kGraft

Live patching of the Linux kernel

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We adapt. You succeed.

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

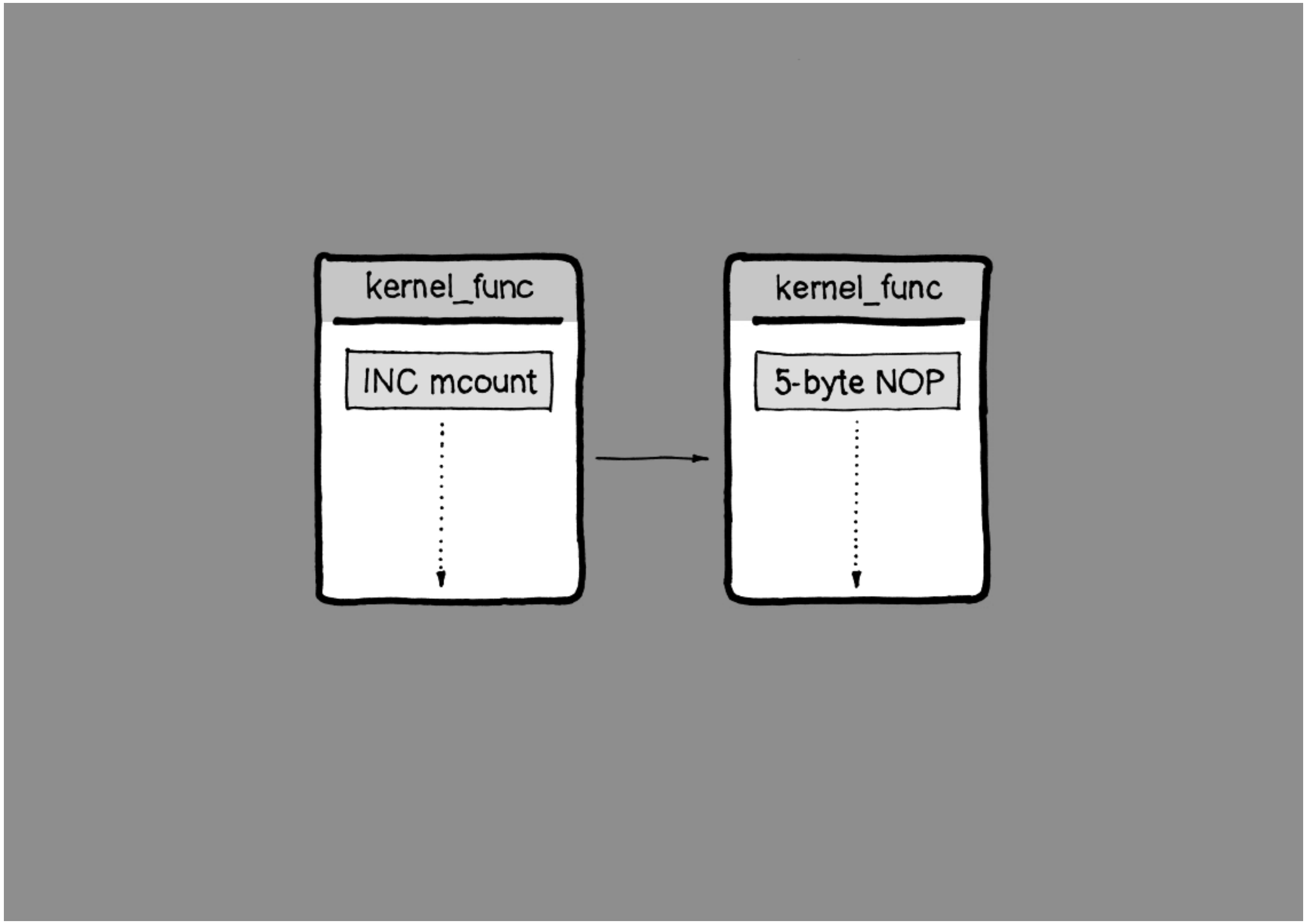
Limitations

- 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

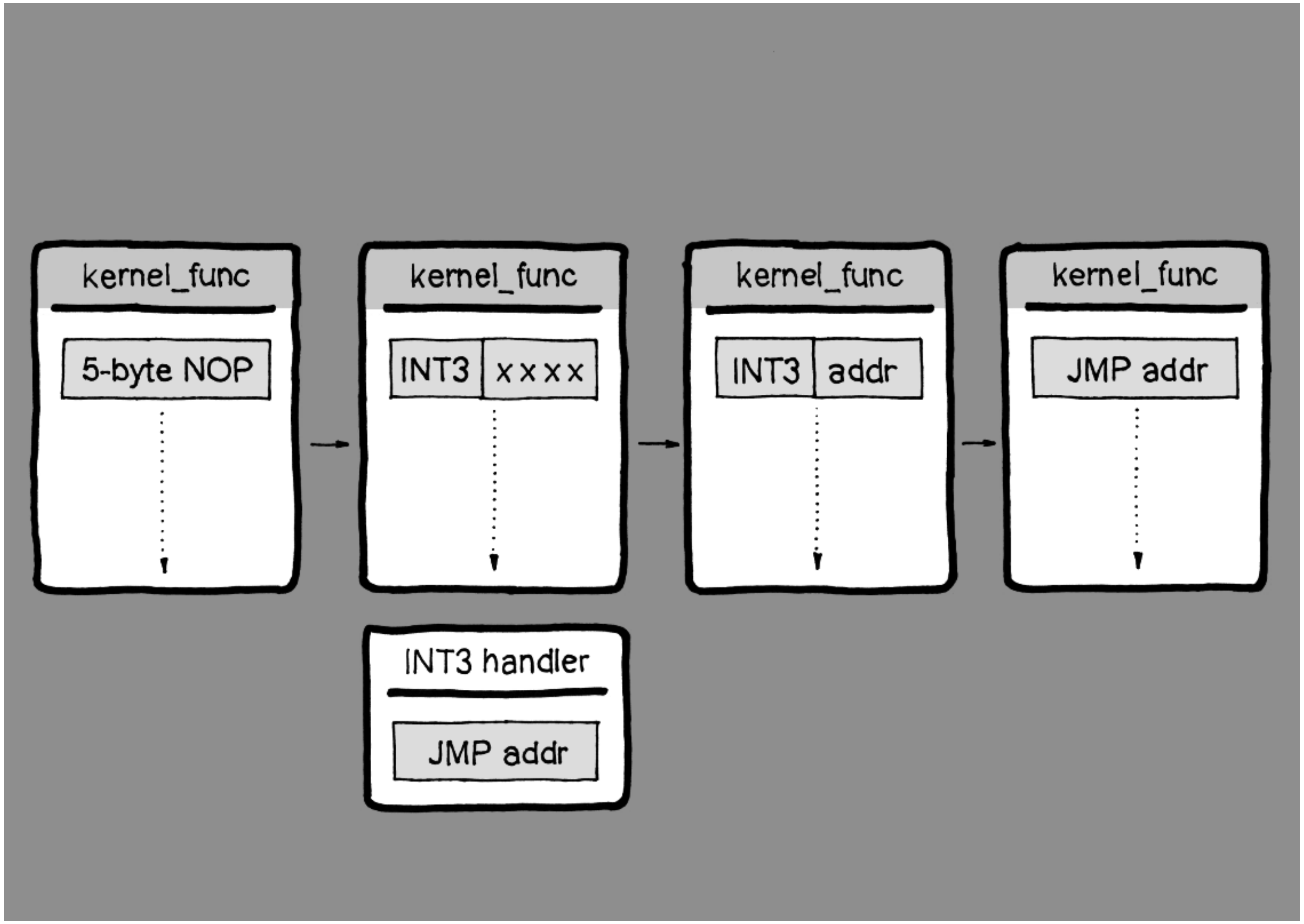
kGraft in detail: where to patch



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

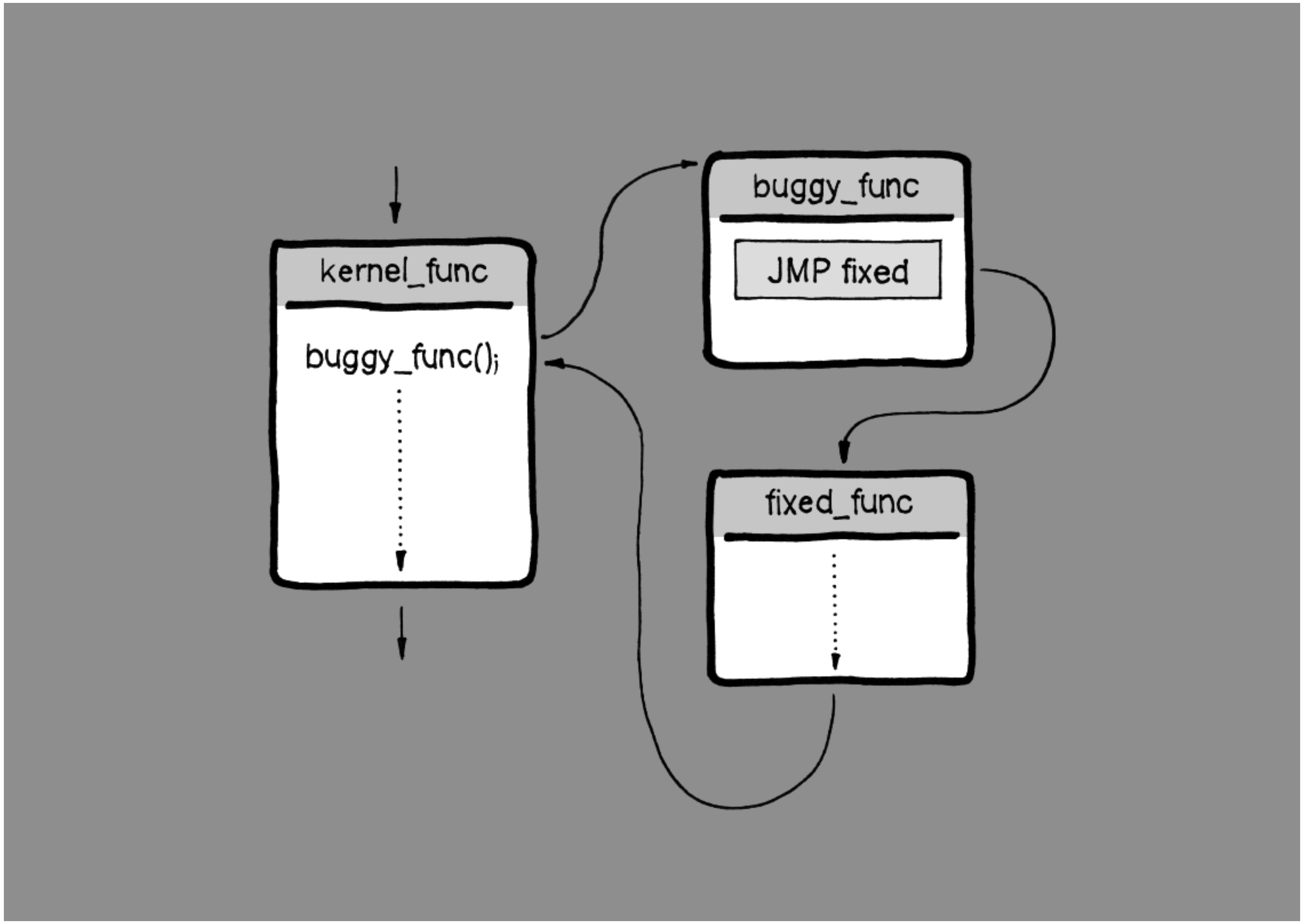
kGraft in detail: code flow redirection



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

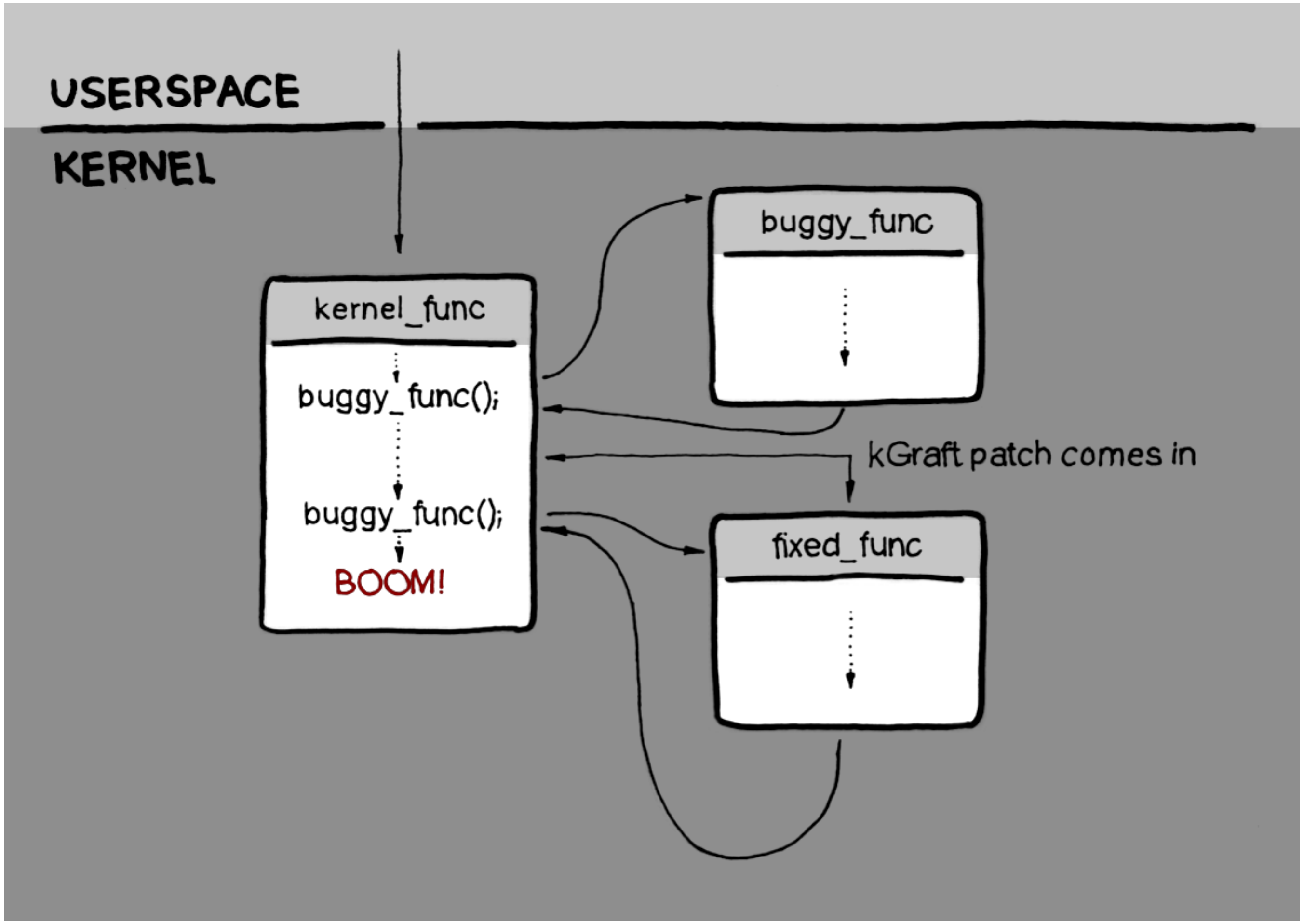
kGraft function in detail: new function



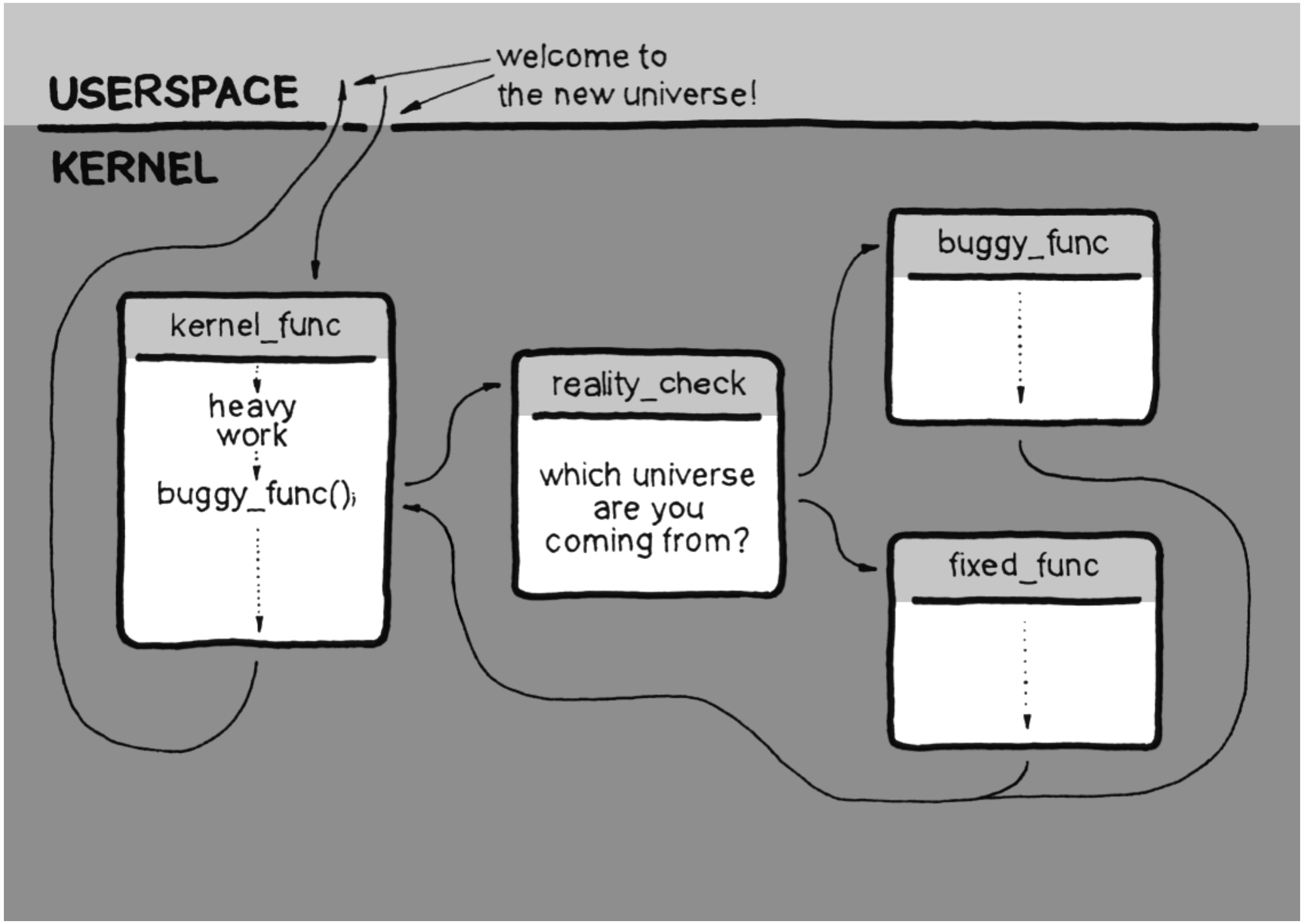
kGraft in detail: RCU-like replacement

- 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



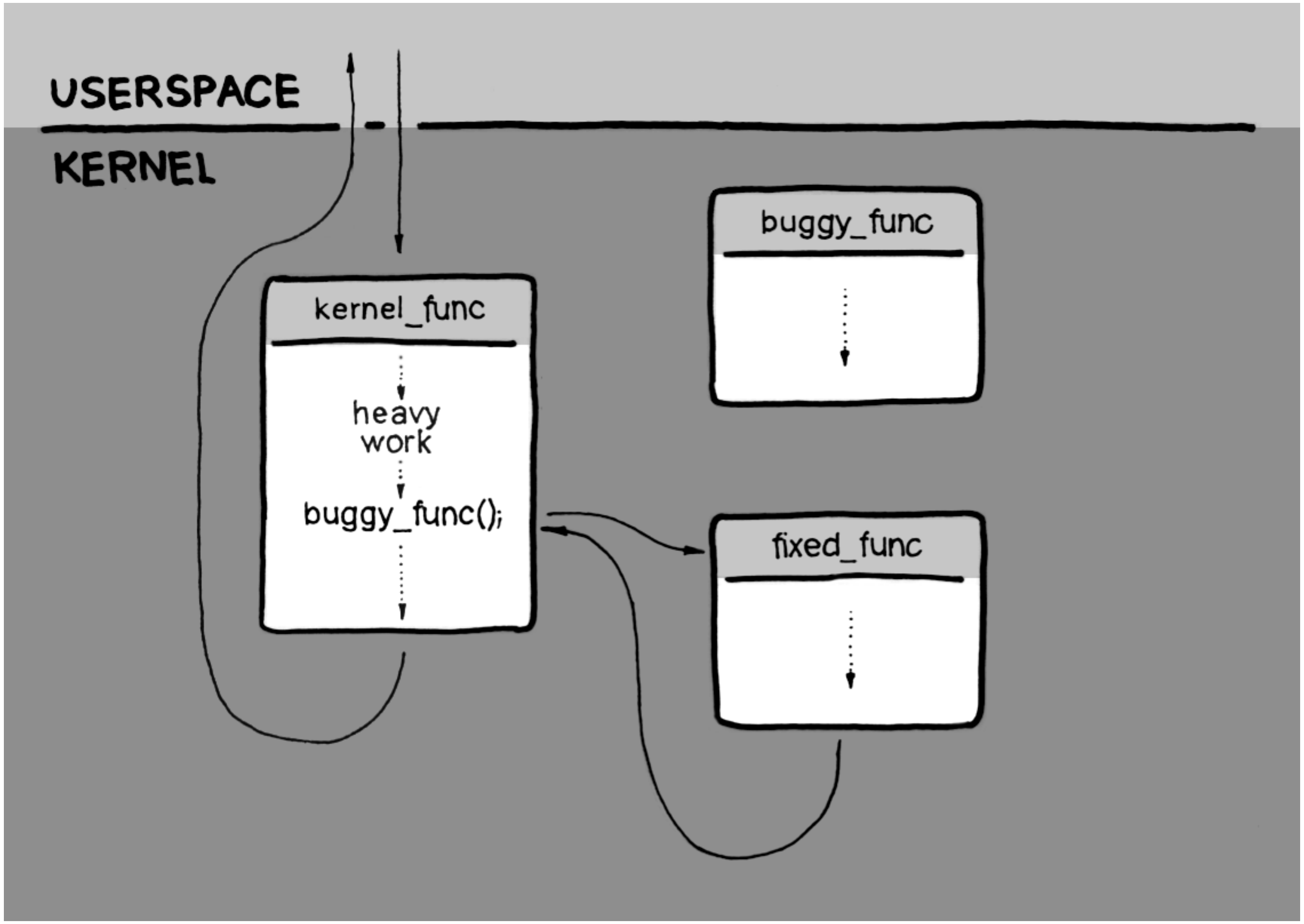
kGraft in detail: RCU-like replacement



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 getties)
- 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
  - https://www.suse.com/communities/conversations/kgraft-live-kernel-patching/
  - https://www.suse.com/communities/conversations/need-kgraft-2/
- Video of kGraft in action
  - https://www.youtube.com/watch?v=d8Y89obtNI8
- Articles/interviews
  - https://www.linux.com/news/featured-blogs/200-libby-clark/764542-suse-labs-director-talks-live-kernel-patching-with-kgraft
  - http://www.serverwatch.com/server-news/linux-kernel-patching-get-dynamic.html
- Collaboration summit talk
  - http://collaborationsummit2014.sched.org/event/0d798ed17bfaa0361d0aec63f2331c8d

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