Kernel Self Protection Project

Collaboration Summit 2016, Lake Tahoe, CA

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https://outflux.net/slides/2016/cs/kspp.pdf

Agenda

- Background
  - “Security” in the context of this presentation
  - Why we need to change what we’re doing
  - Just fixing bugs isn’t sufficient
- Kernel Self Protection Project
  - Who we are
  - What we’re doing
  - How you can help
- Challenges

I. Lietuvių Susivažiavimas Vilniuje.

Lapkričio 21—22 (Gruodžio 4—5) d. 1905.

PROGRAMA:

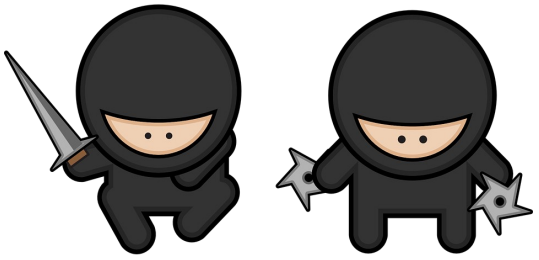
1. *Lietuvystės pradžia ir dabartis.*
2. *Lietuviai, latviai ir įvairios tautos Lietuvoje gyvenančios.*
3. *Caro manifestas nuo Spalinio 17 (30) dienos.*
4. *Lietuvos autonomija ir prikergimas Suvalkų gubernijos prie autonomiškosios Lietuvos.*
5. *Rinkimai į Viešpatystės seimą.*
6. *Lietuvos sodiečiai po rusų valdžia.*
7. *Lietuvos mokyklos.*
8. *Apie įvairius mokesčius.*
9. *Apie žemiečių įstaigas.*
10. *Apie išeivystę (emigraciją).*
11. *Apie kareiviavimą.*

Gali buti įnešami ir kitoki klausimai.

Organizacijos Komitetas.

Kernel Security

- More than access control (SELinux)
- More than attack surface reduction (seccomp)
- More than bug fixing (CVEs)
- More than protecting userspace
- This is about *Kernel Self Protection*



Devices using Linux

- Servers, laptops, cars, phones, …
- >1,400,000,000 active Android devices in 2015
- Vast majority are running v3.4 (with v3.10 a distant second)
- Bug lifetimes are even longer than upstream
- “Not our problem”? None of this matters: even if upstream fixes every bug found, and the fixes are magically sent to devices, bug lifetimes are still huge.

Upstream Bug Lifetime

- In 2010 Jon Corbet researched security flaws, and found that the average time between introduction and fix was about 5 years.
- My analysis of Ubuntu CVE tracker for the kernel from 2011 through 2015:
  - Critical: 2 @ 3.3 years
  - High: 31 @ 6.3 years
  - Medium: 297 @ 4.9 years
  - Low: 172 @ 5.1 years
- http://seclists.org/fulldisclosure/2010/Sep/268

Fighting Bugs

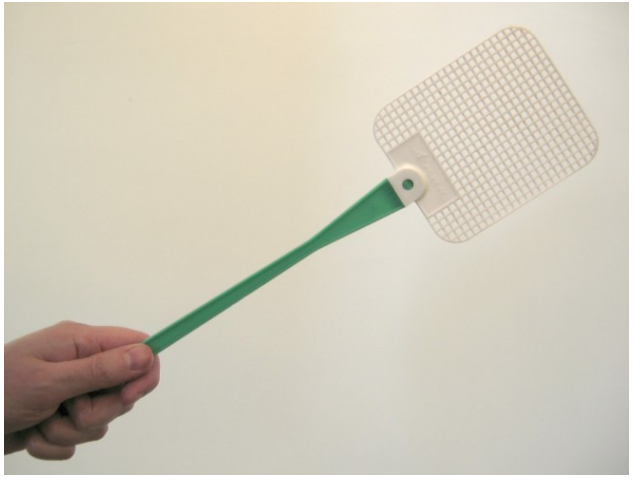
- We’re finding them
  - Static checkers: compilers, smatch, coccinelle, coverity
  - Dynamic checkers: kernel, trinity, KASan
- We’re fixing them
  - Ask Greg KH how many patches land in -stable
- They’ll always be around
  - We keep writing them
  - They exist whether we’re aware of them or not
  - Whack-a-mole is not a solution

Analogy: 1960s Car Industry

- @mricon's presentation at 2015 Linux Security Summit
  - http://kernsec.org/files/lss2015/giant-bags-of-mostly-water.pdf
- Cars were designed to run, not to fail
- Linux now where the car industry was in 1960s
  - https://www.youtube.com/watch?v=fPF4fBGNK0U
- We must handle failures (attacks) safely
  - Lives depend on Linux

Killing bugs is nice

- Some truth to security bugs being “just normal bugs”
- Your security bug may not be my security bug
- We have little idea which bugs attackers use
- Bug might be in out-of-tree code
  - Un-upstreamed vendor drivers
  - Not an excuse to claim “not our problem”



Killing bug classes is better

- If we can stop an entire kind of bug from happening, we absolutely should do so!
- Those bugs never happen again
- Not even out-of-tree code can hit them
- But we'll never kill all bug classes

Killing exploitation is best

- We will always have bugs
- We must stop their exploitation
- Eliminate exploitation targets and methods
- Eliminate information leaks
- Eliminate anything that assists attackers
- *Even if it makes development more difficult*

Typical Exploit Chains

- Modern attacks tend to use more than one flaw
- Need to know where targets are
- Need to inject (or build) malicious code
- Need to locate malicious code
- Need to redirect execution to malicious code

What can we do?

- Many exploit mitigation technologies already exist (e.g. Grsecurity/PaX) or have been researched (e.g. academic whitepapers), but are not present in the upstream Linux kernel
- There is demand for kernel self-protection, and there is demand for it to exist in the upstream kernel
- http://www.washingtonpost.com/sf/business/2015/11/05/net-of-insecurity-the-kernel-of-the-argument/

Kernel Self Protection Project

- http://www.openwall.com/lists/kernel-hardening/
  - http://www.openwall.com/lists/kernel-hardening/2015/11/05/1
- http://kernsec.org/wiki/index.php/Kernel_Self_Protection_Project
- People interested in coding, testing, documenting, and discussing kernel self protection technologies and related topics

Kernel Self Protection Project

- There are other people working on excellent technologies that ultimately revolve around the kernel protecting *userspace* from attack (e.g. brute force detection, SROP mitigations, etc)
- KSPP focuses on the kernel protecting the *kernel* from attack
- Currently 5 organizations and 2 individuals working on about 11 technologies
- Slow and steady

KSPP Developers

- LF’s Core Infrastructure Initiative funded:
  - Emese Revfy
- Self-funded:
  - David Windsor
- RedHat
  - Laura Abbott
- Google
  - Kees Cook
- Linaro
  - Ard Biesheuvel
  - David Brown
- Oracle
  - Quentin Casasnovas
- Intel
  - Casey Schaufler
  - Elena Reshetova
  - Michael Leibowitz

Bug class: Stack overflow

Exploit example:

- https://jon.oberheide.org/files/half-nelson.c

- Mitigations:
  - **stack canaries, e.g. gcc's -fstack-protector (v2.6.30) and -fstack-protector-strong (v3.14)**
  - *guard pages (e.g. GRKERNSEC_KSTACKOVERFLOW)*
    - KSPP: Quentin Casasnovas
  - alloca checking (e.g. PAX_MEMORY_STACKLEAK)
  - kernel stack location randomization
  - shadow stacks

Bug class: Integer over/underflow

- Exploit examples:
  - https://cyseclabs.com/page?n=02012016
  - http://perception-point.io/2016/01/14/analysis-and-exploitation-of-a-linux-kernel-vulnerability-cve-2016-0728/
- Mitigations:
  - *check for refcount overflow (e.g. PAX_REFCOUNT)*
    - KSPP: David Windsor
  - compiler instrumentation to detect multiplication overflows at runtime (e.g. PAX_SIZE_OVERFLOW)

Bug class: Heap overflow

- Exploit example:
  - http://blog.includesecurity.com/2014/06/exploit-walkthrough-cve-2014-0196-pty-kernel-race-condition.html
- Mitigations:
  - *runtime validation of variable size vs copy_to_user / copy_from_user size (e.g. PAX_USERCOPY)*
    - KSPP: Casey Schaufler
  - guard pages
  - metadata validation (e.g. glibc's heap protections)

Bug class: format string injection

- Exploit example:
  - http://www.openwall.com/lists/oss-security/2013/06/06/13
- Mitigations:
  - **Drop %n entirely (v3.13)**
  - detect non-const format strings at compile time (e.g. gcc's -Wformat-security, or better plugin)
  - detect non-const format strings at run time (e.g. memory location checking done with glibc's -D_FORITY_SOURCE=2)

Bug class: kernel pointer leak

- Exploit examples:
  - examples are legion: /proc (e.g. kallsyms, modules, slabinfo, iomem), /sys, **INET_DIAG (v4.1)**, etc
  - http://vulnfactory.org/exploits/alpha-omega.c
- Mitigations:
  - **kptr_restrict sysctl (v2.6.38)** too weak: requires dev opt-in
  - remove visibility to kernel symbols (e.g. GRKERNSEC_HIDESYM)
  - detect and block usage of %p or similar writes to seq_file or other user buffers (e.g. GRKERNSEC_HIDESYM + *PAX_USERCOPY*)

Bug class: uninitialized variables

- This is not just an information leak!
- Exploit example:
  - https://outflux.net/slides/2011/defcon/kernel-exploitation.pdf
- Mitigations:
  - clear kernel stack between system calls (e.g. PAX_MEMORY_STACKLEAK)
  - instrument compiler to fully initialize all structures (e.g. PAX_MEMORY_STRUCTLEAK)

Bug class: use-after-free

- Exploit example:
  - http://perception-point.io/2016/01/14/analysis-and-exploitation-of-a-linux-kernel-vulnerability-cve-2016-0728/
- Mitigations:
  - *clearing memory on free can stop attacks where there is no reallocation control (e.g. PAX_MEMORY_SANITIZE)*
    - KSPP: Laura Abbott
  - segregating memory used by the kernel and by userspace can stop attacks where this boundary is crossed (e.g. *PAX_USERCOPY*)
  - randomizing heap allocations can frustrate the reallocation efforts the attack needs to perform (e.g. OpenBSD malloc)

Exploitation: finding the kernel

- Exploit examples:
  - See “Kernel pointer leaks” above
  - https://github.com/jonoberheide/ksymhunter
- Mitigations:
  - hide symbols and kernel pointers (see “Kernel pointer leaks”)
  - kernel ASLR: **x86 (v3.14)**, *arm64*
    - KSPP: Ard Biesheuvel
  - runtime randomization of kernel functions
  - executable-but-not-readable memory
  - *per-build structure layout randomization (e.g. GRKERNSEC_RANDSTRUCT)*
    - KSPP: Michael Leibowitz

Exploitation: Direct kernel overwrite

- How is this still a problem in the 21st century?
- Exploit examples:
  - Patch setuid to always succeed
  - http://itszn.com/blog/?p=21 Overwrite vDSO
- Mitigations:
  - **Executable memory should not be writable (e.g CONFIG_DEBUG_RODATA)**
    - **x86: v3.18**
    - **ARM: v3.19**
    - **arm64: v4.0**

Exploitation: function pointer overwrite

- Also includes things like vector tables, descriptor tables (which can also be info leaks)
- Exploit examples:
  - https://outflux.net/blog/archives/2010/10/19/cve-2010-2963-v4l-compat-exploit/
  - https://blogs.oracle.com/ksplice/entry/anatomy_of_an_exploit_cve
- Mitigations:
  - *read-only function tables (e.g. PAX_CONSTIFY_PLUGIN)*
    - KSPP: Emese Revfy
  - *make sensitive targets that need one-time or occasional updates only writable during updates (e.g. PAX_KERNEXEC)*
    - KSPP: Kees Cook

Exploitation: userspace execution

- Exploit example:
  - See almost all previous examples
- Mitigations:
  - hardware segmentation: **SMEP (x86), PXN (ARM, arm64), Domains (ARM: v4.3),** *TTBR0 (ARMv8.0)*
    - KSPP: David Brown
  - emulated memory segmentation via page table swap, PCID, etc (e.g. PAX_MEMORY_UDEREF)
  - compiler instrumentation to set high bit on function calls

Exploitation: userspace data

- Exploit examples:
  - https://github.com/geekben/towelroot/blob/master/towelroot.c
  - http://labs.bromium.com/2015/02/02/exploiting-badiret-vulnerability-cve-2014-9322-linux-kernel-privilege-escalation/
- Mitigations:
  - hardware segmentation: **SMAP (x86), PAN (ARM, arm64), Domains (ARM: v4.3)**
  - emulated memory segmentation via page table swap, PCID, etc (e.g. PAX_MEMORY_UDEREF)

Exploitation: Reused code chunks

- Also known as Return Oriented Programming (ROP), Jump Oriented Programming (JOP), etc
- Exploit example:
  - http://vulnfactory.org/research/h2hc-remote.pdf
- Mitigations:
  - *JIT obfuscation (e.g. BPF_HARDEN)*
    - KSPP: Elena Reshetova
  - compiler instrumentation for Control Flow Integrity (CFI)
  - Return Address Protection, Indirect Control Transfer Protection (e.g. RAP)
    - https://pax.grsecurity.net/docs/PaXTeam-H2HC15-RAP-RIP-ROP.pdf

Challenge: Culture

- Conservatism
  - 16 years to accept symlink restrictions upstream
- Responsibility
  - Kernel developers must accept the need for these changes
- Sacrifice
  - Kernel developers must accept the technical burden

Challenge: Technical

- Complexity
  - Very few people are proficient at developing (much less debugging) these features
- Innovation
  - We must adapt the many existing solutions
  - We must create new technologies

Challenge: Resources

- People
  - Dedicated developers
- People
  - Dedicated testers
- People
  - Dedicated backporters

Thoughts?

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