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BinComp: A Stratified Approach to Compiler Provenance Attribution

By

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BinComp: A Stratified Approach to Compiler Provenance Attribution

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Agenda

- Introduction
- Use cases
- Motivating Example
- BinComp Approach
- Evaluation
- Comparison
- Discussion and Limitations

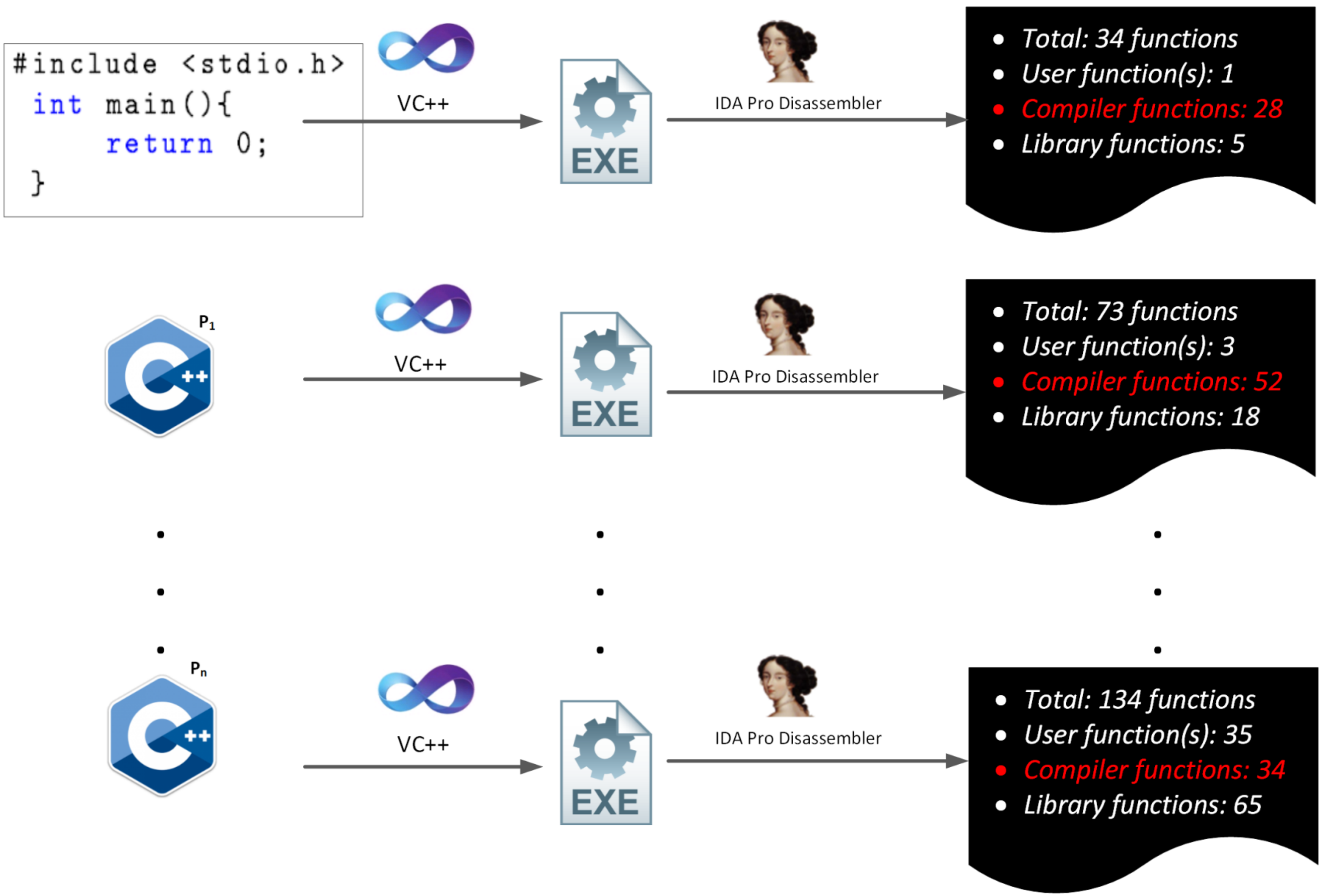
Introduction

- Compiler provenance attribution encompasses
  - Compiler family
  - Compiler version
  - Optimization level
  - Compiler-related functions
- Why compiler provenance attribution?
  - It is a necessary component at pre-processing stage for binary analysis
  - It is important in digital forensics
    - It provides information about the process by which a malware binary is produced

Use Cases

- Compiler identification can be useful for
  - Tool chain malware analysis in binaries
    - Clustering malware samples based on families (assuming each family is using a specific compiler/linker setting)
    - Reasoning about the evolution of malware binaries
  - Library identification, authorship attribution, clone detection, etc.

Motivating Example



Extract Compiler-related Functions

GCC

['___p__environ', '_strlen', '_glob_match', '_rewinddir',
'___mingwthr_run_key_dtors.part.0', '__cexit', '_strncpy', '_signal',
'_memcpy', '_GetCommandLineA@0', '__pei386_runtime_relocator',
'__errno', '___mingw_globfree', '_register_frame_ctor', '_readdir',
'__setmode', '_puts', '_SetUnhandledExceptionFilter@4', …

VC++

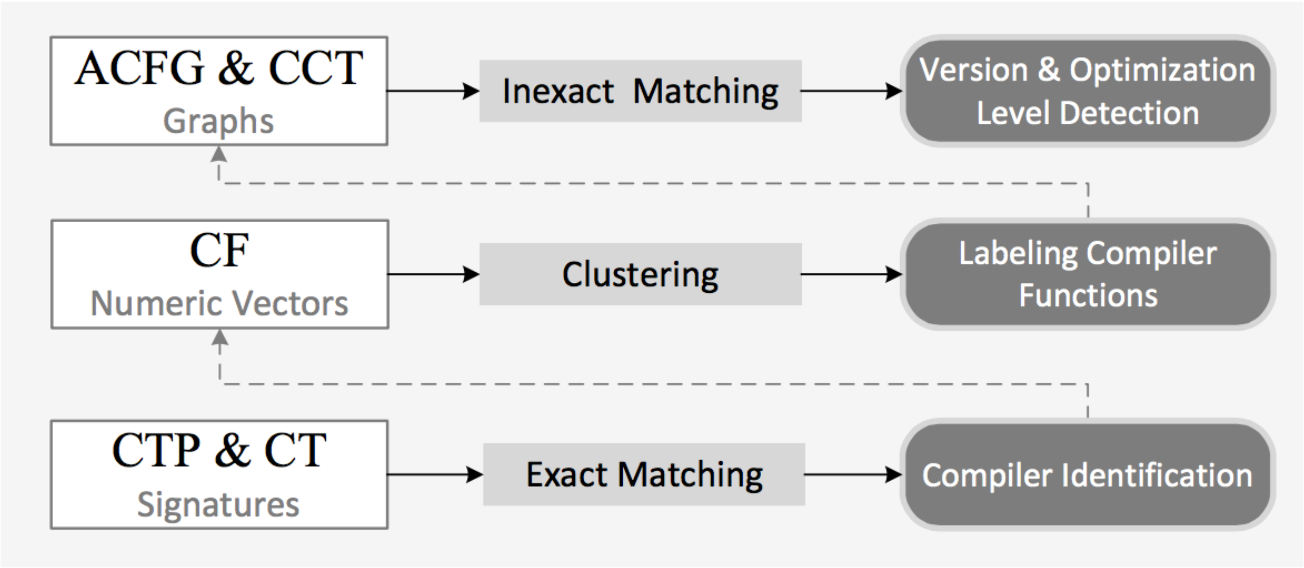
['___tmainCRTStartup', '__ValidateImageBase', '?
__CxxUnhandledExceptionFilter@@YGJPAU_EXCEPTION_POINTERS@@
@Z', '__dllonexit', '_controlfp_s', '_invoke_watson', '_amsg_exit', '?
terminate@@YAXXZ', '__setdefaultprecision', '__SEH_epilog4', '_lock',
'__onexit', 'start', '_pre_cpp_init', '_XcptFilter', '_init, …

ICC

['__cxa_atexit', '.strncat', 'getenv@@GLIBC_2.2.5',
'_ZNSt8ios_base4InitD1Ev', '__intel_cpu_features_init', '.setenv',
'_ZNSt8ios_base4InitC1Ev', '.fprintf', '.catopen',
'catopen@@GLIBC_2.2.5', '.term_proc', 'vsprintf@@GLIBC_2.2.5',
'_start', 'strlen', 'strncpy', 'strchr', …

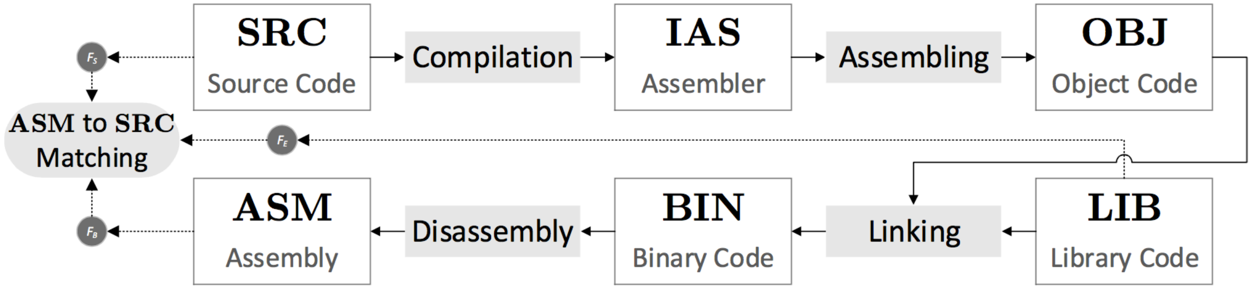
BinComp Approach

- A layered approach
  - Compiler identification (syntax features)
  - Labeling compiler functions (semantic features)
  - Version & optimization level detection (structural & semantic features)



1 st layer: Compiler Identification

- Collecting a set of known source code
- Observing the compiled outputs
- Extracting the features
  - CTP (Compiler Transformation Profile)
  - CT (Compiler Tags)
- Exact matching



1 st layer: Compiler Identification

- CTP (Compiler Transformation Profile)
  - How source-level data and control structures are reflected in the assembly output
    - For example, corresponding assembly code of `if/else` compiled with VS will be `cmp` or `test`, then `jcc`.
- CT (Compiler Tag)
  - Compilers may embed certain tags in the form of strings or constants
    - For example, GCC writes a *.comment* section that contains the GCC version string

2^{nd} layer: Compiler Function Labeling

- Signature generation
  - Extracting CF (Compiler Functions)
    - Numerical vectors such as number of instructions, type of registers, etc.
    - Symbolic vectors: such as function names, function prototypes, etc.
- Signature detection
  - Computing the similarity

n Function Name, **ne** Demangled Name, **i** Imported Function, **k** Call List (From), **ke** Demangled Calls, **ix** Number of Imported Functions, **kx** Number of Calls
c Constant, **s** String, **cx** Number of Constants, **sx** Number of Strings
p Function Prototype, **a** Function Argument, **r** Return Type, **g** Number of a, **b** Size of Arguments, **gx** RES. Number of g
m Number of Instructions, **l** Size of Local Variables, **f** Function Flags, **o** Code References (From), **z** Function Size, **mx** RES. Number of m, **ox** Number of o, **cc** Cyclomatic Complexity, **bx** Number of Basic Blocks
d Dictionary (Malware Tag), **t** API Tag, **dx** Number of d, **tx** Number of t
av Anti-VM, **reg** General Register, **mem** Memory Reference, **bix** [Base +Index], **bid** [Base+Index+Displacement], **imm** Immediate, **ifa** Immediate Far Address, **ina** Immediate Near Address, **fpp** FPP Register, **ctr** Control Register, **dbr** Debug Register, **trr** Trace Register
DTR Data Transfer, **DTO** Data Transfer Address Object, **FLG** Flag Manipulation, **DTC** Data Transfer Conversion, **ATH** Binary Arithmetic, **LGC** Logical, **CTL** Control Transfer, **INO** Input Output, **INT** Interrupt and System, **FLT** Floating, **MSC** Misc.

2nd layer: Compiler Function Labeling

- Example of CF features

COMP	OPL	Symbolic Function ID	DTR,	DTO,	FLG,	ATH,	LGC,	CTL,	INO,	INT,	FLT,	REG,	MEM,	IMM,	IFA,	INA
VS	OP2	@__security_check_cookie@4	0,	0,	0,	0,	0,	4,	0,	0,	0,	001,	001,	000,	000,	002
VS	OP2	___tmainCRTStartup	3,	0,	1,	2,	1,	6,	0,	0,	0,	077,	028,	017,	000,	025
GCC	OP0	___mingw_CRTStartup	3,	1,	1,	3,	6,	7,	0,	0,	0,	216,	015,	068,	000,	071
GCC	OP0	___gcc_register_frame	3,	0,	1,	1,	0,	3,	0,	0,	0,	029,	001,	014,	000,	009

Instruction Categories.

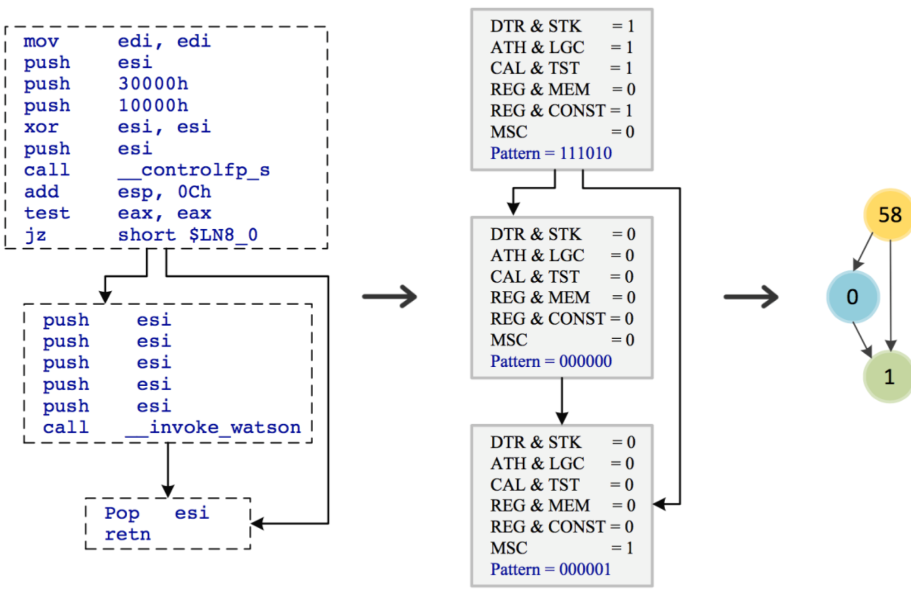
Feature	Description	Feature	Description
DTR	Data Transfer	INA	Indirect Near Address
INO	Input/Output	DTO	Data Transfer Object
FLT	Float Point	FLG	Flag Manipulation
REG	Registers	LGC	Logical Instructions
MEM	Memory	CTL	Control Instructions
IMM	Immediate Value	IFA	Indirect Far Address
INT	Interrupt/System	ATH	Arithmetic Instructions

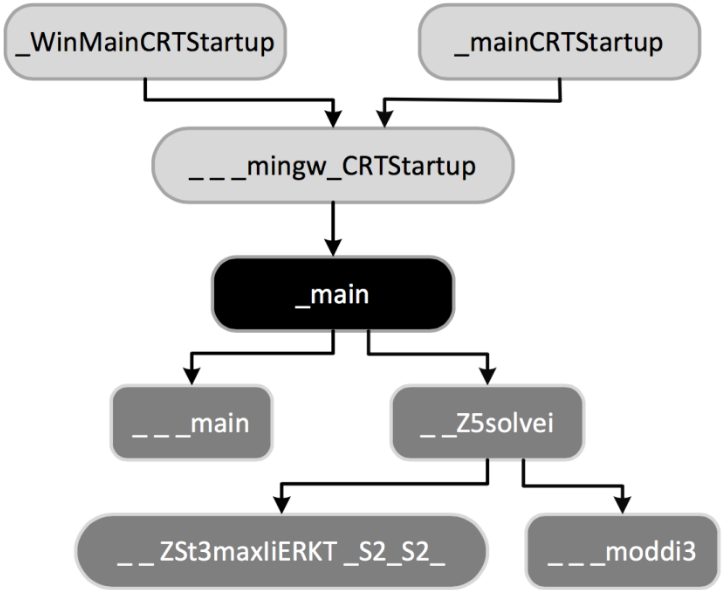
$$d_J(t_i, t_j) = \frac{S(t_i \wedge t_j)}{S(t_i \vee t_j)}$$

t_i, t_j: fingerprint vectors generated from the candidate function pairs

3rd layer: Version & Optimization

- Extracting the features
  - ACFG (Annotated Control Flow Graph)
  - CCT (Compiler Constructor Terminator)





3rd layer: Version & Optimization

- According to our experiments ACFG and CCT are the best features to detect the version and optimization
  - The different versions can affect the ACFG
  - The different optimization levels affect the CCT
    - For instance, the CCT for full optimized is a subset of CCT for the no-optimization code

Data set compilation settings.

Compiler	Version	Optimization
GCC	3.4	O0
	4.4	O2
ICC	10	O0
	11	O2
VS	2010	O0
	2012	O2
XCODE	5.1	O0
	6.1	O2s

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Evaluation

- Dataset
  - Four free open-source projects (SQLite, zlib, libpng, and openSSL)
  - Google Code Jam (232 files)
  - Students Code Projects (993 files)

Evaluation

- Results

Accuracy for variations of compiler versions.

Compiler	Version	Accuracy
GCC	3.4.x	86%
	4.4.x	89%
ICC	10.x	83%
	11.x	90%
VS	2010	70%
	2012	71%
XCode	5.x	78%
	6.1	74%

Accuracy for variations of compiler optimization levels.

Compiler	Optimization	Average Accuracy
GCC	O0, O2	91%
ICC	O0, O2	89%
VS	O0, O2	95%

Comparison

	IDA Pro Disassembler	Rosenblum et al	BinComp
Features	Entry point signatures	Syntax (n-gram)	Syntax, Semantic, Structural
Detection Method	Signature based	Classification	Exact/Inexact matching
Compilers	VS, Delphi, Fortran	GCC, VS, ICC	VS, GCC, ICC, XCODE
Required data set	Small	Large	Small
Scalability	✓	✗	✓
Time efficient	✓	✗	✓
Identifying Ver.	✗	✗	✓
Identifying Opt.	✗	✗	✓

Discussion and Limitations

- BinComp requires few data set and it can be applied for any compiler
- BinComp is efficient in terms of time and scalability
- Limitations
  - The binary code is deobfuscated
  - Only Intel x86/x86-64 architecture is considered

Thank You!

Evaluation

- Accuracy
  - Precision (P)
  - Recall (R)

$$P = \frac{TP}{TP + FP}$$

$$R = \frac{TP}{TP + FN}$$

- Our application domain is much more sensitive to false positives than false negatives

$$F_{0.5} = 1.25 \cdot \frac{PR}{0.25P + R}$$

Neighbor hash graph kernel (NHGK)

- Neighbor hash graph kernel (NHGK)
  - Condense the information contained in a neighborhood into a single hash value
  - Label each node in the function call graph
    - each function is characterized by its numerical and symbolic feature vectors
- our method strives to model the composition of functions
  - The neighborhood of a function must be taken into account.
  - We compute a neighborhood hash over all of its direct neighbors in the function call graph

$$h(f_i) = shr_1(G(f_i)) \oplus \left(\oplus_{f_j \in N_{f_i}} G(f_j) \right)$$

  - shr_1: a one-bit shitt right operation
  - $\oplus$: a bit-wise XOR on the binary labels