Rebootless Kernel Updates

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3 Dec 2018

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Remember this? ☺

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- Downtime:
  - Shutdown + Boot + App startup
- Loss of state (eg: network connections)
- Loss of results from long running processes
- Unexpected complications

Why do kernel updates need rebooting?

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- Kernel manages hardware
  - Driver updates may require re-init of hardware
- Userspace programs need kernel services
  - System calls, signals, IPC etc

Why would you want live kernel updates?

- Minimal service disruption
- Apply security (CVE) fixes ASAP without scheduled maintenance windows
- Avoid application start-up times following OS updates

Adding kernel code on the fly

- Loadable kernel modules

Live kernel updates wishlist

- Ability to fix bugs/vulnerabilities in any part of the kernel (both core + module code)
- Small update latency (say, < 10 seconds)
- Ability to rollback on update failure
- Minimal programmer effort to tailor fixes to live update scenarios

Live update approaches for Linux

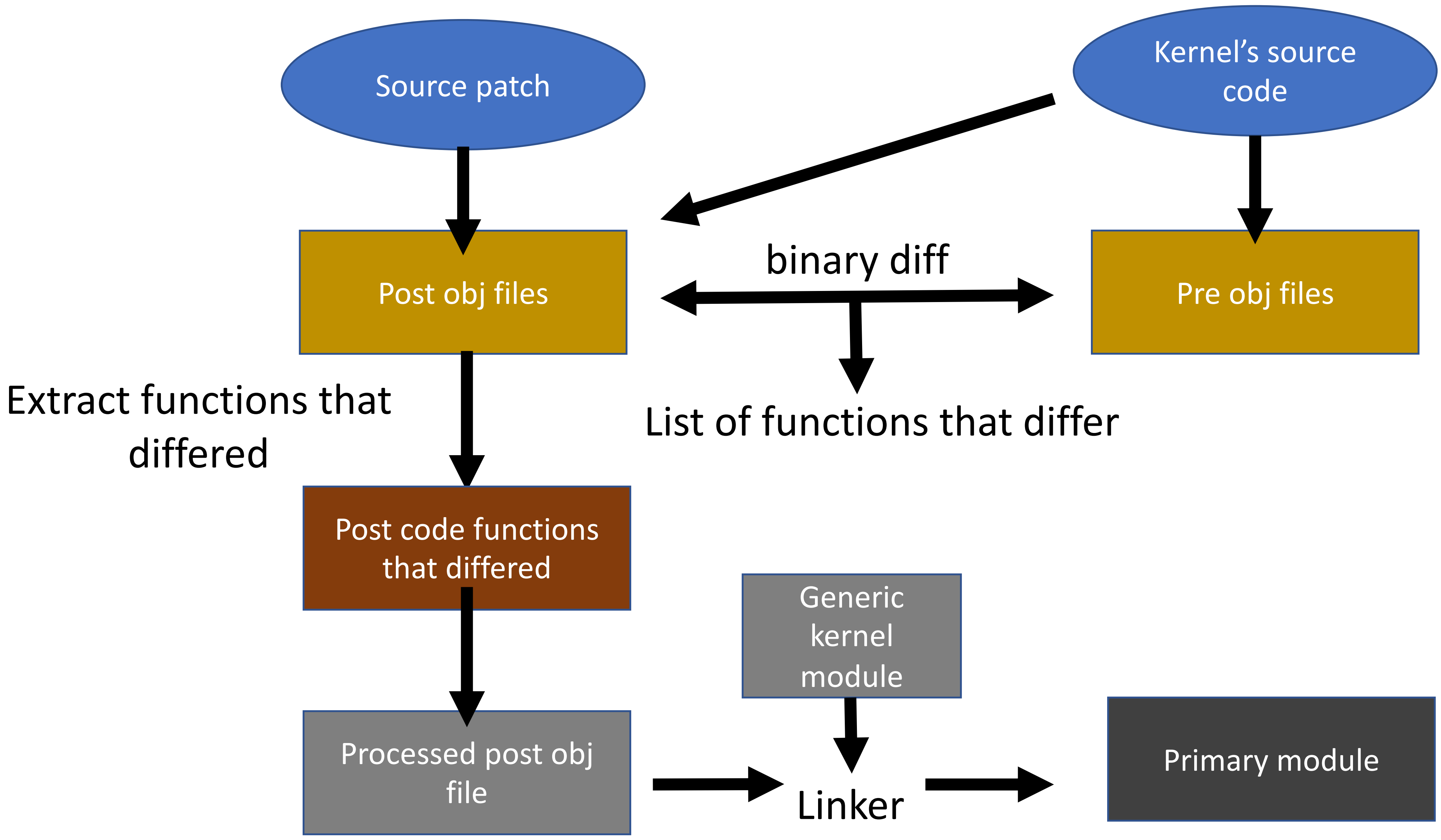
- Ksplice (MIT/Oracle)
- kGraft (SUSE)
- Kpatch (RedHat)
- Livepatch (Upstream) [inspired by kGraft + kpatch]

Ksplice

- Works at the level of object-code
- Function-level code replacement
- Latency: 0.7 milliseconds

- Workflow:
  - Generate binary replacement code using **pre-post differencing**
  - Resolve symbols and verify safety using **run-pre matching**
  - Use stop-machine for quiescence and perform code update

Ksplice : Generating repl code using pre-post differencing



stop-machine framework in Linux

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- “Stopper threads” created for each CPU during boot
  - Have highest priority in the system
  - Execute only in kernel mode
  - Typically in non-runnable state

stop-machine framework in Linux

- Mechanism to run a given function on a given CPU with the rest of the machine stopped!
- “Stopper threads” created for each CPU during boot
  - Have highest priority in the system
  - Execute only in kernel mode
  - Typically in non-runnable state
- stop-machine flow:
  - Mark all per-CPU stopper threads as runnable
  - Each stopper thread preempts userspace and hogs the CPU
    - Interrupts disabled on each CPU
  - Runs the requested function on the specified CPU

kGraft

- Replaces entire functions
- Uses ftrace to perform code patching
- Process by process transition to new kernel code:
    - Old vs New Universe
        - Band-Aid functions that understand both old and new layouts of data-structures
    - Uses fake signals to force “slow” processes to transition

- Needs special care to deal with:
    - Kernel threads
    - Interrupt handlers

kpatch

- Similar to kGraft for the most part
- A fundamental difference from kGraft:
  - Uses stop-machine for quiescence:
    - Examine kernel stacks of all processes with machine stopped.
    - If function not on any stack, proceed to patch.
    - Can’t patch functions always found on the stack
      - Eg: schedule()

Livepatch

- Best of both kGraft and kpatch
- Consistency model:
  - Supports both stop-machine and process-by-process transition
  - Stack traces used to be unreliable
    - Assembly routines may not setup stack frames
    - Fixed by ORC unwinder + objtool (stack validation)

Challenges for Livepatch / similar mechanisms

- Data-structure / semantic changes
  - (Partially) solved using shadow data-structures
- Changes to initialization routines
- Changes to static variables
- Dealing with compiler optimizations
- Patching hand-written assembly
- Handling changes in locking rules
- Patching modules that are not yet loaded
- Patching patched kernels
- Reverting live patches in case of failures
- …
- Undecidability: In the general case, can't prove that patch + state transition leads to valid state.

“Seamless” kernel updates

- Achieved via a combination of:
  - Kexec – exec a new kernel image from a running kernel
  - CRIU – Checkpoint Restore In Userspace

- Approach:
  - Similar to hibernation, but more generic
  - Checkpoint all userspace state using CRIU to disk
    - Kernel-version agnostic checkpointed state/format
  - Kexec into new kernel
  - Restore all userspace from checkpointed image

Kernel updates via kexec + CRIU

- Latency improvements
  - Incremental checkpoints
  - On-demand restore
  - Persistent Physical Pages

Kernel updates via kexec + CRIU

- Demo
  - https://gts3.org/pages/kup.html

PROTEOS

- Assumes microkernel design (eg: Minix)
- Performs process-level updates (unlike function-level updates)
- State quiescence (unlike function quiescence)
- State-transfer between old/new process versions
- Uses LLVM link-time pass for instrumentation
- Per-update state filters and interface filters
- Strictly event-driven process loops
- Structured design to handle many live update complications
- Supports a wider range of OS updates automatically than Livepatch-like approaches.
- Updating the microkernel itself might be challenging.

Revisiting the wishlist – Are we there yet?

- Ability to fix bugs/vulnerabilities in any part of the kernel (both core + module code)
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References

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