Methodologies for Quantifying (Re-)randomization Security and Timing under JIT-ROP

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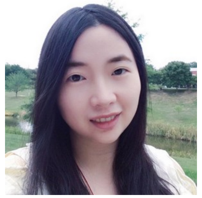




JIT-ROP Attack and Fine-grained ASLR

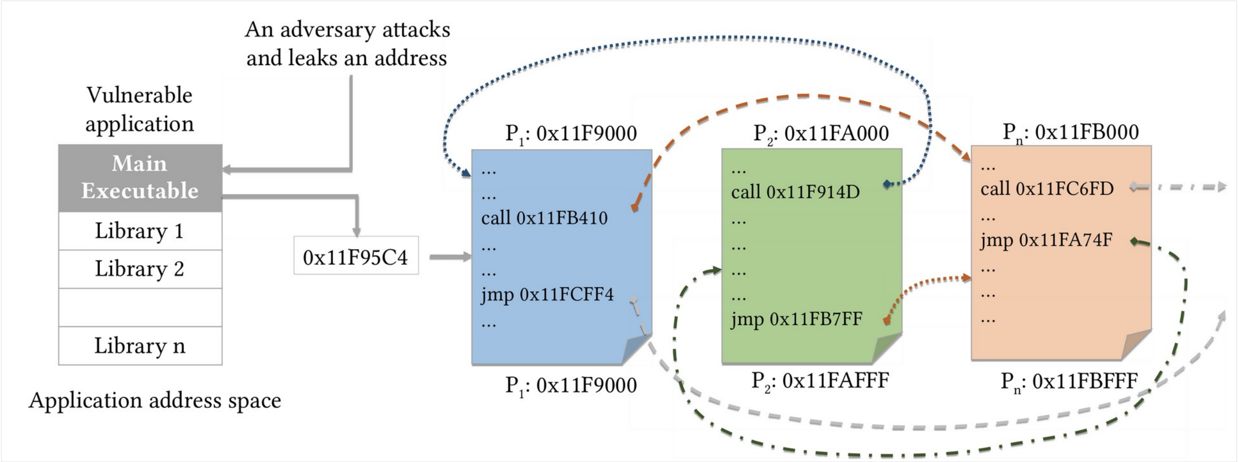
JIT-ROP is a powerful attack technique known for bypassing fine-grained ASLR

- Repeated code pointer leak from a single leak

Does JIT-ROP completely break fine-grained ASLR?

- How much broken the fine-grained ASLR is?

- Are there still good elements of fine-grained ASLR?



Just-In-Time Return-Oriented Programming (JIT-ROP)

Motivation

In-depth questions regarding the impact of fine-grained ASLR on code reuse attacks is not clear

Unclear to choose re-randomization intervals.

Key Questions to Answer

(1) What impact do fine-grained ASLR have on the Turing-complete expressiveness of JIT-ROP payloads?

(2) How do attack vectors (e.g., code pointer leaks) impact the code reuse attacks?

(3) How would one compute the re-randomization interval effectively to defeat JIT-ROP attacks?

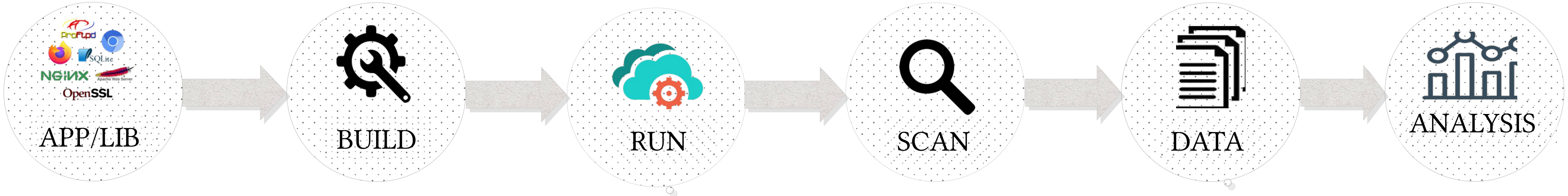
Our Measurement Approach

We emulate parts of the JIT-ROP attack.

We evaluated 5 fine-grained ASLR tools using 20 applications, and 25 dynamic libraries.

Fine-grained versions are built using Zipr[1], SR[2], CCR[3], MCR[4], Shuffler[5]

JIT-ROP code harvest is performed



Apps/libs run workloads & intentionally leak code pointers.

Gadgets, havest-time, and libc pointers are stored.

[1]https://git.zephyr-software.com/opensrc/irdb-cookbook-examples
[2]https://github.com/immunant/selfrando
[3]https://github.com/kevinkoo001/CCR
[4]https://github.com/securesystemslab/multicompiler
[5]https://github.com/orgs/columbia/teams/shuffler-ro

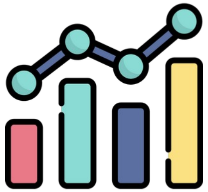
Why NOT Launching JIT-ROP Exploits?

We did not launch **JIT-ROP** exploits due to

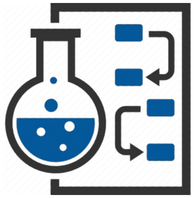
(1) low scalability,

(2) low reproducibility, and

(3) inaccurate measurement issues



Need **specific**, **relevant**, and **measurable** metrics



Require **systemic** measurement methodologies

Our Metrics and Methodologies

We identify **FOUR** security metrics and design **FOUR** measurement methodologies.

Security metrics

1. Attack time
2. Gadget availability
3. Quality of gadget
4. Number of libc pointers

Methodologies

1 Upper bound
We determine the upper bound for re-randomization intervals using attack time and gadget availability metrics.

2 Attack surface reduction
We determine attack surface reduction using availability of gadgets.

3 Security impact
We quantify the security impact of defenses by varying attack time and attack vectors and using quality of gadget chain.

4 Critical module
We determining the critical module of a binary using the number of libc pointers.

Our Gadget Availability and Gadget Quality Metrics

We represent each gadget using TWO footprints.

(1) Minimum footprint gadgets: mov rax, rbx; ret;

(2) Extended footprint gadgets: mov rax, rbx; add rax, rsi; ret;

We compute **gadget corruption rate** based on the register corruption in extended footprint gadgets.

```
mov edx, dword ptr [rdi];
mov eax, edx;        <- core instruction
shr eax, 0x10;
xor eax, edx;
ret;
```

Details of gadget sets in the paper

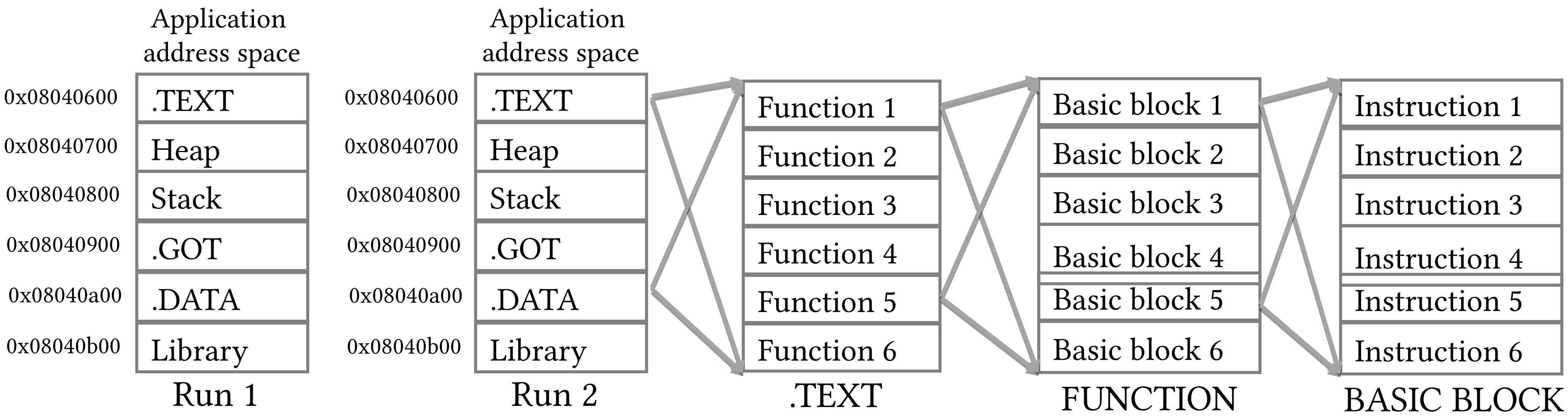
We combine **FOUR** sets of gadgets for the gadget availability metric.

1. Turing-complete (TC) gadget set
2. Priority gadget set
3. MOV TC gadget set
4. Payload gadget set

Our Threat Model

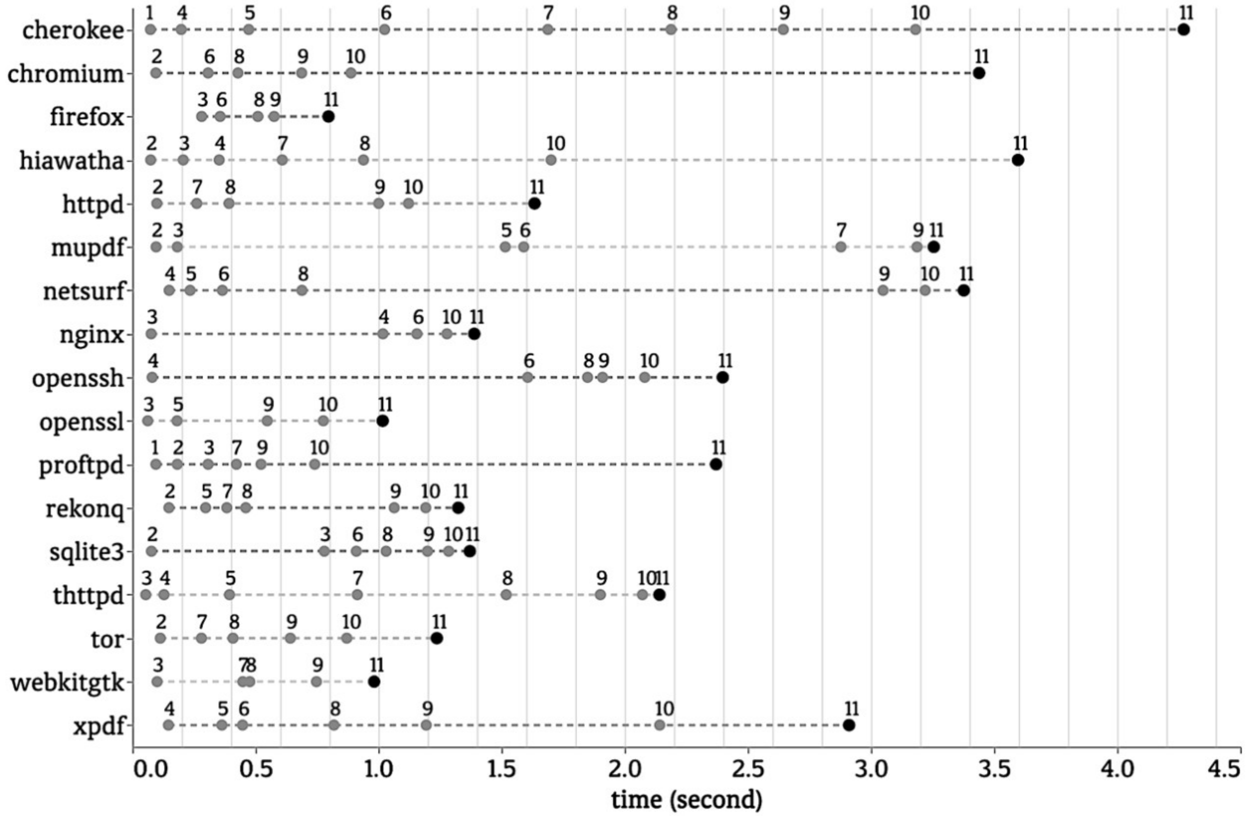
- Stack Canary, W⊕X, RELRO
- **Fine-grained ASLR**
- A leaked pointer is available
- No CFI + XoM + CPI
- Attack model: JIT-ROP

Decoupling them helps one better understand the individual factor's security impact.



Our Findings

Our Finding 1: Computing Re-Randomization Upper Bound



Turing-complete gadget set with a timeline for new gadget type leaks.

The upper bound* ranges from 1.5 to 3.5 seconds in our tested applications such as nginx, proftpd, firefox, etc.

	Time to leak all gadget types	
Gadget set	**Minimum (s)**	**Average (s)**
TC	2.2	4.3
Priority	1.5	3.5
MOV TC	3.5	5.3
Payload*	2.1	4.8
Average	**2.3s**	**4.5s**

* May vary with machine configurations

Our Finding 2: Quantification of Attack Surface Reduction

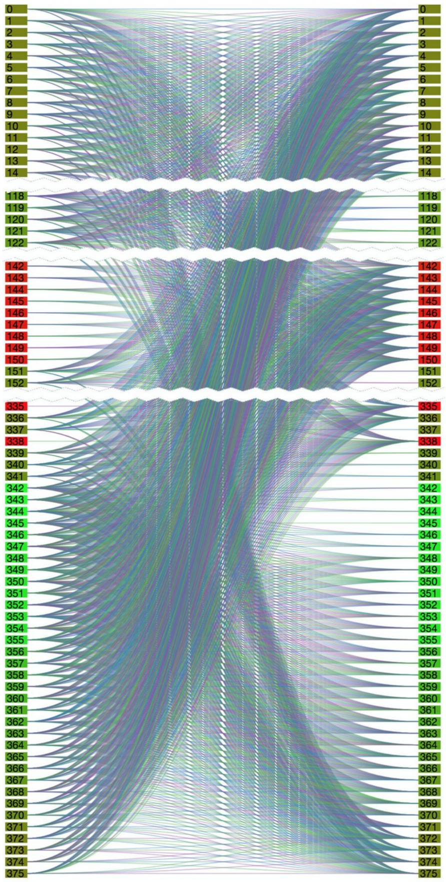
Single-round **instruction-level** randomization limits up to **90%** gadgets and restricts Turing-complete operations.

Randomization schemes	Granularity	$\Downarrow$ (%) MIN-FP	$\Downarrow$ (%) EX-FP
Main executables			
Inst. level rando. [50]	Inst.	**79.7**	**82.5**
Func. level rando. [25]	FB	27.63	36.55
Func.+Reg. level rando. [53]	FB & Reg.	17.62	42.37
Block level rand. [59]	BB	19.58	44.64
Dynamic libraries			
Inst. level rando. [50]	Inst.	**81.3**	**92.2**
Func. level rando. [25]	FB	46.5	43.8
Func.+Reg. level rando. [53]	FB & Reg.	44.2	43.9
Block level rand. [59]	BB	20.98	37.0

Reduction of Turing-complete gadget set with different randomization schemes

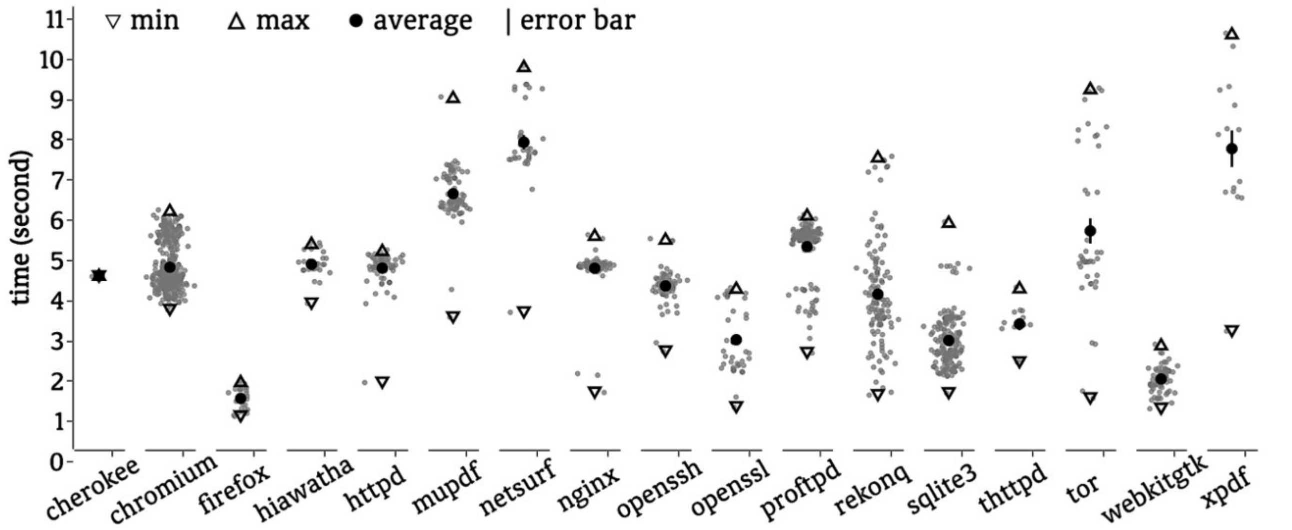
Our Finding 3: Impact of the Location of Pointer Leakage

No impact on connectivity



Connectivity of libc

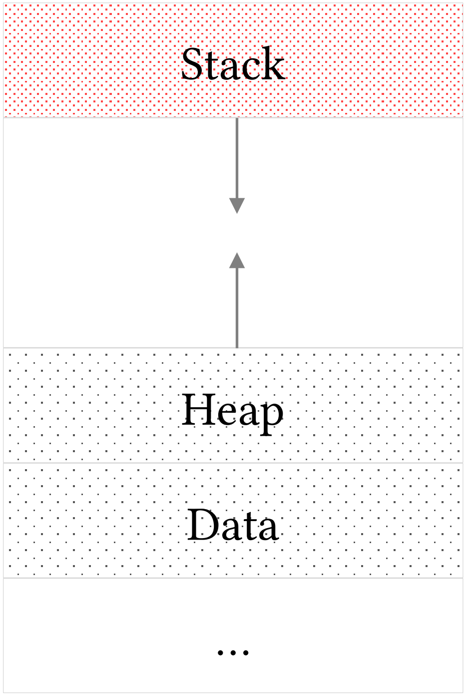
Has an impact on the attack time: dense code pages contain diverse set of gadgets

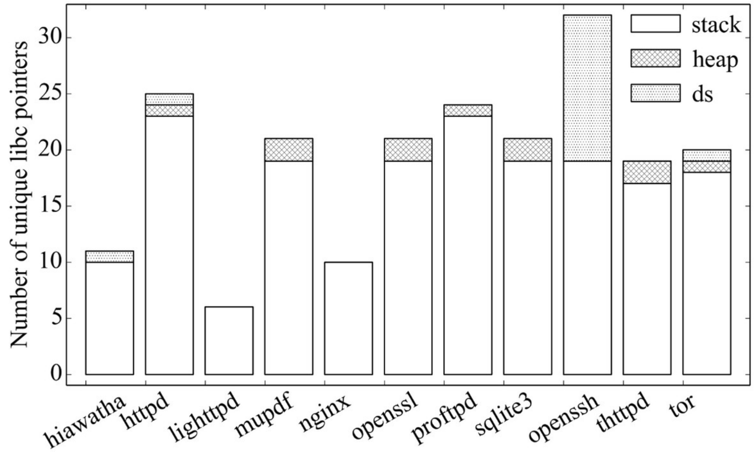


Impact of starting pointer locations on gadget harvesting time.

Our Finding 4: Critical Module Determining

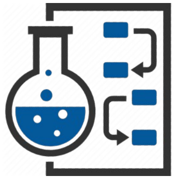
A Stack has higher risk than heap or data-segment





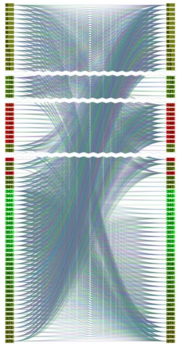
Stacks contain 16 more libc pointers than heaps or data segments on average.

Key Takeaways



Security metrics and methodologies for large-scale evaluations

Methodology to compute effective re-randomization upper bound



High connectivity in code, enabler for JIT-ROP

Instruction-level randomizations limit Turing-complete operations

All leaked pointers are created equal for gadget availability, but not for the time to leaks gadgets

Acknowledgment

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Code availabile on GitHub
https://github.com/salmanyam/jitrop-native

Thank You