Challenges Of Enabling Golang Binaries Optimization By BOLT

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Acknowledgement

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Contents

Golang Specifics

- Golang (aka Go) is a statically typed, compiled programming language
- The major toolchain implementation is a self-hosted Golang Compiler (github.com/golang/go), it doesn't use the LLVM framework for its implementation
- Supports a list of target operating systems, including Linux, Android, Windows, etc.
- Supports a list of target platforms, including AMD64, ARM64, MIPS64, etc.
- Uses it’s own runtime which operates with compiler/runtime version-specific metadata to implement language-specific functionality like Garbage Collector, Scheduler, etc.
- By default - project source code, all imported packages and the whole runtime library are built into a single statically linked executable

Why BOLT?

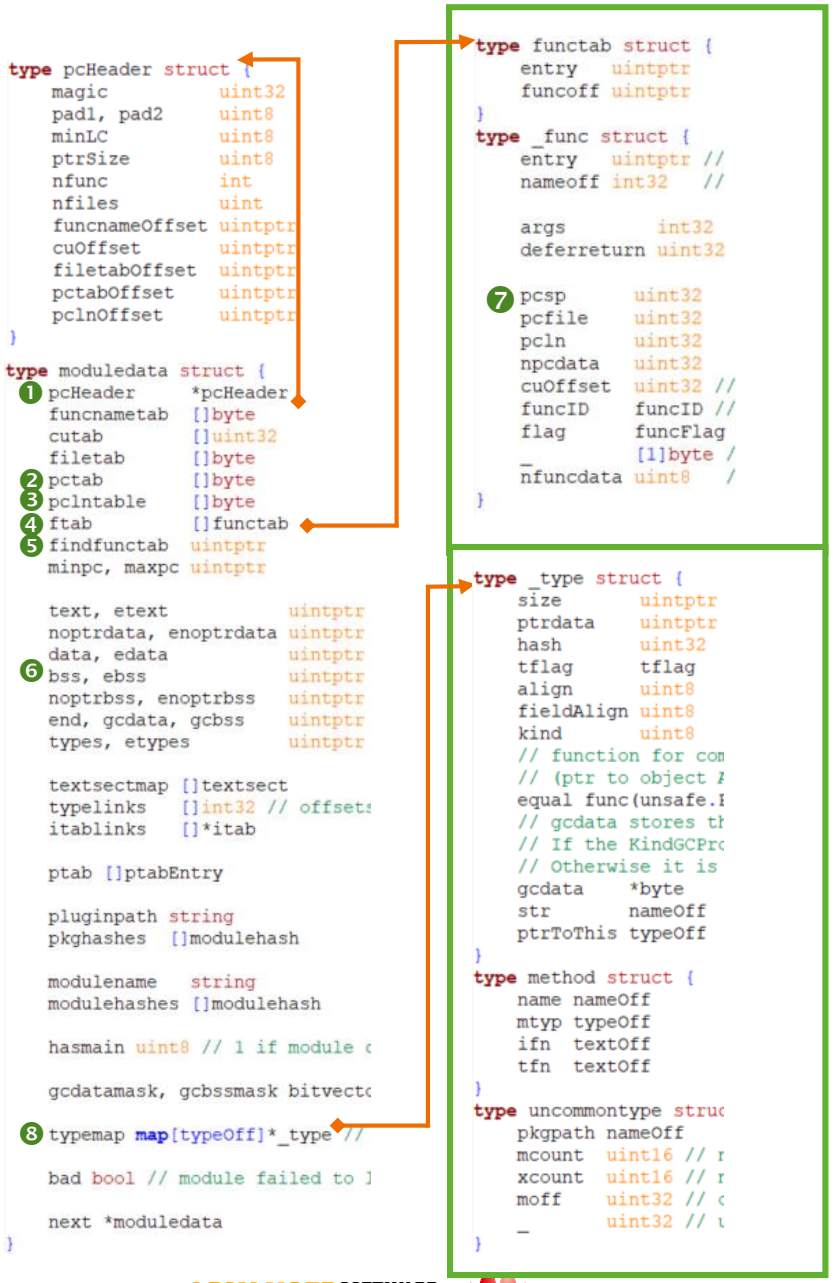
- Golang Compiler still doesn’t support profile-guided optimization
- Output binaries are huge (compared to C/C++ project executables) -> i-cache locality issues
  - E.g. K8s kubelet executable .text section size is ~50M

- BOLT is known as an efficient tool to improve i-cache utilization and reduce branch miss-prediction
- BOLT optimization doesn’t require rebuilding application with a specific compiler

Golang Runtime Data Structures

Golang Runtime metadata includes the following most important structures (actual for Go 1.17):

- ❶ moduledata – The main structure in Golang executable. It records information about the layout of the binary file.
- ❷ pctab – Holds all deduplicated pcdata (used in ❹)
- ❸ pclntable – Header + array of pairs of **function address** and offset in ftab table for each function sorted by address
- ❹ ftab – Array of **function** descriptor structures with glued pcdata & funcdata table reference. Each function descriptor contains information about **address**, name, arguments, **size**, pcsp table offset, number of entries in pcdata & funcdata tables.
  - > pcdata – up to 3 varint-encoded pairs [Value, **PC**]. Types: UnsafePoint – used by scheduler, StackMapIndex – index for stack-related funcdata, InlTreeIndex – index for inline related funcdata.
  - > funcdata – up to 7 pointers to special structures. Types: ArgsPointerMaps, LocalPointerMaps, RegPointerMaps, StackObjects - connects **PC** with stack-related info, required for Garbage Collector and Scheduler work. InlTree type – array of offsets pointing start of inlined function. OpenCodedDeferInfo type – used to store max defers arguments size.



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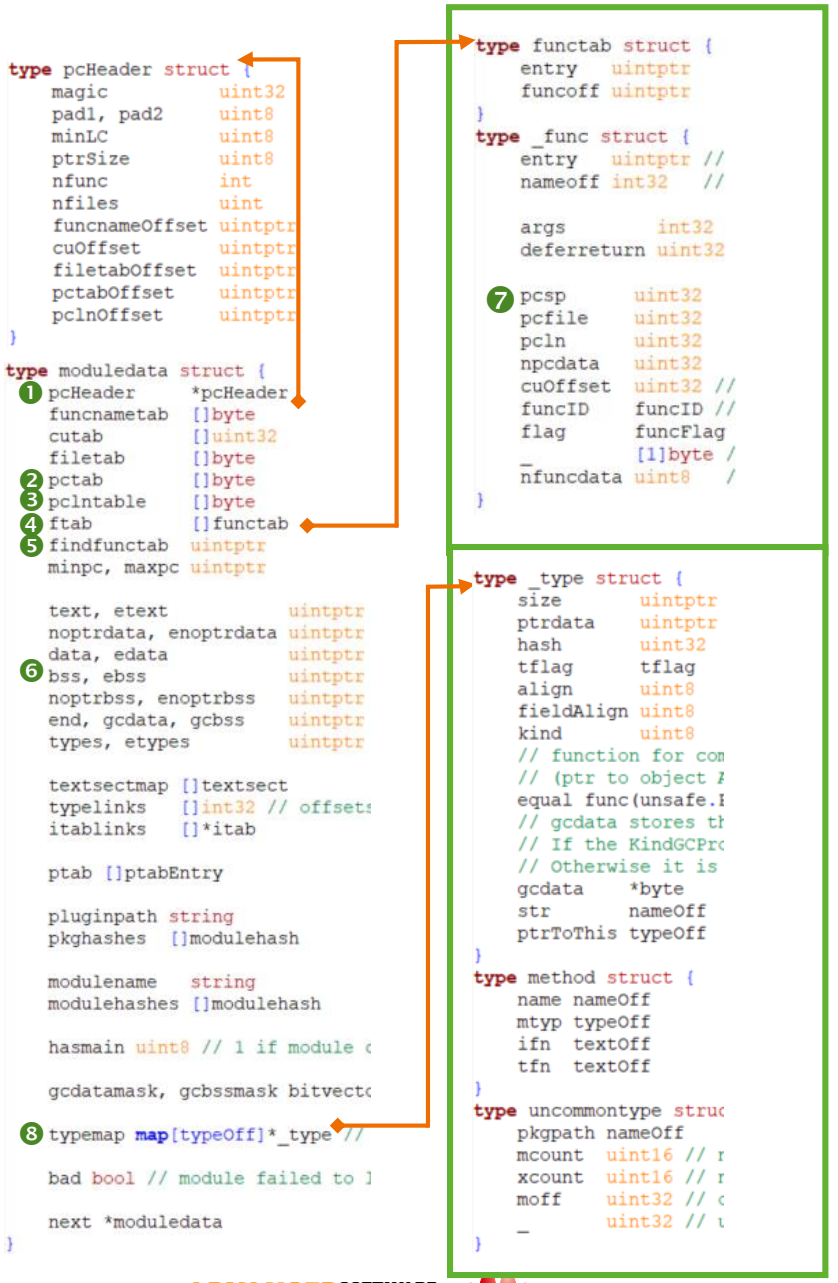
Golang Runtime Data Structures

- ❺ findfunctab – Service table used to speedup search of a function in ftab table by **PC** value
- ❻ Pointers to file sections (text, data, bss, etc.)
- ❼ pcsp – **Program Counter** to Stack Pointer table offset. It's used for stacktrace resolving.
- ❽ type descriptors – set of glued structures which may include an array of functions/methods referenced using **offsets** from Golang text start to function entry point

- Data structures mentioned above will be broken after BOLT will finish execution of optimization passes, so offsets and addresses of these data structures in output binary should be updated



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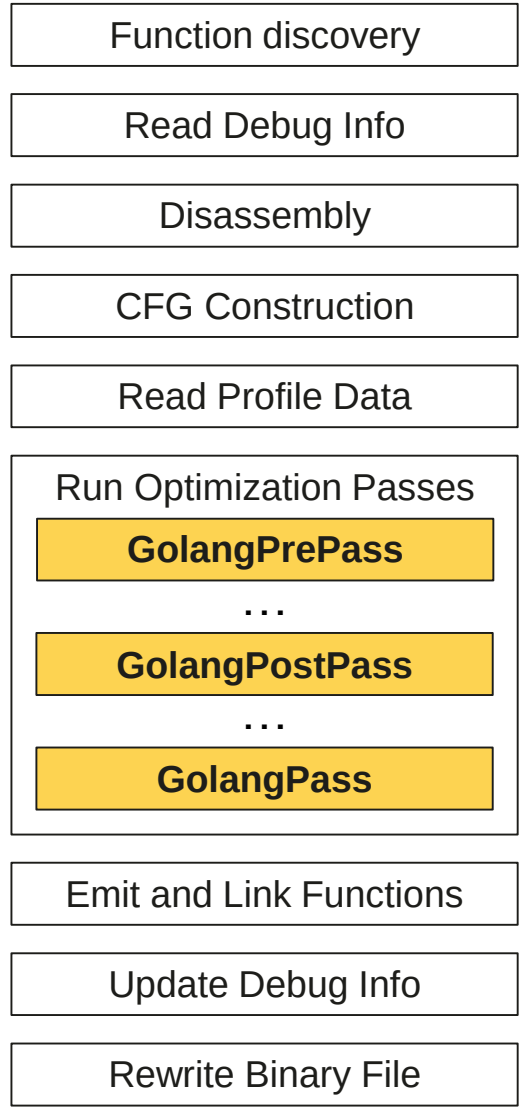
Enabling Support in BOLT

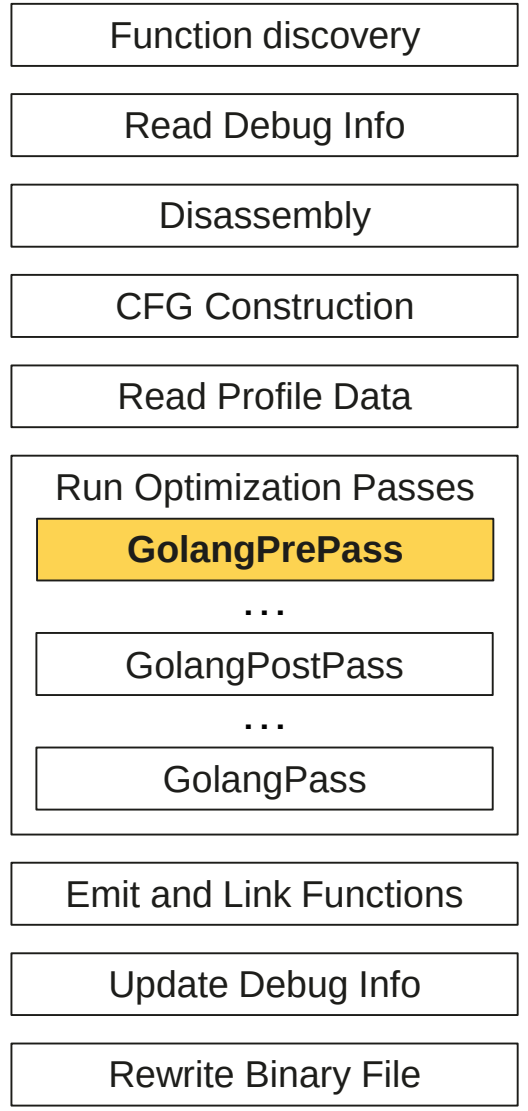
We added three Golang passes to Optimization phase to handle Golang specifics:

- GolangPrePass: Preprocessing stage, runs right after the binary file was disassembled and no changes applied yet
- GolangPostPass: Postprocessing stage, must be the latest pass that changes text
- GolangPass: The very last pass, fixes data section and does not change text



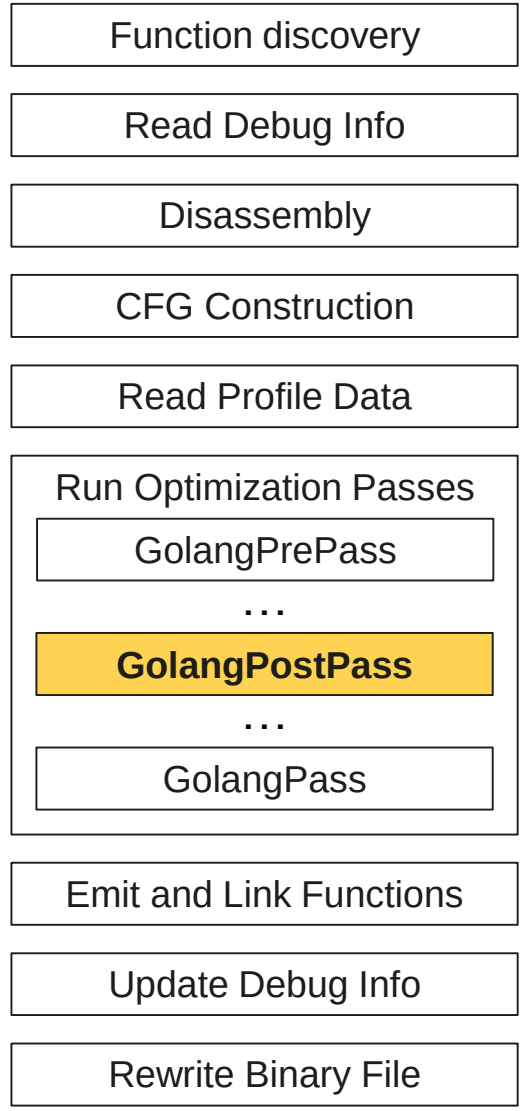
Enabling Support in BOLT

- GolangPrePass: Preprocessing stage
- Runs right after the binary file was disassembled and no changes applied yet
  - > For every function from **pclntable** - save offset in **ftab** for each golang function to extra field of BinaryFunction
  - > For every BinaryFunction:
    - Mark as non-simple if the function has non-standard ID or from the exclusion list (special asm-written functions, that are dangerous to change)
    - Save values of **pcdata** tables in corresponding MCInst (using MCAnnotation)
    - For StackMapIndex **pcdata** additionally save the next instruction to restore table properly
    - Mark deferreturn call instructions (using MCAnnotation with IsDeffer name)
    - Store **pcsp** table conditionally (using MCAnnotation)
    - For every InlTree **funcdata** - store inline index to the first inline caller instruction for each of the inlined functions (using MCAnnotation with FUNCDATA* names)



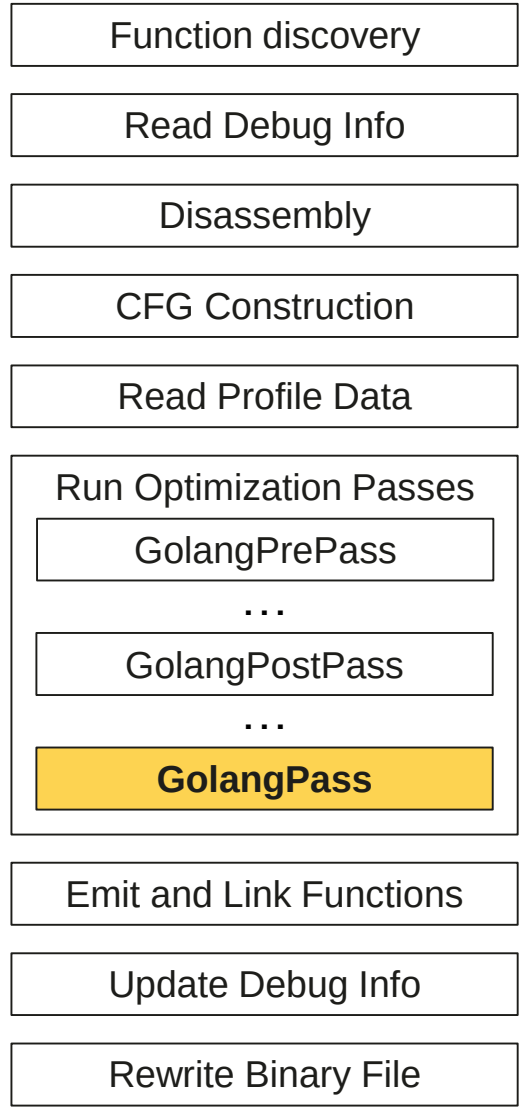
Enabling Support in BOLT

- GolangPostPass: Postprocessing stage
- Must be the latest pass that changes text.
- Also, it used for instrumentation support enabling.
  - > Inserts instrumentation dump() call in runtime.exit function
  - > Restores NOPs padding for some special runtime functions (runtime.skipPleaseUseCallersFrames)
  - > Fixes **pcdata** tables:
    - UnsafePoint table: handles extra instrumentation snippet instructions
    - StackMapIndex table: During preprocessing stage we saved pcdata value to the next instruction as MCAnnotation. If “next” instruction was modified by preceding BOLT passes - we need to insert NOP instruction with added MCAnnotation with correct pcdata to restore it correctly on next stage.



Enabling Support in BOLT

- GolangPass: Final stage
- The very last pass. Fixes data section and does not change text
  - > Fixes offsets of functions/methods of **type descriptors**
  - > Creates a new **pclntable** and **ftab** tables
  - > Restores **pcdata** & **funcdata** tables: inline funcdata, deferreturn call, **pcsp** table
  - > Creates a new **findfunctab** table
  - > Fixes pointers in **firstmoduledata** structure



Status

- Supports Go Compiler versions 1.14, 1.16, 1.17, passes 100% Golang Runtime functional tests
- Supports x86_64 & ARM64 binaries
- Supports Instrumentation for two platforms: x86_64 and ARM64
- Minor changes required for Golang support were merged to BOLT
- Published RFC: https://reviews.llvm.org/D124347
  - This patch is quite big and requires splitting into a series of patches

Performance Impact

- Up to **19%** of relative performance improvement on internal applications
- goweb “Light weight web framework based on net/http”
  - Repo: https://github.com/twharmon/goweb.git
  - Profile collected using BOLT instrumentation
  - Go 1.17
  - .text size ~3.5M
  - Performance Improvement (Xeon Gold 6230N): +**8.13%**
  - Performance Improvement (Kunpeng 920): **+11.74%**

```
name                 old time/op  new time/op  delta
GowebPlaintext-8     2.12µs ± 0%  1.89µs ± 0%  -10.54%  (p=0.008 n=5+5)
GinPlaintext-8       1.40µs ± 1%  1.31µs ± 2%   -6.36%  (p=0.008 n=5+5)
GorillaPlaintext-8   3.19µs ± 0%  3.09µs ± 0%   -3.25%  (p=0.008 n=5+5)
EchoPlaintext-8      1.39µs ± 0%  1.29µs ± 0%   -7.39%  (p=0.008 n=5+5)
MartiniPlaintext-8   17.9µs ± 0%  15.9µs ± 0%  -11.04%  (p=0.008 n=5+5)
GowebJSON-8           119µs ± 0%    99µs ± 0%  -16.81%  (p=0.008 n=5+5)
GinJSON-8             130µs ± 0%   110µs ± 0%  -15.61%  (p=0.008 n=5+5)
GorillaJSON-8         121µs ± 0%   101µs ± 0%  -16.26%  (p=0.008 n=5+5)
EchoJSON-8            117µs ± 0%    98µs ± 0%  -16.11%  (p=0.008 n=5+5)
MartiniJSON-8         169µs ± 0%   143µs ± 0%  -15.23%  (p=0.008 n=5+5)
GowebPathParams-8    5.97µs ± 0%  5.26µs ± 0%  -11.84%  (p=0.008 n=5+5)
GinPathParams-8      4.07µs ± 0%  3.67µs ± 0%   -9.81%  (p=0.008 n=5+5)
GorillaPathParams-8  7.18µs ± 0%  6.40µs ± 0%  -10.77%  (p=0.008 n=5+5)
EchoPathParams-8     4.24µs ± 0%  3.74µs ± 0%  -11.76%  (p=0.008 n=5+5)
MartiniPathParams-8  20.3µs ± 0%  17.9µs ± 0%  -12.09%  (p=0.008 n=5+5)
[Geo mean]           13.8µs       12.2µs       -11.74%
```

- benchmark of graphql frameworks
  - Repo: https://github.com/appleboy/golang-graphql-benchmark.git
  - Profile collected using BOLT instrumentation
  - Go 1.17
  - .text size ~6M
  - Performance Improvement (Xeon Gold 6230N): +**11.36%**
  - Performance Improvement (Kunpeng 920): +**8.98%**

```
name                      old time/op    new time/op    delta
GinHttpRoute-8              1.92µs ± 0%    1.70µs ± 0%  -11.50%  (p=0.008 n=5+5)
GinGQLGenRoute-8            1.95µs ± 0%    1.76µs ± 0%   -9.84%  (p=0.008 n=5+5)
GinGoGraphQLRoute-8         22.5µs ± 0%    19.3µs ± 0%  -14.09%  (p=0.008 n=5+5)
GinGopherGraphQLRoute-8      754ns ± 0%     686ns ± 1%   -9.01%  (p=0.008 n=5+5)
GinThunderGraphQLRoute-8    1.30µs ± 0%    1.16µs ± 1%  -10.48%  (p=0.008 n=5+5)
GoGraphQLMaster-8           59.4µs ± 0%    51.9µs ± 0%  -12.67%  (p=0.008 n=5+5)
PlaylyfeGraphQLMaster-8     5.18µs ± 0%    4.70µs ± 0%   -9.20%  (p=0.008 n=5+5)
GophersGraphQLMaster-8      4.08µs ± 0%    3.56µs ± 0%  -12.77%  (p=0.008 n=5+5)
ThunderGraphQLMaster-8      2.31µs ± 0%    2.02µs ± 1%  -12.57%  (p=0.008 n=5+5)
[Geo mean]                  3.96µs         3.51µs       -11.36%
```

Known Limitations

- Golang Compiler Linker doesn’t support emitting static relocations (emit-relocs option)
  - Resolved by usage of an external linker
- Golang Compiler doesn’t fully follow ARM64 ELF Specification in context of mapping symbols generation
  - Fixed with patches in Golang Compiler (not yet merged) https://go-review.googlesource.com/c/go/+/343150 (https://github.com/yota9/golang_aarch64_mapping_symbols)

- High memory consumption (we observed up to 80GB memory usage for processing of large binaries)
- Some BOLT optimizations are disabled: Inlining, frame optimizations, hot/cold functions splitting, lite mode, updating debug information

Future Plans

- Continue working on RFC, split it into a series of patches and gradually upstream
- Continue upstreaming of ARM64 ELF Symbols support in Golang Compiler
- Add support of newer Golang Compiler versions

Thank you.