Live Patching:
The long road from Kernel to User Space

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Software has bugs,
and bugs have to be fixed

+ security issues
+ execution degradation
+ undefined behavior

Fixing bugs:

+ replace broken software in disk
+ shutdown running software instance
+ start software based on fixed version
+ wait until process is ready
+ re-establish services

Fixing bugs: downtime

+ replace broken software in disk
+ shutdown running software instance
+ start software based on fixed version
+ wait until process is ready
+ re-establish services

Downside of downtime

+ Some services may take very long to restart
+ Active connections will drop
+ Interruption of large computations

Live Patching

+ Fixing bugs in the **OS** without rebooting
+ Already a thing in the Linux Kernel

+ Fixing bugs in **applications** without restart
+ A wild challenge in user space

Kernel Live Patching

+ Ksplice, kGraft, kpatch... **upstream**
    - x86_64, s390x, powerpc (arm, arm64 soon)
+ Patch code is loaded in the kernel as a module

Kernel Live Patching

+ **ftrace** framework:
  - GCC emits ftrace calls on function prologues
  - **`calls`** are overwritten with **`nops`** during boot
  - **`nops`** can be reverted to **`calls`** during runtime
  - patched function calls handler which does the...

Kernel Live Patching

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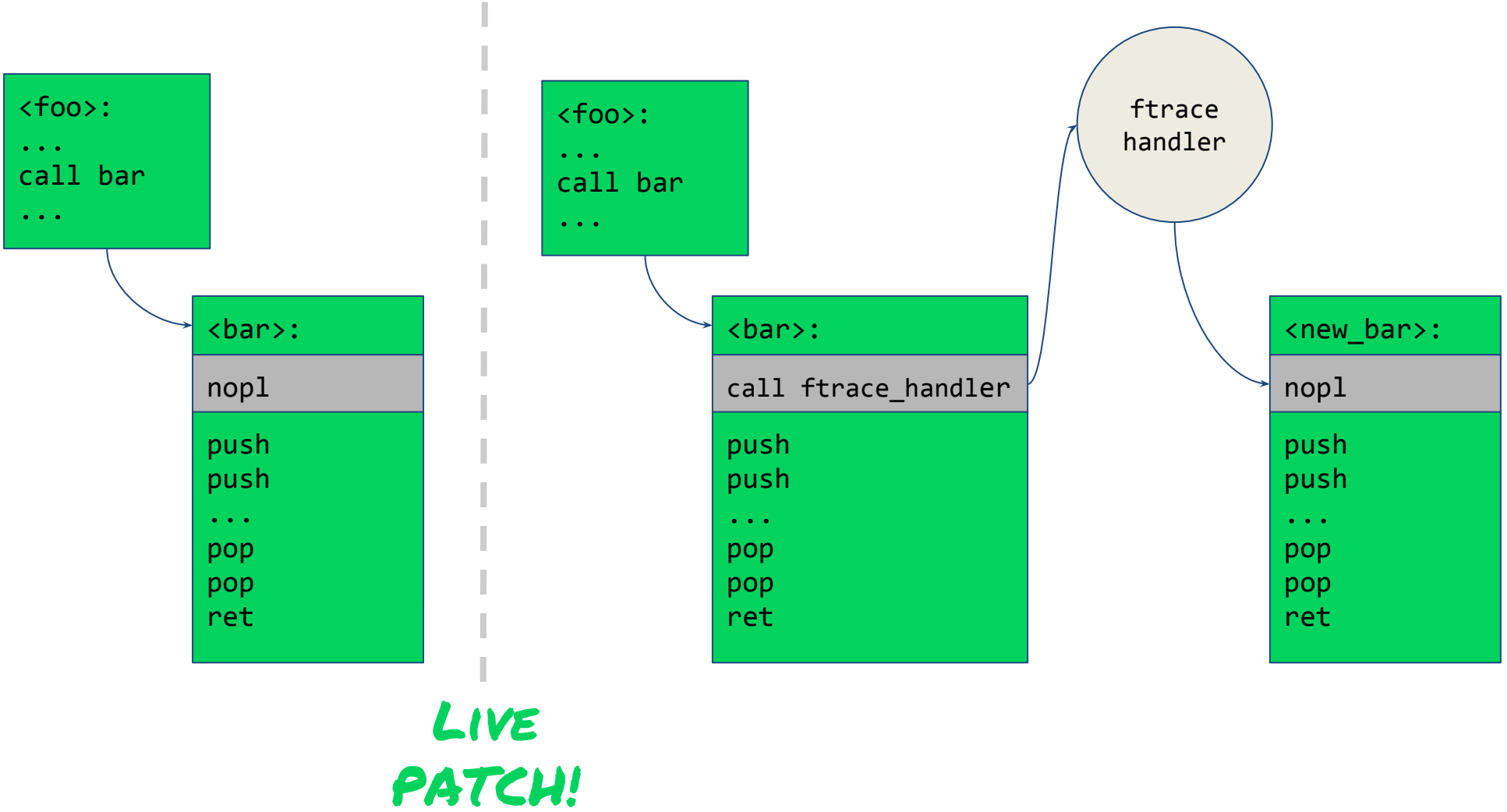
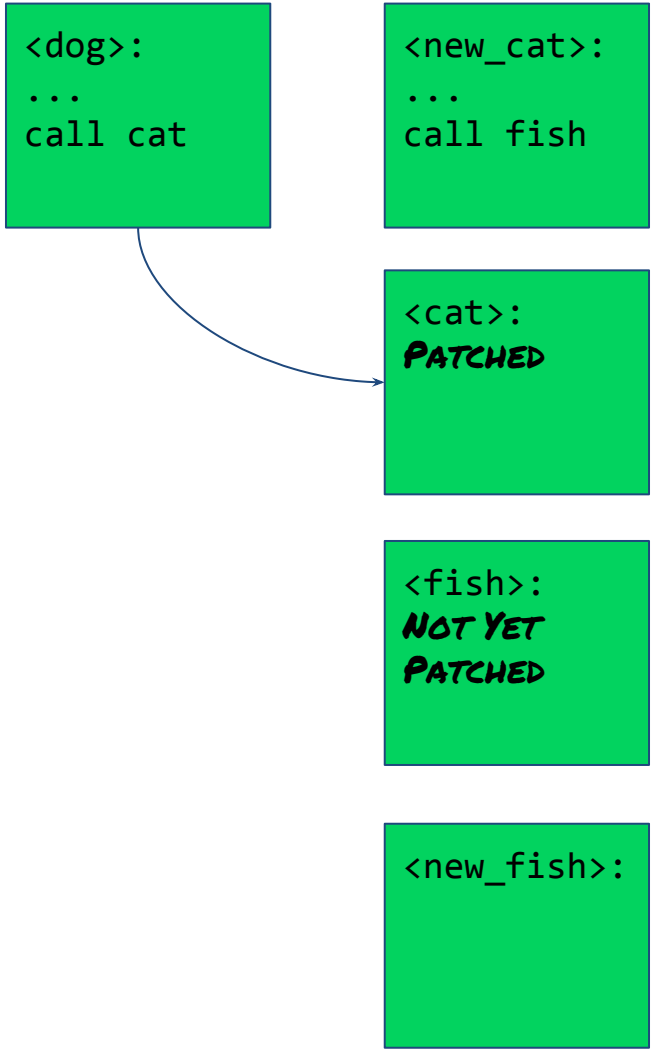
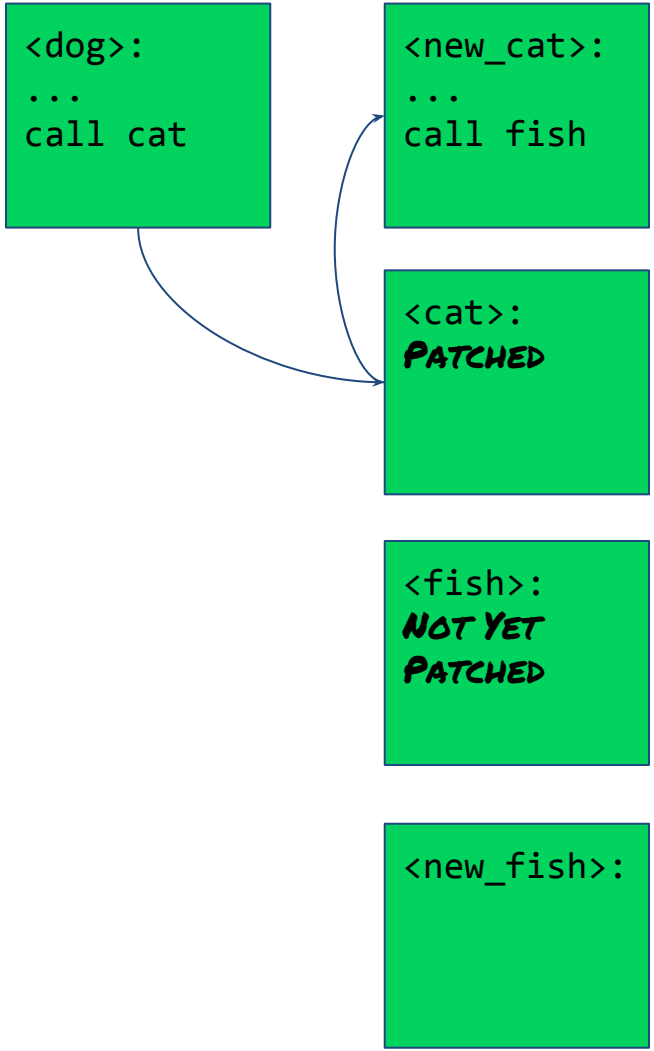
MAGIC

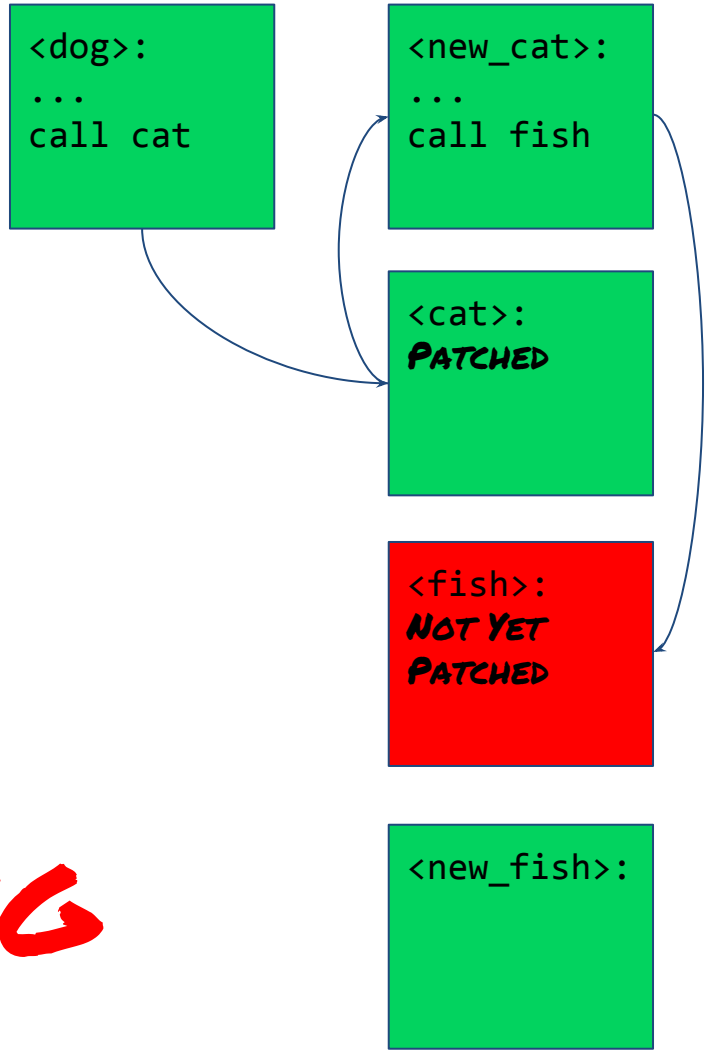

<foo>:
...
call bar
...
<bar>:
nopl
push
push
...
pop
pop
ret
LIVE PATCH!
<foo>:
...
call bar
...
ftrace handler
<bar>:
call ftrace_handler
push
push
...
pop
pop
ret
<new_bar>:
nopl
push
push
...
pop
pop
ret

Call redirection

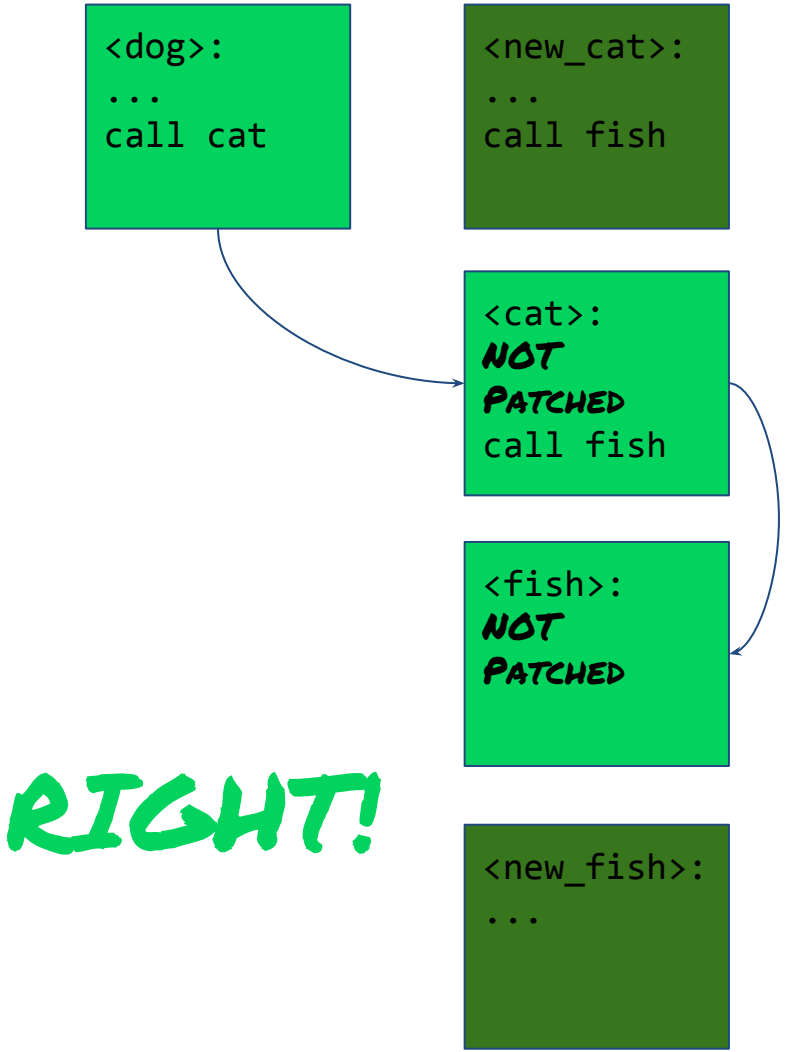
+ Functions are patched one at a time
+ Scheme works fine for patching single functions
+ ...but many function patching requires consistency
    + Start using **all** new versions at the same time
    + Switch happens when it is safe
    + Patched functions cannot be active


<dog>:
...
call cat
<new_cat>:
...
call fish
<cat>:
PATCHED
<fish>:
NOT YET
PATCHED
<new_fish>:

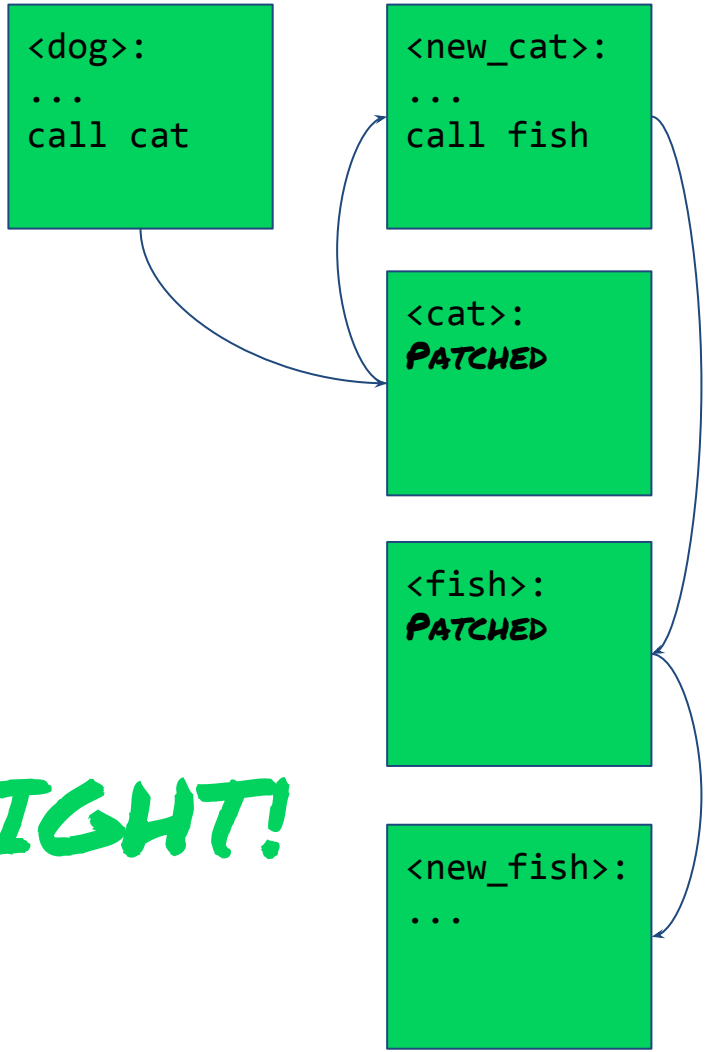

<dog>:
...
call cat
<new_cat>:
...
call fish
<cat>:
Patched
<fish>:
Not Yet
Patched
<new_fish>:


<dog>:
...
call cat
<new_cat>:
...
call fish
<cat>:
PATCHED
<fish>:
NOT YET
PATCHED
<new_fish>:

WRONG


<dog>:
...
call cat
<new_cat>:
...
call fish
<cat>:
NOT
PATCHED
call fish
<fish>:
NOT
PATCHED
<new_fish>:
...

RIGHT!


<dog>:
...
call cat
<new_cat>:
...
call fish
<cat>:
PATCHED
<fish>:
PATCHED
<new_fish>:
...

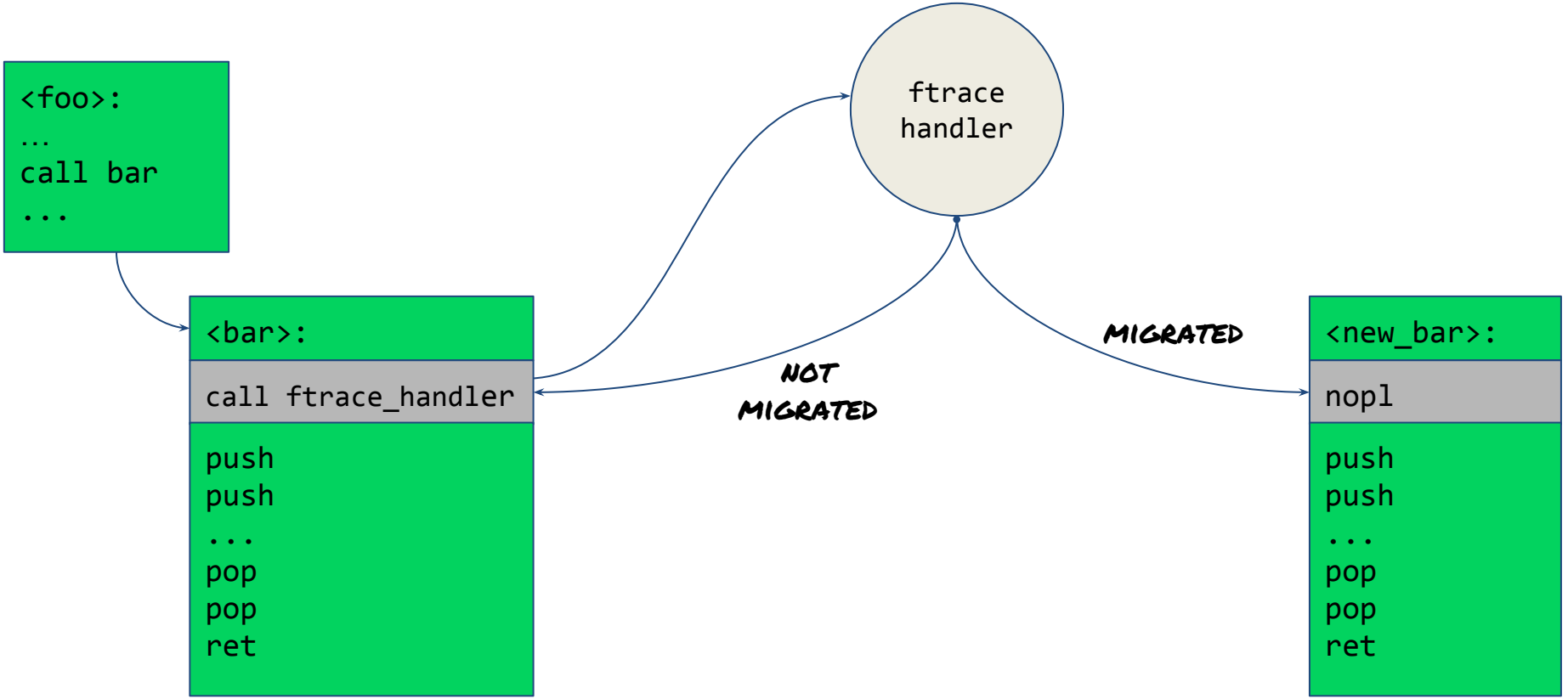
RIGHT!

Hybrid Consistency Model

+ **kGraft:** Per-task consistency and syscall barrier
+ **kpatch:** Stack trace switching
+ Plus some fallback options to make it flexible

Per-task Consistency

+ Threads in kernel are migrated one by one
+ Switching done by the ftrace handler


<foo>:
...
call bar
...
<bar>:
call ftrace_handler
push
push
...
pop
pop
ret
ftrace
handler
NOT
MIGRATED
MIGRATED
<new_bar>:
nopl
push
push
...
pop
pop
ret

Syscall Barrier

+ Kernel exit switch
+ Safe to patch when thread returns to user space
    + After syscalls, user space IRQ or signal

Stack Checking

+ Enables patching of sleeping tasks
+ Checks if affected functions are active
    + If yes, retry later
+ Requires config **HAVE_RELIABLE_STACKTRACE**
    + rarely the case...
    + Recent merge of ORC

Open challenges

+ Static or non-exported symbols in patches
    + Use of kallsyms
    + klp-convert: automatic resolution of symbols

Open challenges

+ GCC Optimizations
    + Inlining and partial inlining
    + Removing unused parameters
    + Changing parameters from reference to value
    + Creating many variants of the same function
    + Eliminating calls to pure const functions
    + Caller not saving registers when supposed to

+ and more of crazy stuff...

Open challenges

+ Very hard to deal with data structure changes

ok ok, Kernel is burning hot…

… but what about user space?

User Space Live Patching

+ Currently lacks a complete implementation
+ Under development at SUSE

Is it Different?

+ No ftrace
+ Harder to identify when it is safe to patch
    + Unable to use syscall barriers
    + Stack checking is also unreliable
+ Not every application can load code dynamically

Libulp

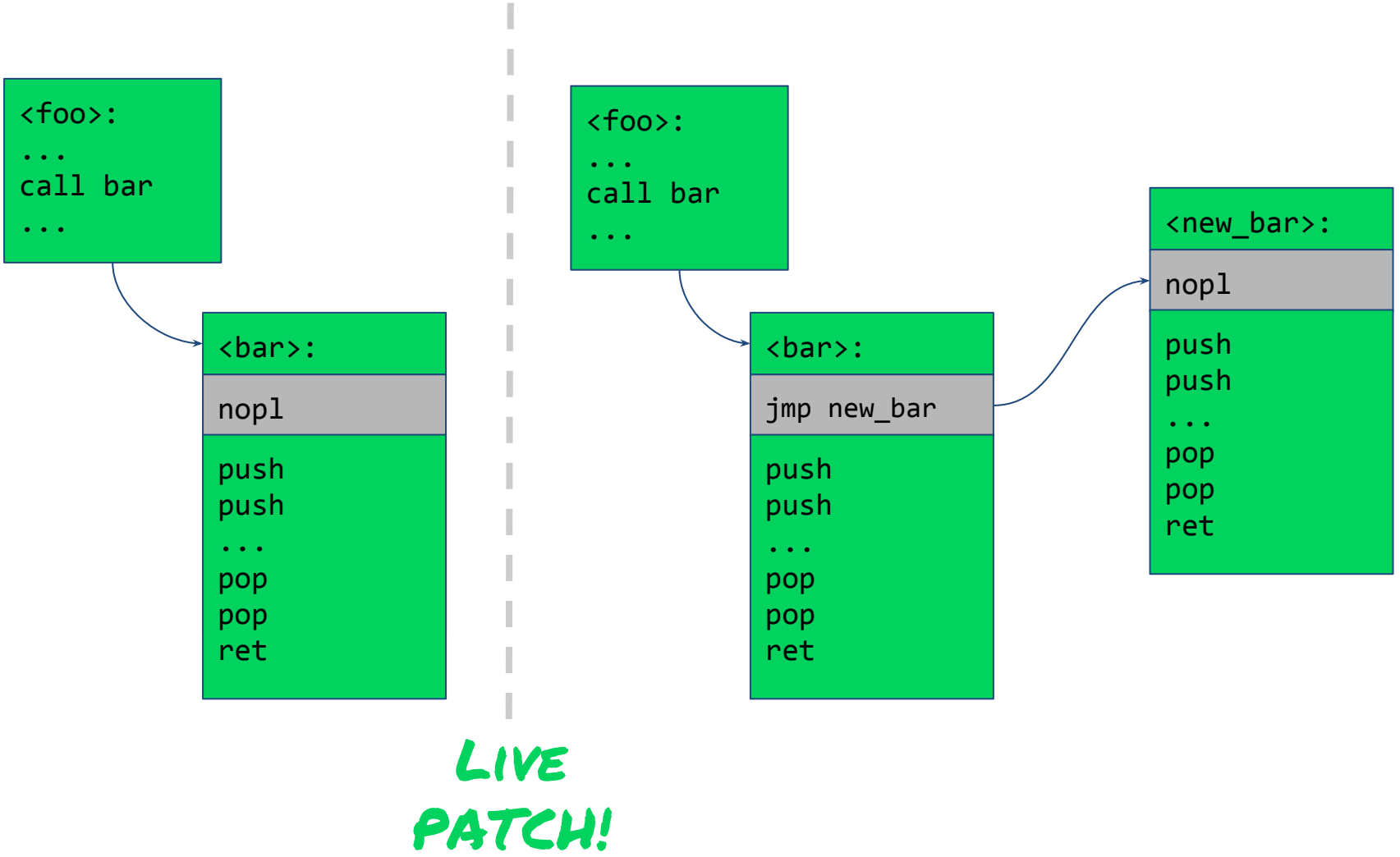
+ User Space Live Patching Library
+ Can be statically linked to application
+ Can also be LD_PRELOAD’ed
+ Signals and checkpoints used to start live patching
+ Loads code using glibc’s dlopen

Libulp Consistency

+ Checkpoints in code synchronize the patching process
+ Check trigger before applying the patch
+ Functions stacked under the checkpoint can't be patched
+ Multi-threaded applications:
  - All threads need to reach checkpoint
  - After patched, threads leave checkpoint together
  - No need to track versions

Detour-based Patching

+ Just like in the Kernel
+ Fixed functions are loaded elsewhere in memory
+ Bad function's prologue is patched with a **`jmp`**
+ `jmp` target is the patched function


<foo>:
...
call bar
...
<bar>:
nopl
push
push
...
pop
pop
ret
LIVE
PATCH!
<foo>:
...
call bar
...
<bar>:
jmp new_bar
push
push
...
pop
pop
ret
<new_bar>:
nopl
push
push
...
pop
pop
ret

Libulp Consistency

+ But this model is not that good...
  + Multi-threaded requirement would lead to dead-locks
  + Tailoring checkpoints inside code is undesirable

So we keep searching :-)


SUSE
We adapt. You succeed.

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