Visualizing Page Tables

… for Local Exploitation: Hacking Like in the Movies

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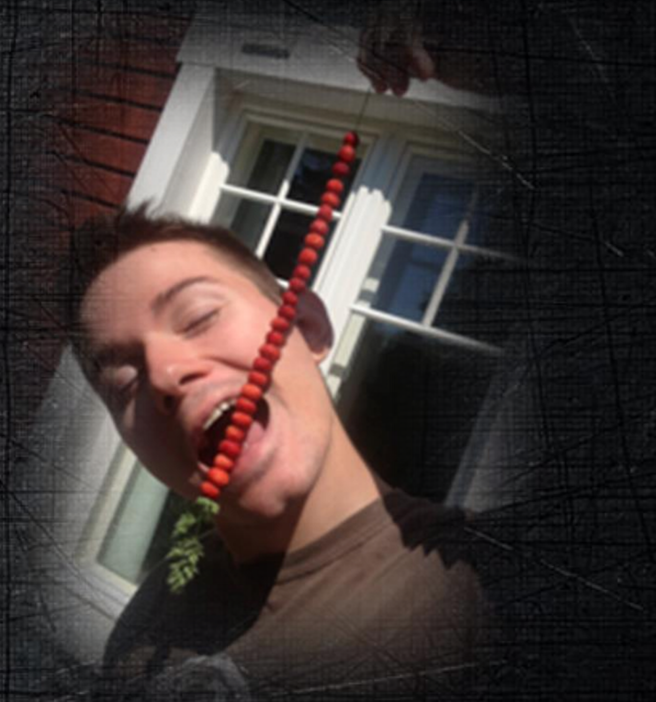
  - Recovering software security assessor
  - Likes bringing pain to the adversary
- @defendtheworld on Twitter



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Georg Wicherski

- Researcher at CrowdStrike, Inc.
  - x86 & ARM low-level stuff
  - Reverse Engineering, Malware analysis
  - Exploitation and Mitigation research
- @ochsff on Twitter
- http://blog.oxff.net/

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Introduction

Paging 101

- Translation from virtual addresses to physical
  - Virtual address: the pointers your program works with
  - Physical address: the actual address of a memory cell in the physical RAM chip
- Virtual address unique per virtual memory space
  - Usually means per process for userland, one shared kernel space for all processes

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Efficient Hardware Implementation

- Group addresses into pages: block of addresses that are translated in the same way
- Cache translation results: TLB
- Hierarchical translation tables (trees) to conserve memory
  - Three levels on x86 and amd64
  - Two levels on ARMv7-A, three levels with LPAE

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Memory Protections

- Memory protections implemented on top of paging
  - Read-only vs. read-write memory areas
  - Executable vs. data-only memory areas
    - x86: NX (No-eXecute) bit per page
    - ARM: XN (eXecute-Never) bit per page ☺
  - Privilege level to access page
    - ARM: Supervisor bit, Domains, different table sets
    - x86: Supervisor bit (CPL, SMEP, SMAP)

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What a Movie Hacker Looks for

- Mappings at repeatedly constant addresses
  - Constant physical address: Subject to reliable FireWire attacks
  - Constant virtual address: ASLR bypass
- Mappings with unexpected protections
  - Read-write but not NX/XN: Classical copy shellcode and execute scenario
  - Driver specific weirdness (DMA memory, …)

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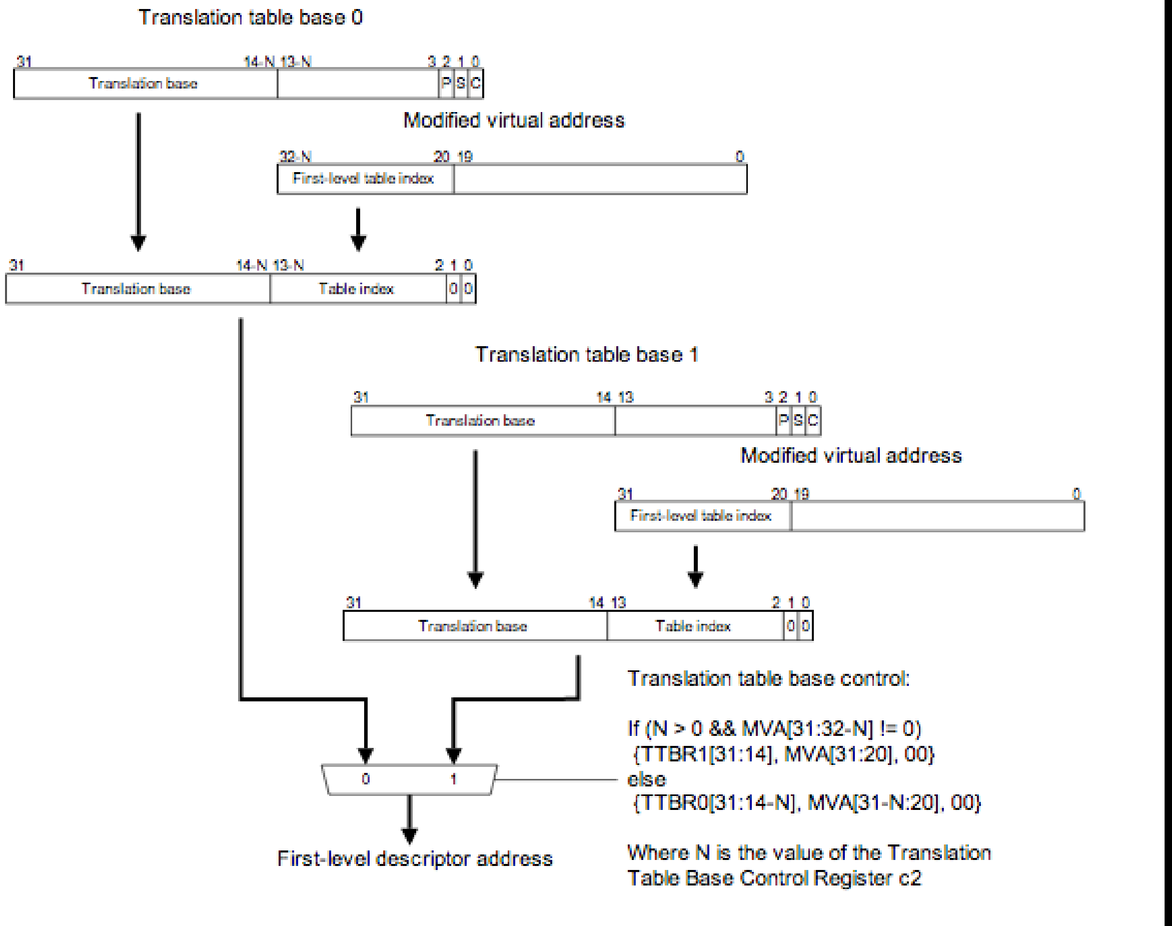
Background and Methodology

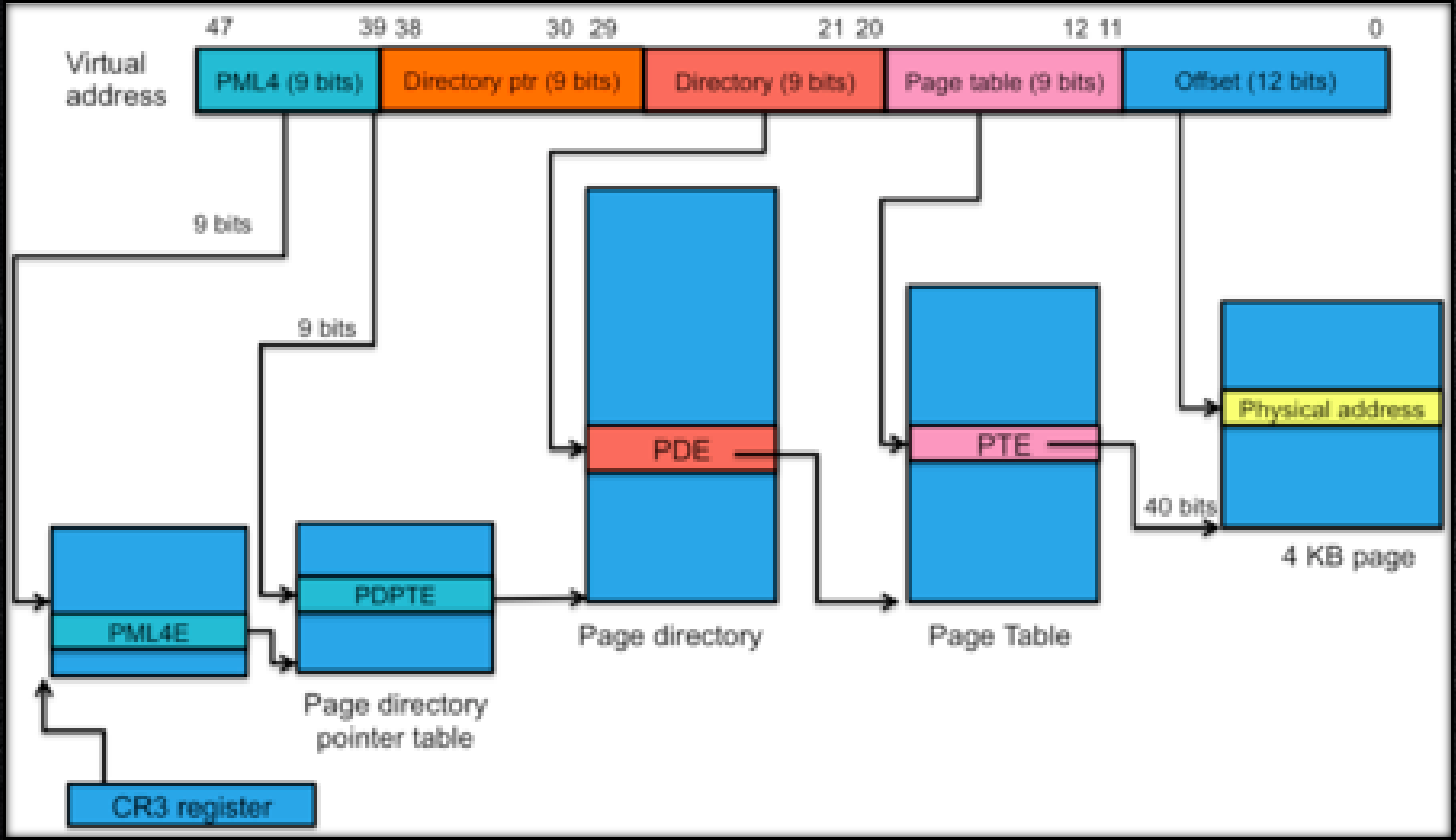
ARMv7-A VMSA

Figure 6.10. Creating a first-level descriptor address



http://infocenter.arm.com/help/index.jsp?topic=/com.arm.doc.ddi0333h/Cihbfagh.html

IA-32e, four layers of fun



http://www.cs.rutgers.edu/~pxk/416/notes/09a-paging.html

Data Collection

- Android: Both custom kernel and local exploit
- iOS: Custom driver for jailbroken device
- x86_64 Linux: Custom kernel module
- x86_64 OS X: Custom kernel extension
- Windows Surface RT: Crash dumps & WinDBG
- Windows 8 x86_64: Custom kernel driver

Hilbert Curve Legend

User read only

Super read only

User write

Super write

User exec

Super exec

User WX

Super WX

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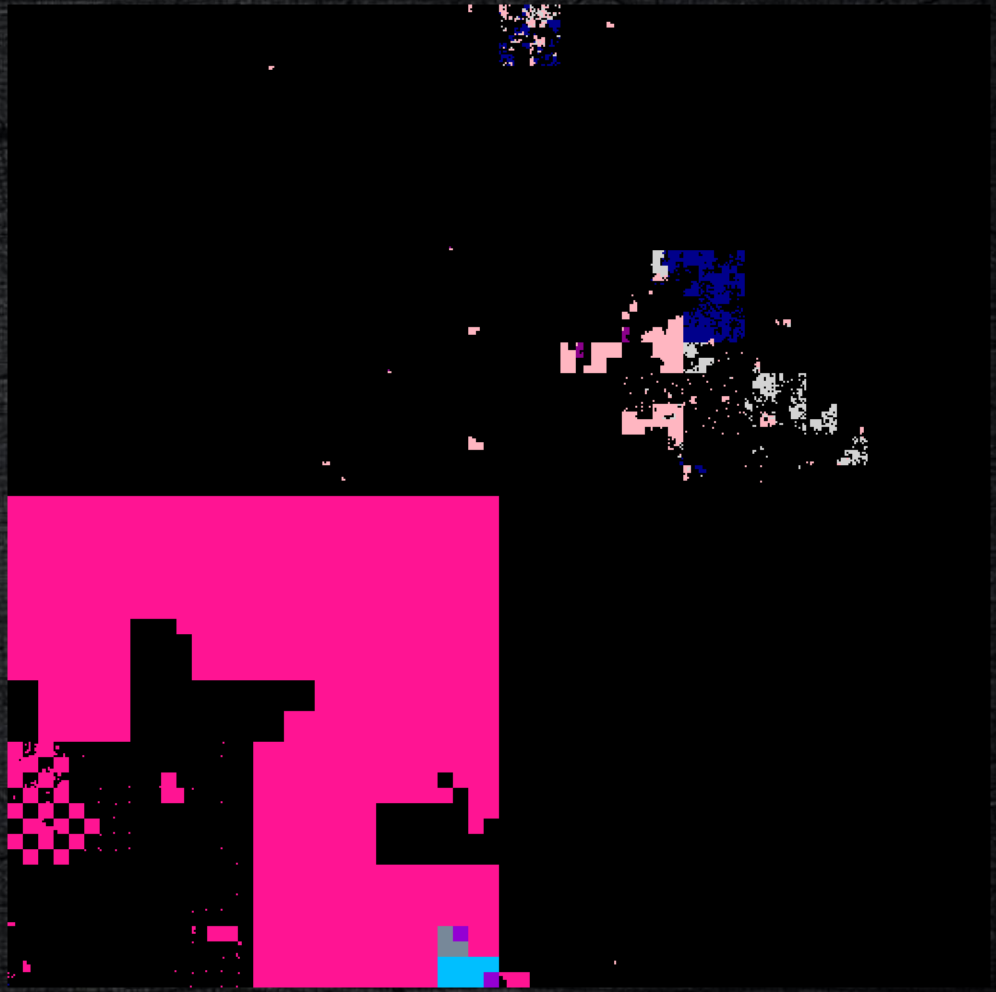
Case Studies

Android Process Comparison

1. init
2. dhcpd
3. zygote
4. com.android.email
5. sandboxed_process0 (Chrome)



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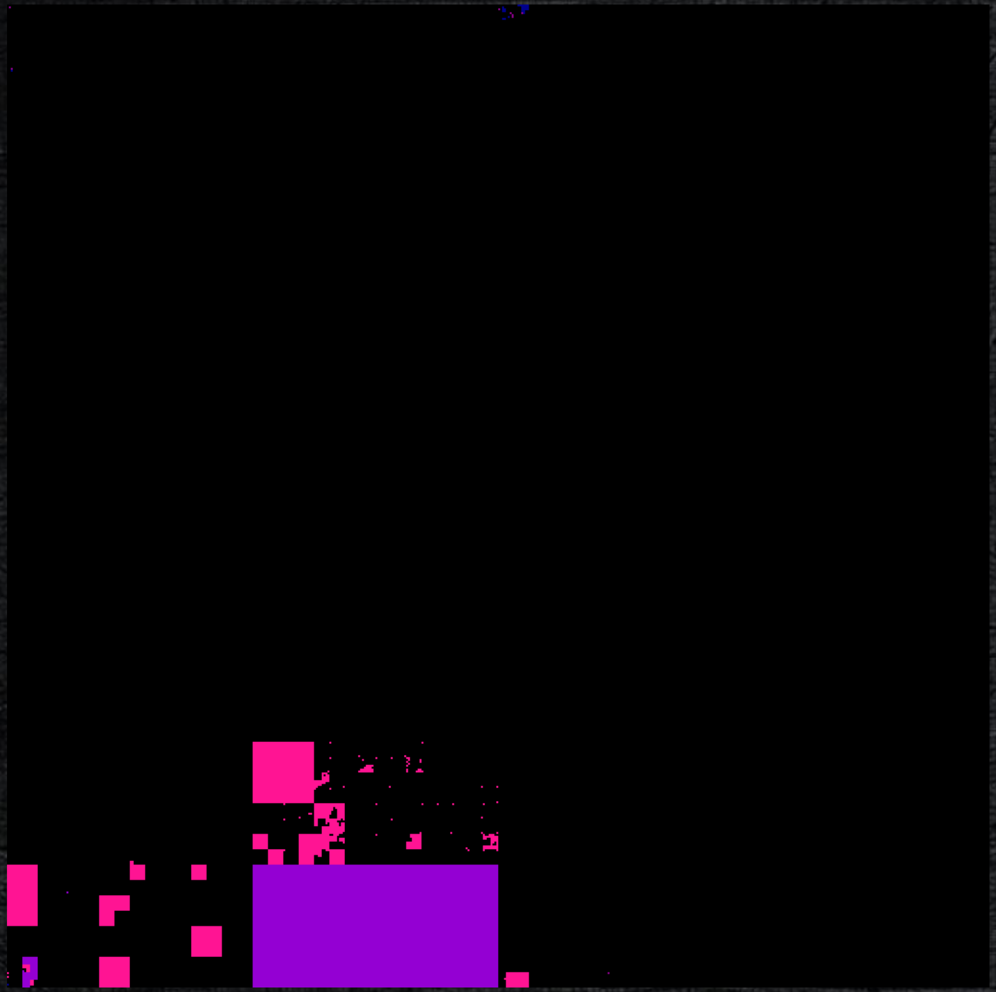
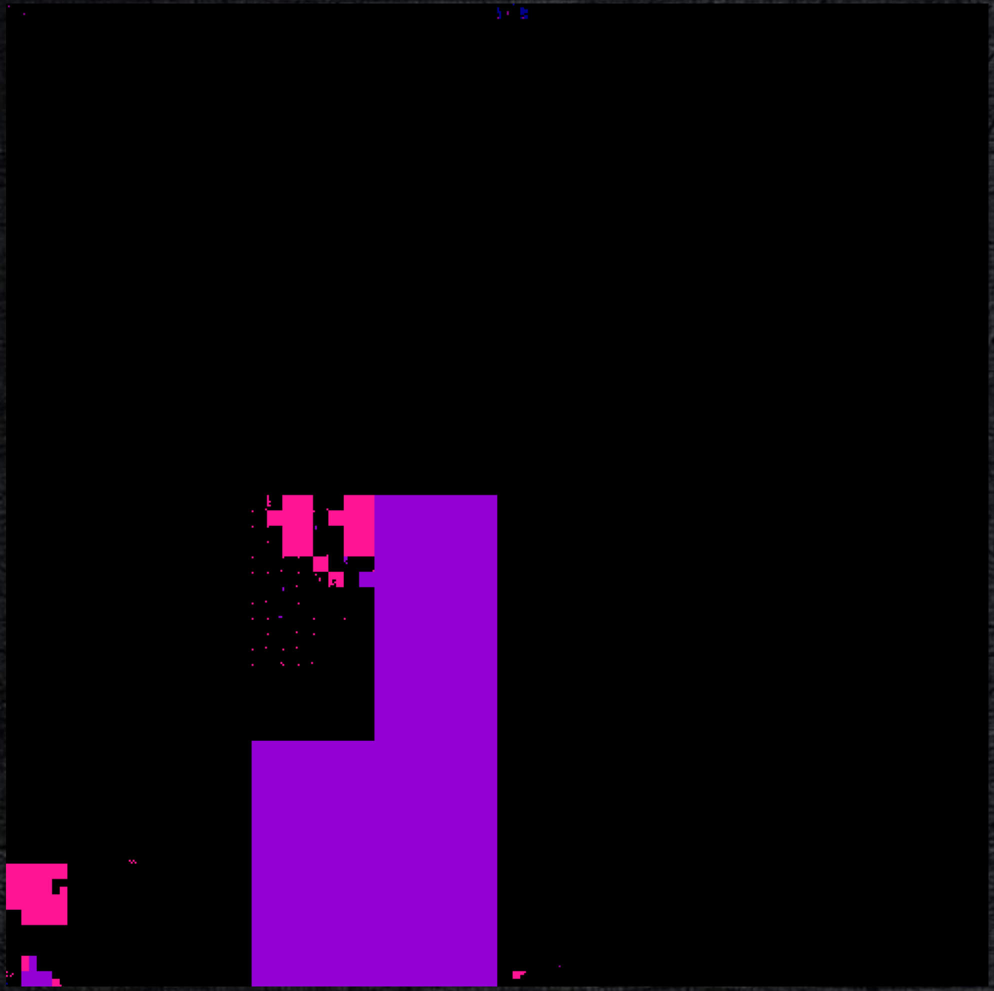
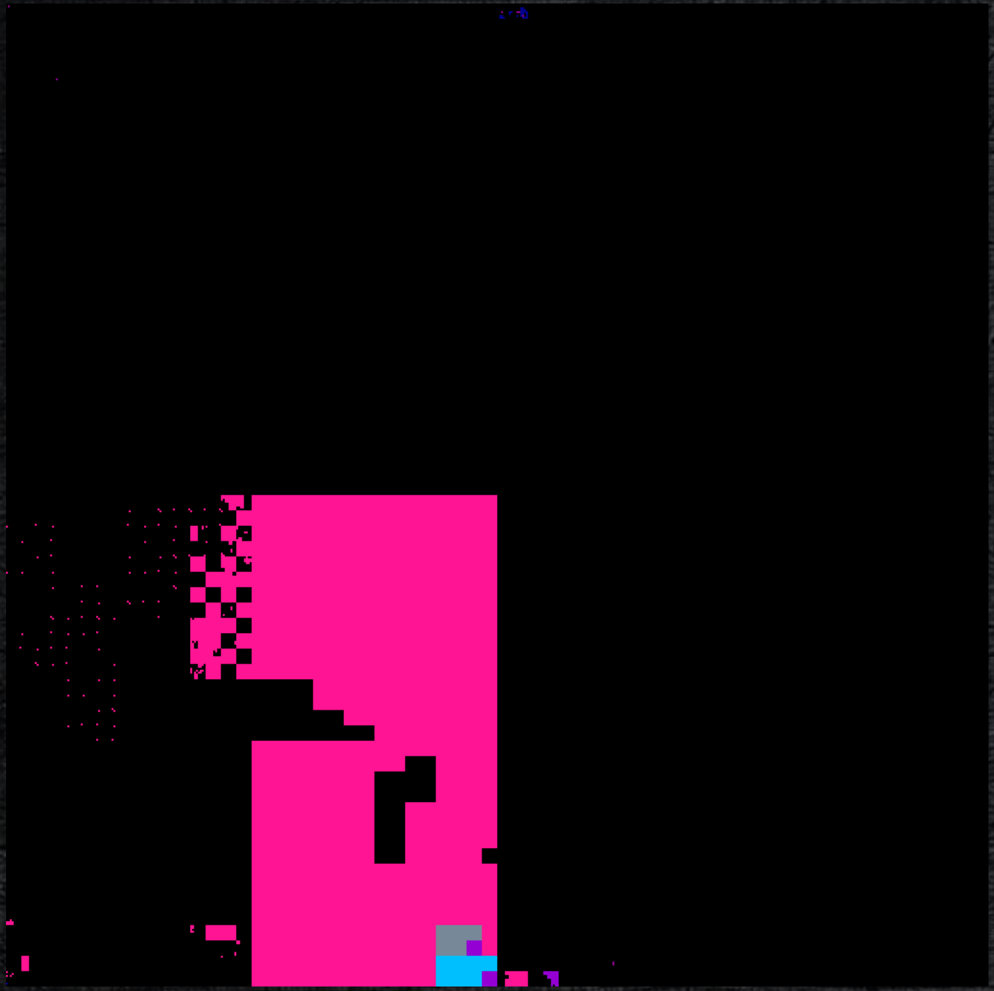
Galaxy Nexus, Android 4.2.2



Nexus 7, Android 4.2.2



Galaxy S4, Android 4.2.2 (MSM)



Android Observations

- Fixed r-x mapping at 0xffff0000 in all processes
  - 0xffff0000 is the ARM exception vectors base address
  - Abused in a *vsyscall* like manner by Linux on ARM
- Kernel `.text` is rwx on almost all kernels
  - `CONFIG_DEBUG_RODATA` not set in kernel configs
  - 3.4.x MSM kernel has RO .text
    - `CONFIG_STRICT_MEMORY_RWX` (Qualcomm)
    - Still has two rwx supervisor sections (1Mb pages)

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Android 4.2.2 ASLR Bypass

- `__kuser_cmpxchg: @ 0xffff0fc0`
  - `arch/arm/kernel/entry-armv.S`
  - `iff *r2 == r0: *r2 := r1`
  - Bruteforce addresses by invoking a loop, `r0`-`r2` are legitimate register parameters
  - Jump past equality check for arbitrary write gadget
- `__kuser_cmpxchg64: @ 0xffff0f60`
- `ffff0008:   ldr pc, [pc, #1072]   ; 0xffff0440`
  - This leaks the kernel's system call handler address to user-space

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OS X Observations

- Userland
  - Per-boot randomization (shared cache)
  - Per-execution randomization (dyld, pfz, commpage, stack, heap)

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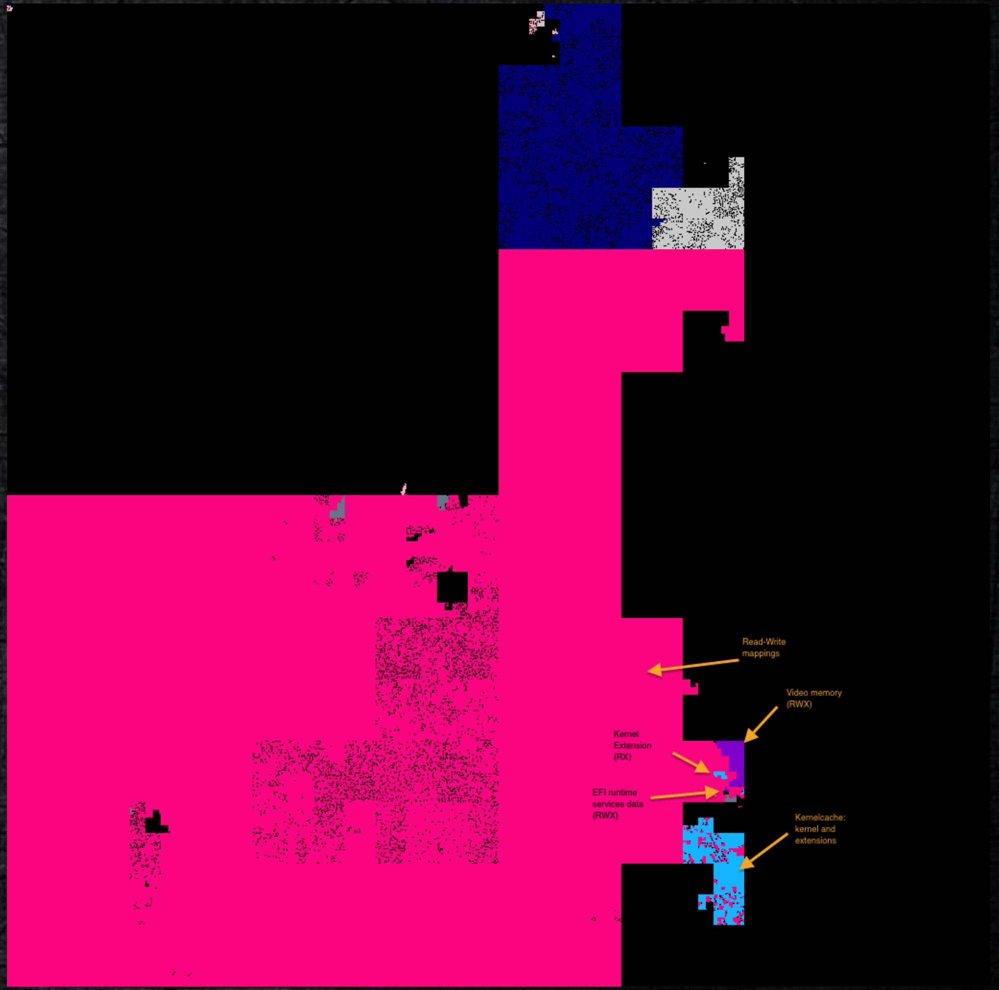
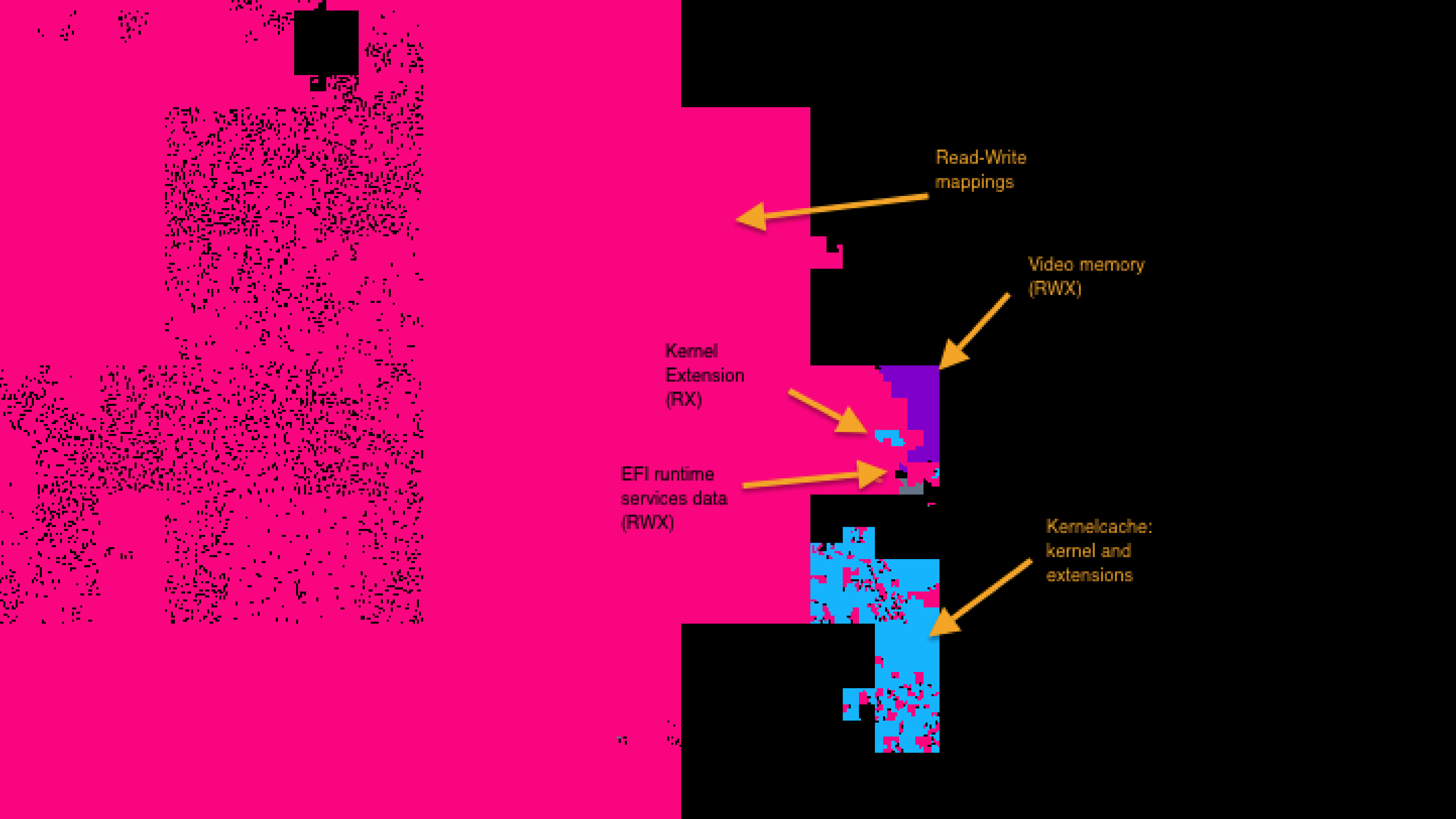
OS X Observations

- Kernel
  - KASLR
  - Incomplete W^X
    - Randomized RWX
  - Shared address space
    - SMEP available




Read-Write
mappings
Video memory
(RWX)
Kernel
Extension
(RX)
EFI runtime
services data
(RWX)
Kernelcache:
kernel and
extensions

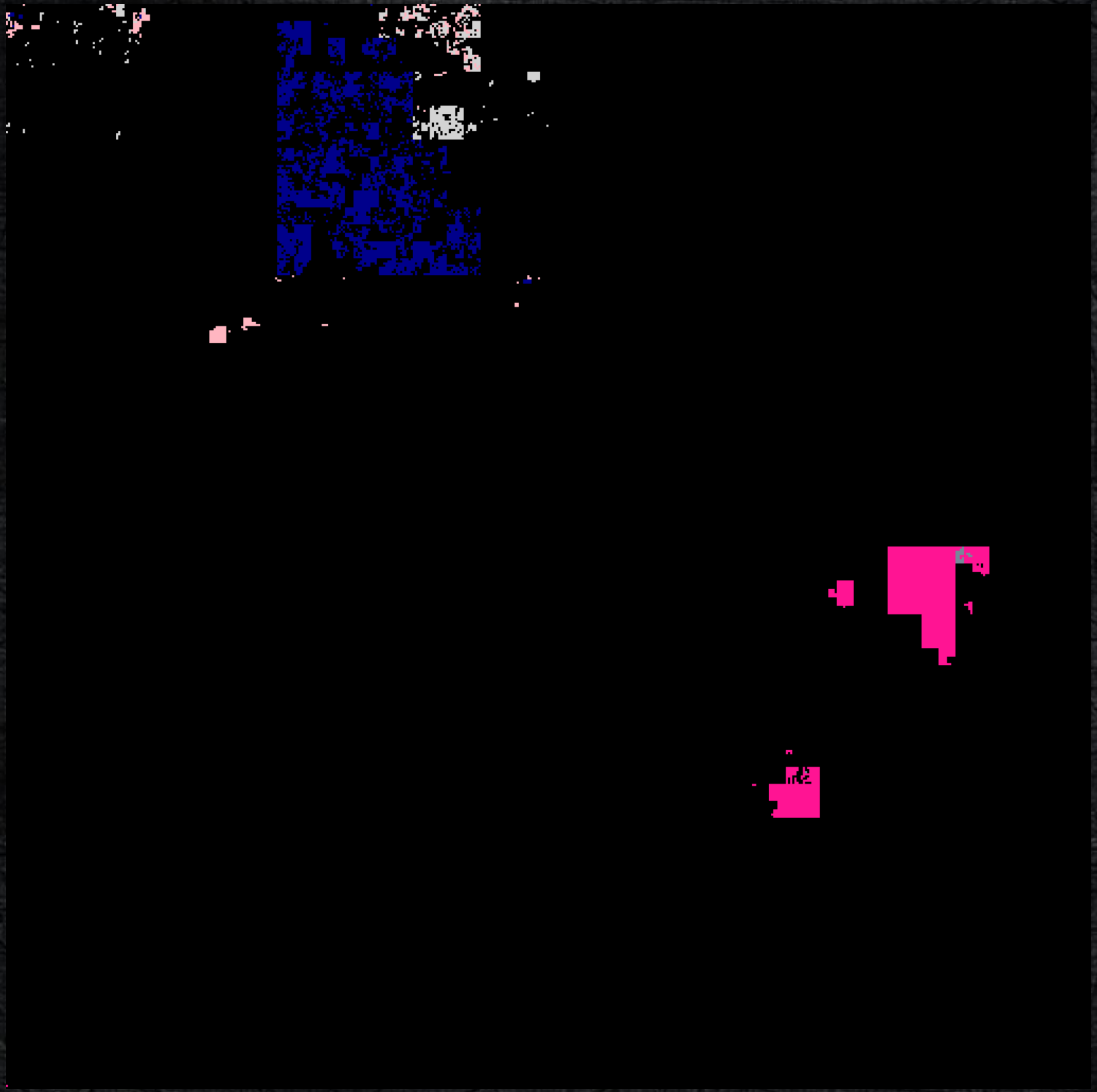
iOS 6 Security Properties

- Userland
  - Per-boot randomization (shared cache)
  - Per-execution randomization (dyld, .text, stack, heap)
  - Heap and stack separately randomized
  - W^X + Signed pages

iOS 6 Security Properties

- Kernel
  - KASLR
  - W^X
  - TTBR0/1 swapping

iOS: Example process (MobileSlideshow)



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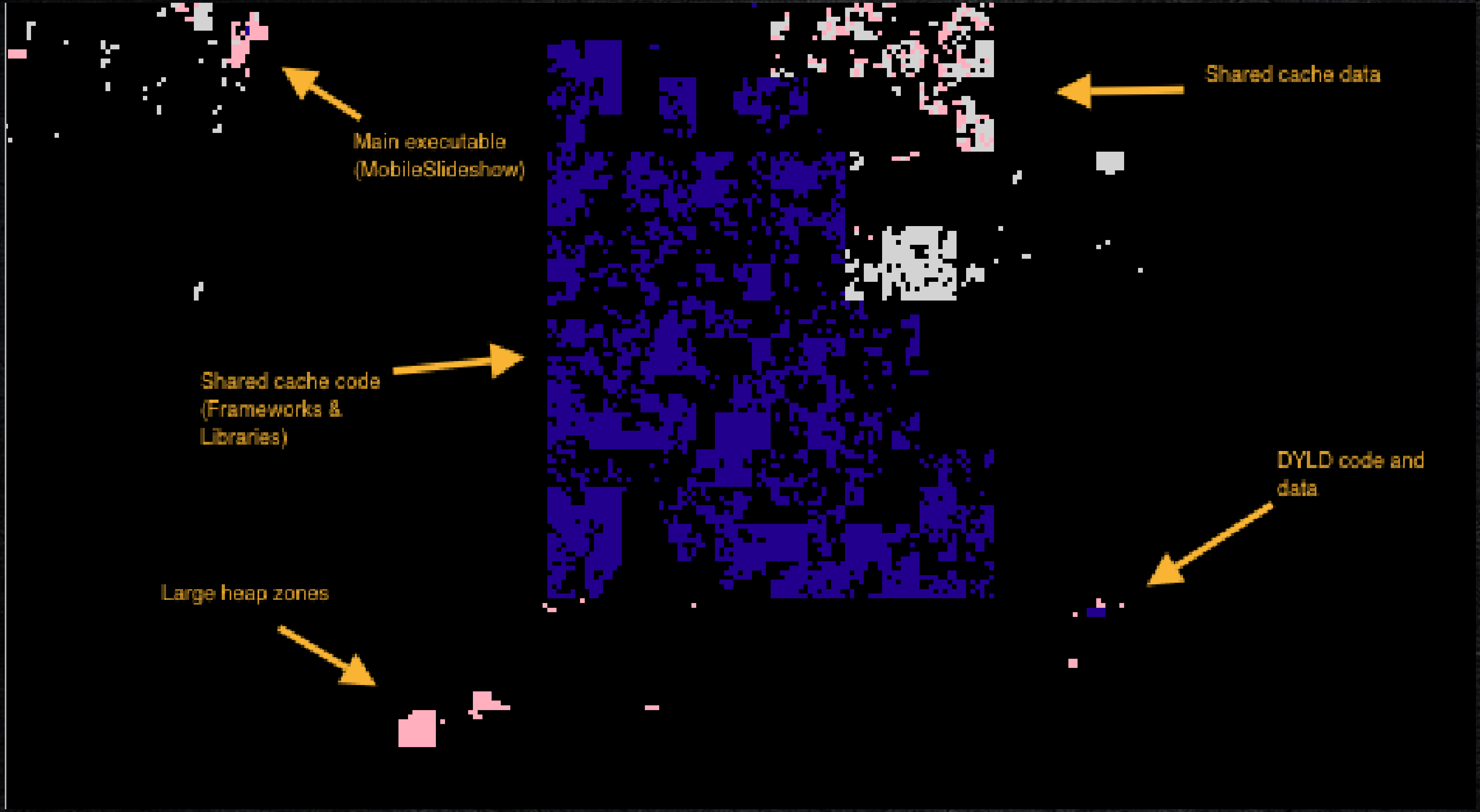
iOS: Example process (MobileSlideshow)



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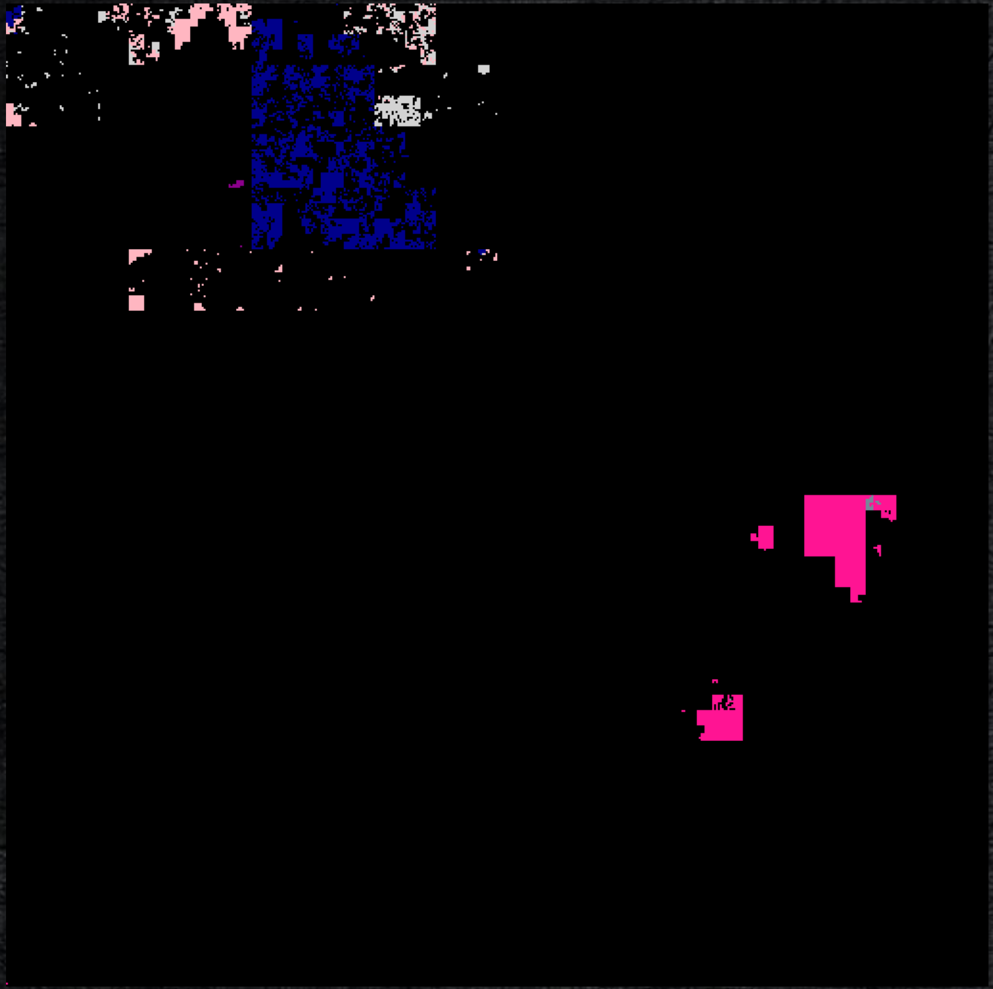
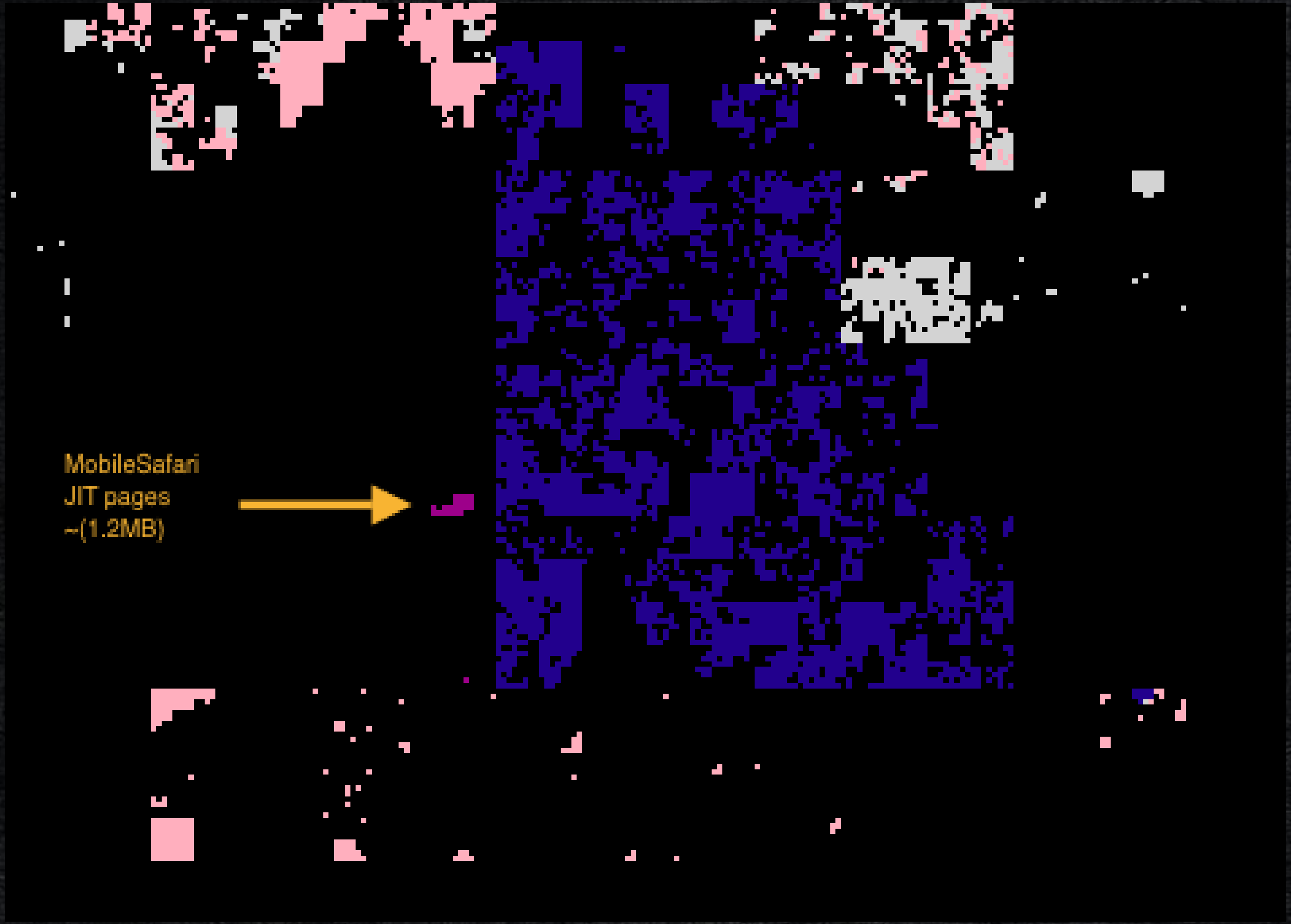
iOS: Example process (MobileSafari)



iOS: Example process (MobileSafari)



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iOS Observations

- Evasi0n jailbreak leaves kernel mappings as RWX
- Fixed physical memory mappings across boots
  - Weakness with virtual mapping leak or physical memory write

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