [24] introduced a runtime monitoring approach for deadlock detection for Occam based on wait-for graphs and some heuristics. Occam is a concurrent language based on CSP semantics, and similar to Go, it uses channels to establish communication between processes. Sulzmann and Stadtmuller proposed a dynamic verification approach for synchronous (unbuffered) channels [17], and a vector-clock-based approach for asynchronous channels [18]. Both approaches require heavy code instrumentation and replay of collected traces. Although they may support a larger subset of the Go language, they only focus on channels as the root cause of deadlocks and evaluated only on relatively small examples. Generally, dynamic analyzers are not *sound* meaning that they are only able to catch occurred bugs and might miss potential unhappened bugs.

Systematic testing combines ideas from static and dynamic approaches to reduce the state space and reflect realistic behavior. Assuming the scheduler causes concurrency bugs (and not the program input), they may not manifest during conventional testing and difficult to reproduce, both due to non-deterministic decisions that the scheduler makes. Stress testing the scheduler to examine possible interleaving is useful to expose hidden bugs, but they are exponentially expensive relative to the number of concurrent units. Researchers have applied different methods [19] to reduce the interleaving space to explore effectively and efficiently. Delay-bounded [3, 6] and preemption-bounded [13] techniques systematically "fuzz" the scheduler to equally and fairly cover feasible interleaving. Other tools like Maple [22], CalFuzzer [9], and ConTest [4,5] *actively* control the scheduler to maximise a pre-defined concurrency coverage criterion [8] or the probability of bug exposure [3].

Adopting ideas from existing concurrency testing tools, we systematically navigate the scheduler towards executing likely-erroneous interleaving. We first identify the usage of concurrency primitives (*critical points*) in the program using a tracing mechanism. We automatically inject random delays around the critical points to increase the probability of bug exposure (more in section 3).

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