kGraft
Live patching of the Linux kernel

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Why live patching?

• Common tiers of change management:
  1. Incident response – (we're down, actively exploited …)
  2. Emergency change – (we could go down, are vulnerable …)
  3. Scheduled change – (time is not critical, we keep safe)

• Live patching fits in with 1 and 2

• Rebooting a 1000 servers is not a quick way to fix a pressing issue and also carries the risk of them not coming up for other reasons

• Live patching allows quick response and leaving an actual update to a scheduled downtime window
What is kGraft?

- A research project
- A live patching technology
- Developed by SUSE Labs
- Specifically for the Linux kernel
- Based on modern Linux technologies
  - INT3/IPI-NMI self-modifying code
  - RCU-like update mechanism
  - mcount-based NOP space allocation
  - standard kernel module loading/linking mechanisms
Advantages of kGraft

• Doesn't require stopping the kernel, ever
  - not even for short time periods unlike other technologies

• Allows code review on kGraft patch sources
  - kGraft patch can be built from C source directly, without the need for object code manipulation
  - Object-code based automated patch generation is provided as an alternative

• kGraft is lean
  - Small amount of code thanks to leveraging other Linux technologies, no complex instruction decoders or such
How does kGraft work?

• A kGraft patch is a .ko kernel module in a KMP RPM
• The .ko is inserted into the kernel using 'insmod' at RPM install or update time
• kGraft replaces whole functions in the kernel
  - even while those functions may be executed
• An updated kGraft RPM/module can replace an existing patch
Limitations

- kGraft is designed for fixing critical bugs
  - and thus primarily for simple changes
- Changes in kernel data structure layout require special care
  - and depending on the size of the change, the change may not be possible to do without rebooting at all – same as with other live patching tech
- kGraft depends on a stable build environment
  - and thus best suited for Linux distributions, their customers or anyone who builds their own kernels, rather than 3rd party support companies
kGraft in detail: where to patch

- To patch a function, kGraft needs some space at the start of a function
- This is, fortunately provided by GCC's profiling code
- ftrace uses the compiler profiling options (-pg) to obtain this space (__fentry__ call)
- __fentry__ call instructions are patched out at boot and replaced with 5-byte NOPs
- kGraft uses the same space
kGraft in detail: where to patch
kGraft in detail: code flow redirection

- kGraft uses the same infrastructure as ftrace to perform patching
- INT3 handler is installed with a JMP to the destination address
- first byte of NOP is replaced by INT3, taking care of incomplete instruction
- remaining bytes are replaced by address
- first byte is replaced by JMP
- NMI IPIs are used throughout to flush instruction decoders on other CPUs
kGraft in detail: code flow redirection
kGraft function in detail: new function

- Patching during runtime, no `stop_kernel();`
- Callers are never patched
- Rather, callee's NOP is replaced by a JMP to the new function
- So a JMP remains forever
- But this takes care of function pointers, including in structures
- And doesn't require saving any old data in case we want to un-patch
kGraft function in detail: new function
kGraft in detail: RCU-like replacement

- So what happens when a replaced function changes semantics and subsequent calls rely on each other?
- Or when it is called recursively?
- We need to provide a consistent 'world-view' to each execution thread
  - user processes
  - interrupts
  - kernel processes
- This is done through a "reality check" trampoline and a per-thread flag set on each kernel entry/exit
kGraft in detail: RCU-like replacement
kGraft in detail: RCU-like replacement
kGraft in detail: RCU-like replacement

- All processes must wake up or execute a syscall
- Sometimes this requires a signal to be sent (like for gettites)
- Once all processes have the "new universe" flag set, patching is complete and trampolines can be removed
kGraft in detail: RCU-like replacement
kGraft in detail: Automatic generation

• Start with a list of functions to be replaced
• This is automatically extended by any functions that inline them based on original kernel debuginfo
• Patched kernel is compiled with
  -ffunction-sections -fdata-sections
• Modified objcopy copies all functions and required symbols into a .o file
• A stub .c file is generated including module init, kgraft register, and references to functions
• Both are compiled and linked into a .ko module
Get it

• Upstreaming
  - kGraft will be submitted into Linus's upstream kernel
  - SUSE will work together with the community to create a common standard kernel live patching solution
  - Suggestions welcome!

• Publishing
  - kGraft code has become available in a GIT repository TODAY

  https://git.kernel.org/cgit/linux/kernel/git/jirislaby/kgraft.git
Read more about kGraft

• Initial blogs

• Video of kGraft in action
  https://www.youtube.com/watch?v=d8Y89obtNI8

• Articles/interviews

• Collaboration summit talk
  http://collaborationsummit2014.sched.org/event/0d798ed17bfaa0361d0aec63f2331c8d
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