HI-CFG: Construction by Dynamic Binary Analysis, and Application to Attack Polymorphism

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Recovering Information

Knowledge of information (data) flow and control flow of an application crucial for analysis

- Current tools focus on just one type of flow

Combine information flow and control flow into high-level data structure

- Hybrid, Information- and Control-Flow-Graph (HI-CFG) using binary analysis
HI-CFG Overview

CFG view

Data flow view

Buffer A

Buffer B

Buffer C
Outline

Motivation
Attack Polymorphism
Dynamic HI-CFG Construction
Evaluation
Conclusion
HI-CFG: Attack Polymorphism

Step one: phase partitioning
- Divide a computation into steps that transform data from an original input to an internal format
- Based on HI-CFG buffers, information-flow and producer/consumer edges

Step two: phase aware input generation
- Aim is to produce an input that triggers a vulnerability deep within a program
- Use phase structure to divide and conquer
- Symbolic execution with search pruning
HI-CFG: Attack Polymorphism

Program (with target condition)
HI-CFG: Attack Polymorphism

Program (with target condition)

Input → buf0 → trans. → buf1 → trans. → buf2 → trans. → PoC

Input
HI-CFG: Attack Polymorphism

Program (with target condition)

PoC Input

Input | buf0 |(buf1 |(buf2 |(SE |(SE |(SE | Trans. | Trans. | Trans. |
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HI-CFG: trace-based construction 1/3

Trace enables us to recover both control-flow and information-flow of an application using some concrete input

1. Start with specific input data
2. Collect an instruction level trace (TEMU)
3. Process the traces to create a HI-CFG
HI-CFG: trace-based construction 2/3

Work through the execution trace and group "related" memory accesses

- Categorize buffers hierarchically
- Conservative and taint-based information flow

Grouping heuristics

- Instructions use same base pointer
- Temporally and spatially correlated memory accesses
HI-CFG: trace-based construction 3/3

Apply graph partitioning algorithms to divide the HI-CFG at “natural” boundaries to separate code and data structures

- Extract functionality into separate modules for reuse or transformation

No source info needed, except addresses of `malloc/calloc/free`
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Evaluation
- Scalable Symbolic Execution
- Poppler Case Study

Conclusion
Scalable SE is key

Vulnerability detection
  • Both in malware and legit applications

Model extraction
  • Automatically learn security-relevant models

Binary code reuse
  • Identify interface and extract components
Evaluation setup

Simple transformation
  • RLE decoding
  • Output as target, SE produces input

Configurations
  • KLEE
  • FuzzBALL
Limitations of SE
Limitations of SE

Vanilla symbolic execution does not scale!
Transformation-aware SE

Computations rely on input transformations

Focus on transformations to reduce complexity
  • Surjectivity guarantees existing pre-image
  • Sequentiality ensures output is never revoked
  • Streaming bounds the transformation state

Covered transformations include decryption, decompression, escape sequences, image or sound decoding
Feedback-guided optimization (FGO)

Search pruning
- if target “unreachable”

Search prioritization
- look for short inputs that maximize size of output

Symbolic array accesses
- treat choice of index like a branch (baseline)
- combine all possible values into formula
Evaluation setup

Simple transformation
- RLE decoding
- Output as target, SE produces input

Configurations
- KLEE
- FuzzBALL
- FuzzBALL-FGO
FGO: 1 order of magnitude
Transformation-aware SE

Divide-and-conquer strategy for SE

- HI-CFG captures transformations
- Split SE on transformation boundaries
Evaluation setup

Two transformations

• HEX decoding
• RLE decoding

Different configurations:

• KLEE/FuzzBALL
• FuzzBALL-FGO
• FuzzBALL-HI-CFG (includes FGO)
Transformation-aware SE: another 1 order of magnitude
Poppler Case Study

Poppler PDF viewer
  • Type 1 font parsing vulnerability CVE-2010-3704

HI-CFG construction using benign document that loads a font
  • PDF generated by pdftex using a small tex file
Poppler Phases

I/O

Flate decode

Read Font

Parse Font
Poppler Buffers

memcpy

space
bf792000
4096

alloc
828b420
312

(implicit)

alloc
829f008
34104

alloc
82b7550
9887

GfxFont::readEmbed
FontFile(Xref*, int*)

FlateStream::getHuffmanCode
Word(FlateHuffmanTab*)

FoFiType1::parse()
Poppler Buffers

Automatically produces compressed exploit

memcpy

GfxFont::readEmbed(FontFile(Xref*, int*)

FlateStream::getHuffmanCodeWord(FlateHuffmanTab*)

FoFiType1::parse()
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Related Work

HOWARD (Slowinska et al., NDSS’11, ATC12):
Type and data structure inference from binaries
  • HI-CFG looks at code & relationships between code and data (not just data structures)

AEG (Avgerinos et al., NDSS’11) and MAYHEM (Cha et al., Oakland’12):
SE-based attack input generation
  • HI-CFG enables focus on iterative and scalable SE (not focus on coverage)
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Presented HI-CFG as new data-structure
- Construction from binary execution traces

HI-CFG enables
- Deep program analysis
- Recover components from binaries
- Guide SE along probable paths

FuzzBALL symbolic execution engine:
- [http://github.com/bitblaze-fuzzball/fuzzball](http://github.com/bitblaze-fuzzball/fuzzball)