WarpAttack: Bypassing CFI through Compiler-Introduced Double-Fetches

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Course of ICT Risk Assessment

Overview

WarpAttack exploits compiler-introduced double-fetch optimizations to mount TOCTTOU attacks.

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- Evaluation and mitigations

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Not a total solution!

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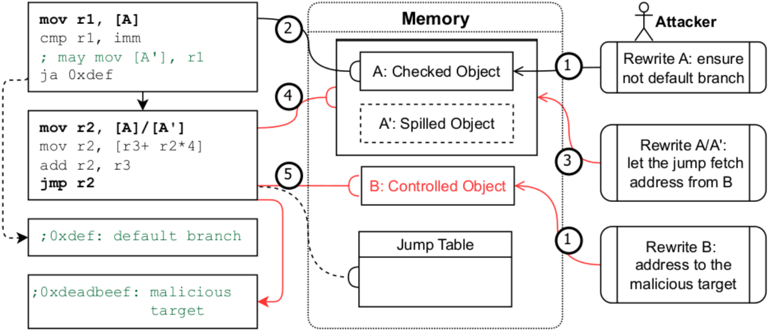
30,000-foot view



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Double-Fetch

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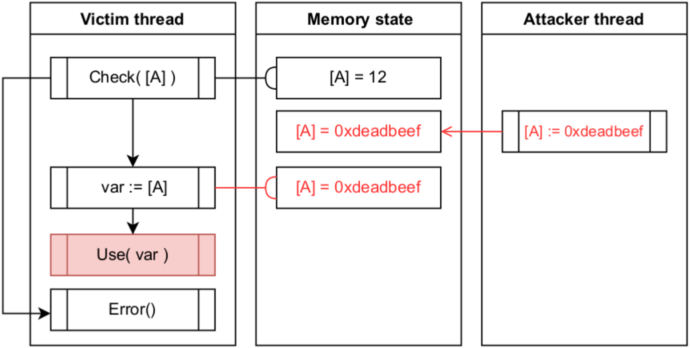

Double-Fetch

"Double-fetch bugs occur when a privilege system reads a variable multiple times, but the fetched value is inconsistent due to concurrency issues"

- CVE-2008-2252: Windows
- CVE-2005-2490: Linux kernel
- CVE-2015-1420: Linux kernel (Android)
- CVE-2022-48357: Huawei products

⋮

Bound-Checked Jump Table

The code for a jump table lookup consists of

- a bound check;
- an indirect jump (whose address is computed with the checked value).

```
;switch(obj->type) {
;   case 0:
; ...
;   default:
; ...
;}
mov     rax, rdi
mov     eax, DWORD PTR [rdi+0x30]
add     eax, 0xffffffff
cmp     eax, 0x11 ;the bound check
ja      401163  ;default branch
lea     rdi, [rax+0x30]
jmp     QWORD PTR [rax*8+0x402008]
```

Assumptions

Adversarial Capabilities

- Arbitrary read-write

Defensive Assumptions

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PoC Exploit

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Version: 106.0.1
Built by: GCC 12.1.1

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- Gain arbitrary read/write capability: CVE-2022-26485

PoC Exploit

- Gain arbitrary read/write capability: `out-of-bound` that grants arbitrary read/write capabilities through *ArrayBuffers*.

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out-of-bound `Uint8Array` → leak ArrayBuffer._elements → libxul base address → __environ → stack base address

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  `document.getElementById('textarea').value += x`

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- Orchestrate the thread scheduling to win the data race
- Overwrite the checked object and hijack the control flow

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Gadget Code Detection

Binary Analysis tool

- designed for offensive purposes

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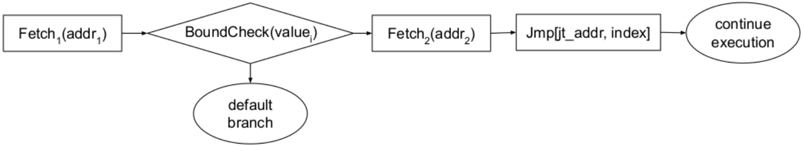

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Benchmarks

Intel(R) Core(TM) i7-10700 CPU (8 cores) @ 2.90GHz with 32GB of memory and Fedora 36

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Algorithm 1 Measuring our PoC's success rate.

```
function EXPERIMENT
    while 2000 times do
        repeat                          ▷ one attempt
            attack()        ▷ run the race to overwrite
        until 20s have passed
    end while
end function
```

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TABLE 1. DIFFERENT SUCCESS RATES BY TUNING NUMBER OF CORES AND NUMBER OF ATTACKER THREADS (IN 2000 RUNS).

#Core	#Attacker Threads		
	1	3	7
1	0	0	0
4	0.05%	0.25%	0.2%
8	0.15%	0.15%	0.45%

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- Which compiler is affected by such situation?
- Which CFI implementation is vulnerable to WarpAttack?
- What architectures are affected by WarpAttack?

TABLE 2. STATISTICS OF DOUBLE-FETCH GADGETS IN THE WILD. WE EXCLUDED APACHE FOR MAC OS BECAUSE WE FAIL TO FIND THE CORRECT PRE-COMPILED VERSION FOR INTEL MAC OS.

Program	Fedora	Debian	Ubuntu	Windows	Mac OS
Chrome	1024	16	23	24	16
Firefox	616	659	31	0	29
Apache	15	17	16	0	-
JVM	0	0	0	0	1
7-zip	24	24	24	0	0
Texstudio	8	9	9	230	20
Total	1687	725	103	254	66

A Study of Compilers

TABLE 3. COMPILERS THAT CAN INTRODUCE EXPLOITABLE DOUBLE-FETCH PAIRED TO THEIR COMPILATION OPTIONS. THE SYMBOL "*" INDICATES CASES OBSERVED FROM REAL WORLD PROGRAMS.

Compiler	Option	double-fetch Type	version
GCC	`O1,O2,O3,Ofast`	Var. 1 (fetch-fetch)	12.1
*G++	`O1,O2,O3`	Var. 2 (fetch-spill-fetch)	12.1
Clang	`O0`	Var. 2 (fetch-spill-fetch)	14.0.*
*Clang	`O1,O2,O3`	Var. 2 (fetch-spill-fetch)	14.0.*
*Clang	`O3`	Var. 1 (fetch-fetch)	14.0.*
*Clang++	`O3`	Var. 1 (fetch-fetch)	14.0.*
MSVC	`Od`	Var. 1 (fetch-fetch)	19.32.*

Vulnerable CFI implementations

TABLE 4. CFI IMPLEMENTATIONS VULNERABLE TO OUR ATTACK.

CFI Type	Compiler	Vulnerable CFI
Compiler-based CFI	GCC	VTV [13]
	Clang	LLVM-CFI [12]
	MSVC	CFG [43]
Binary only CFI	–	Lockdown [20]

Vulnerable Architectures

TABLE 5. CONFIRMED VULNERABLE ARCHITECTURES AND INVOLVED VARIANTS AND COMPILERS.

	Variant 1 (fetch-fetch)	Variant 2 (fetch-spill-fetch)
X86/-64	GCC O1/O2/O3	Clang O0; MSVC Od
ARM 32/64	-	Clang O0; MSVC Od
RISCV 32/64	-	Clang O0
MIPS 32/64	GCC O1/O2/O3	-

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- Avoiding Gadget code generation: GCC's `-fno-switch-tables` Clang, MSVC optimization level > O0
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- Protecting Indirect Jump: dynamic checks
- Monitoring for Attack Behavior: spawning several threads, constantly writing a certain memory site; crashes; ...
- Making compilers aware of sensitive code: annotating security-related code

Based on the work of

J. Xu, L. Di Bartolomeo, F. Toffalini, B. Mao, M. Payer

Thank You.