Drammer: Deterministic Rowhammer Attacks on Mobile Platforms

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Outline

- Summary
- Problem
- Background
- Goal
- Mechanisms
- Key Results: Methodology and Evaluation
- Novelty, Key Approach and Ideas
- Strengths
- Weaknesses
- Thoughts and Ideas
- Takeaways
- Questions/Open Discussion

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Summary

- ARM based devices can be vulnerable to Drammer as well.
- Drammer:
  - Memory templating
    - Scan memory for vulnerable bits
  - Land sensitive data
  - Reproduce the bit flip
- Root access exploitation possible with high reliability.
  - By modifying entries in Page Table Pages (PTP)
- Severe consequences for numerous devices that are currently in use.

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Problem

- Rowhammer failure mechanism only exploitable in a probabilistic way
  - Can it be done deterministically?
- Not clear if Rowhammer attacks are possible on ARM
  - Some researcher thought that it might be impossible on ARM

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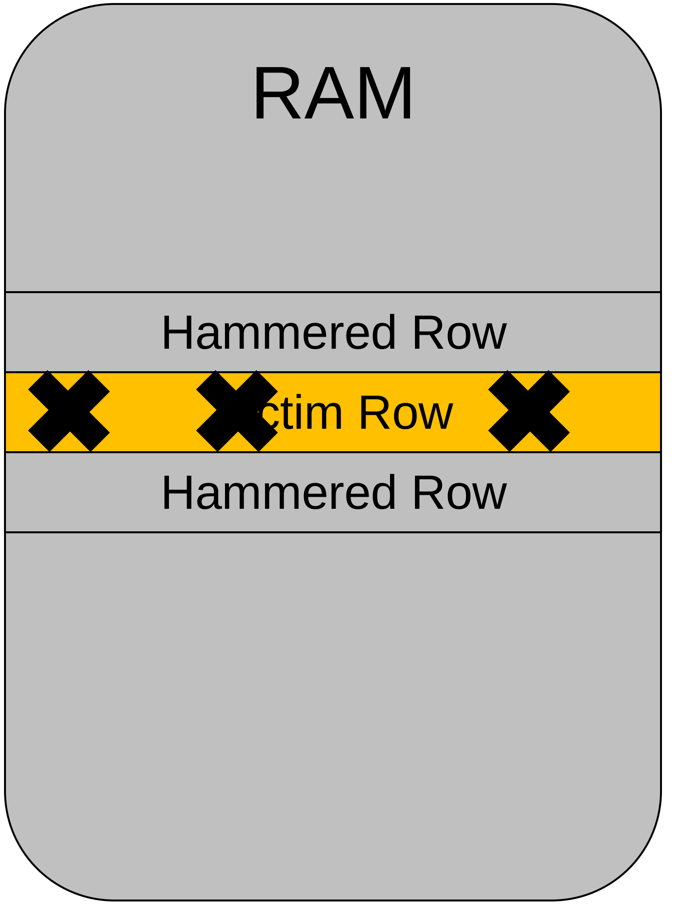
Rowhammer Failure Mechanism

- Access adjacent rows at a high frequency (hammer)
- This causes voltage leakage in the victim row
- Bit flips are induced



Primitives to exploit Rowhammer Bug – x86

- P1: Fast uncached memory access
  - Explicit cache flush (`clflush` instruction)
  - Cache eviction sets
  - Non-temporal access instructions
- P2: Physical memory massaging
  - Page-table spraying (probabilistic)
- P3: Physical memory addressing
  - Pagemap interface
  - Huge pages

Rowhammer Bug on x86

- Probabilistic
  - Page-table spraying used because we don't know exactly where bitflips will occur.
- Countermeasures
  - Disable `clflush`
  - Error Correcting Codes (ECC)
  - Probabilistic Adjacent Row Activation (PARA)
  - Many more

Primitives to exploit Rowhammer Bug – ARM

- P1: Fast uncached memory access
  - Explicit cache flush (`clflush` instruction) — Privileged instruction
  - Cache eviction sets — Too slow
  - Non-temporal access instructions — Only suggests to not cache it
- P2: Physical memory massaging
  - Page-table spraying (probabilistic) — Can crash the system
- P3: Physical memory addressing
  - Pagemap interface — No unprivileged access anymore
  - Huge pages — Disabled on stock Android

Rowhammer Failure Mechanism

- x86 Architectures are known to be vulnerable if the DRAM is modern enough.
  - Are ARM architectures vulnerable as well?
- Before this paper:
  - Probabilistic Rowhammer attacks on x86 based devices
    - Low reliability
    - Limited impact in practice
- After this paper:
  - Deterministic Rowhammer attacks
    - High reliability
    - Allows to completely subvert any vulnerable system
    - Requires to trick the OS to put a page table in a known and vulnerable memory location.

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Goal

- *"Deterministic Rowhammer Attack on Mobile Platforms"*
  - Deterministic:
    - Memory templating
    - Land sensitive Data → Phys Feng Shui
    - Reproduce the bit flip
    - *Note: This approach is not completely deterministic but much more reliable than the probabilistic approach that we know from Rowhammer attacks on x86.*
  - Rowhammer Attack:
    - Vulnerable system required
  - Mobile Platforms:
    - ARMv7, ARMv8 running Android

Primitives to exploit Rowhammer Bug - ARM

- P1: Fast uncached memory access
  - Provided by DMA buffer management APIs (ION)
- P2: Physical memory massaging
  - Memory Templating
  - Physical Memory Allocator
    - Buddy allocator
  - Phys Feng Shui
- P3: Physical memory addressing
  - Provided by DMA buffer management APIs (ION)

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Phys Feng Shui

- Variant of Flip Feng Shui
  - FFS was used to mount attacks against other guest OSes running on the same hypervisor.
- Goal
  - Force the OS to place a page-table in a vulnerable memory location such that we can modify an entry in a deterministic way.
- Some size definitions
  - S chunk = chunk of the size of a page (typically 4KB)
  - M chunk = chunk of the size of a row (has to be determined)
  - L chunk = largest possible contiguous chunk

Determining Row Size

- Access time for page pairs
- If access time increases then the pages are on different rows
  - Therefore we can determine the row size

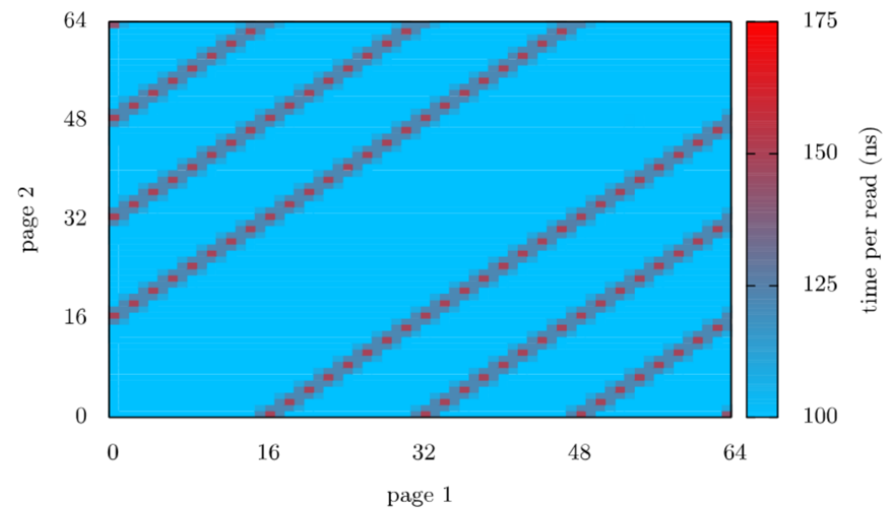
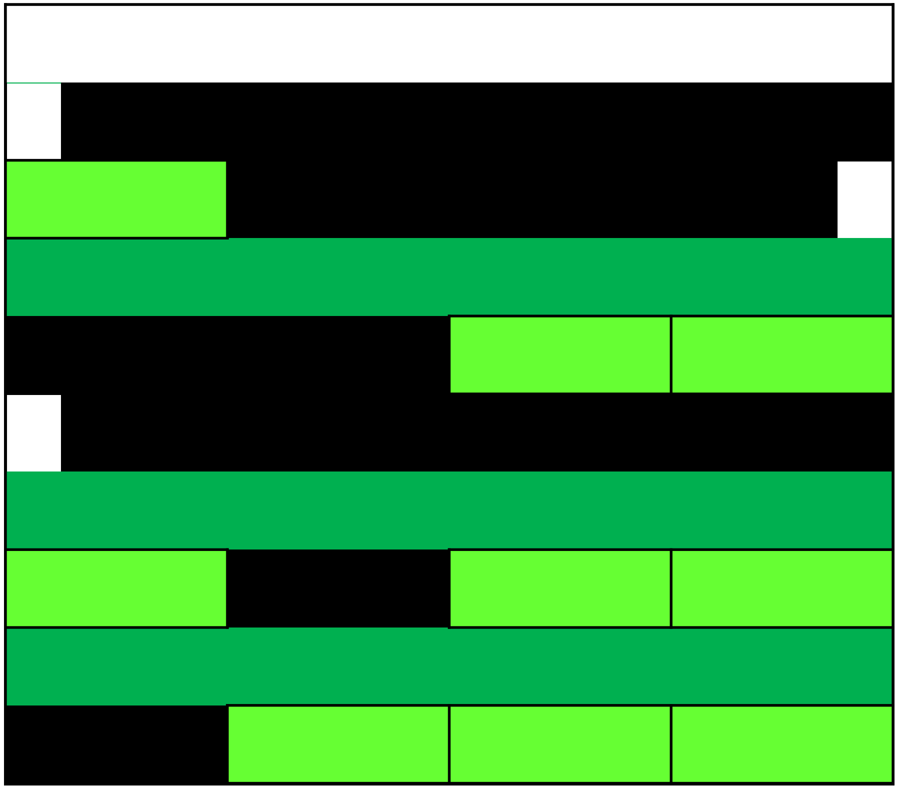


Figure 3: Heatmap representing the time required to access a given pair of pages on a LG Nexus 5. The diagonal pattern clearly indicates that the row size is 16 pages = 64K.

(0,1) (0,2) (0,3) … (0,16)

Phys Feng Shui

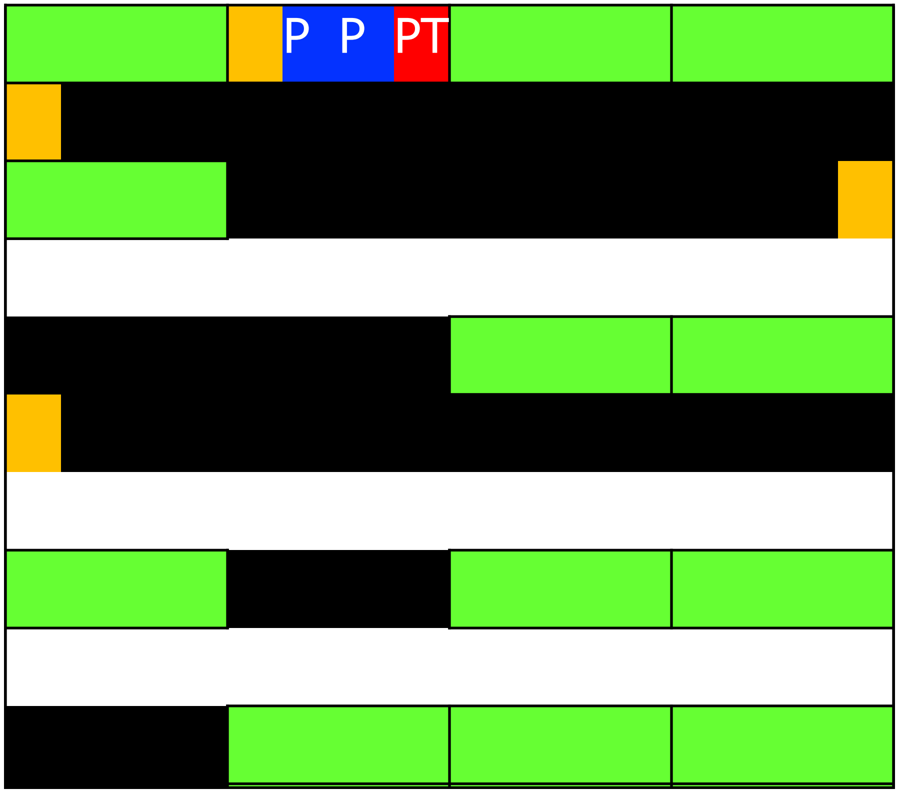
- Step 1: Fill in as many L chunks as possible and create templates
- Step 2: Fill in as many M chunks as possible
- Step 3: Free one L chunk where we want to launch the attack



Free(L*)

Phys Feng Shui

- Step 4: Fill L* with M chunks
- Step 5: Free M* and all L chunks (M* is where we launch the attack)
- Step 6: Fill in S chunks until the first one falls into M*
- Step 7: Add padding to align victim page table
- Step 8: Launch attack on the victim page table that then points to a page table which we created in L*



Map(M)

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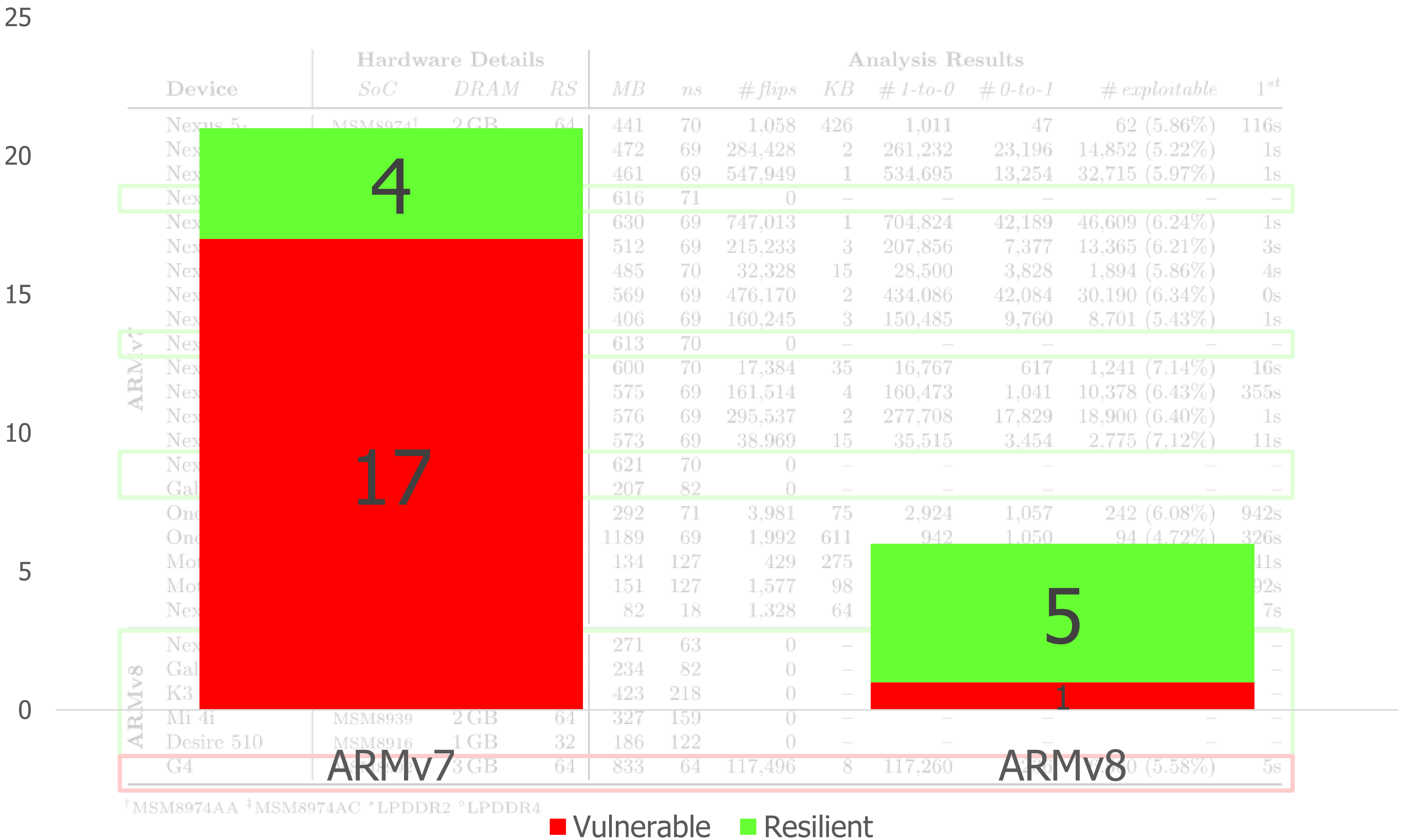
Empirical Results



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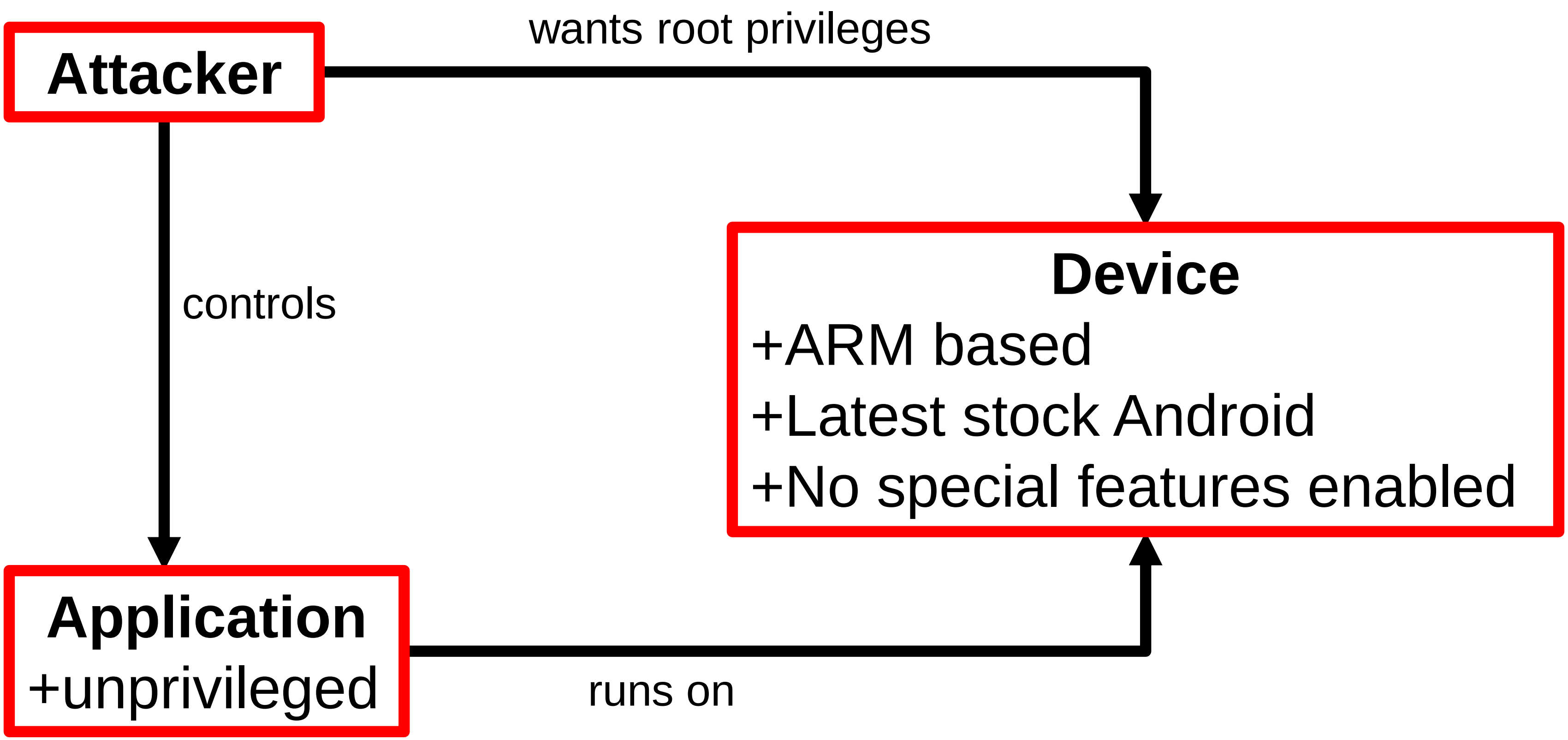
Threat Model

- Set up:
  - Attacker has control over an unprivileged app running on a ARM based Android device.
  - No permissions at all.
  - Latest stock version of Android with all the latest security updates installed.
  - No special features enabled.
- Goal of the attacker:
  - To mount an privilege escalation attack to acquire root privileges.

Threat Model



Novelty, Key Approach and Ideas

- First deterministic Rowhammer attack on ARM architecture
- Generalization of deterministic Rowhammer attacks on x86 architecture
- Mounting a Drammer attack using Direct Memory Access (DMA) bypasses existing defenses (i.e. disabling `clflush`) on x86 architectures

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Strengths

- Shows a severe problem current mobile devices have.
  - First paper that shows a Rowhammer attack on ARM architecture based devices.
- The attack is deterministic.
  - Much more serious consequences in practice.
- Very detailed description of the work that was done

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Weaknesses

- All countermeasures have an overhead
- ARMv8 sample size too small
  - No representative conclusion possible
  - No explanation why they seem more resilient
- Tested only Android smartphones (i.e. no Smartwatches, no IPhones, etc.)
- Considering that the occurrence of bitflips also depends on environmental aspects, the sample size is clearly too small.
- Not so easy to understand (Phys Feng Shui)

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Thoughts and Ideas

- Future research needs to test the influence factors like temperature, age of the components, etc. have on the number of vulnerable bits.
- A broader range of devices needs to be tested (also running other OSes than Android).
- More effective and efficient countermeasures need to be found.

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Takeaways

- Rowhammer on ARM
- Deterministic exploitation
- Practical impact

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QUESTIONS?

Discussion Question

- What do you consider being more valuable regarding security?
  - Opensource Android
    - Known that Drammer is possible
    - Countermeasures proposed by third parties
  - Proprietary iOS
    - Unsure if Drammer is possible
    - If possible then there are not yet any countermeasures

Discussion Question

Opensource Android

- Positive:
  - Huge research community doing research on Android
  - More vulnerabilities get found and can be patched
- Negative:
  - Attacker can learn more about the OS
  - Practical attacks happen faster

Proprietary iOS

- Positive:
  - Attackers have it harder to mount a practical attack since they know less about the OS
- Negative:
  - Once an attacker is successful, he can be active for a very long time
  - Fewer security researchers

Discussion Question

- Do you think it is okay that the researchers published the paper before Google was able to patch it’s devices?

Discussion Question

- Researchers reported the attack to Google 91 days before the release of the paper at CCS 2016
  - Including some mitigation techniques
- Google asked them to delay the release of the paper
- The researchers refused
- Google asked them to obfuscate parts of the paper
- The researchers refused again
- → Did the researchers act responsibly?

Discussion Question

- Can you think of countermeasures that have little to no overhead?

Discussion Question

- Hardware based:
  - Probabilistic Adjacent Row Activation (PARA) looks promising
  - Better isolation between rows in DRAM?
- Software based:
  - Disallow features that can be used to satisfy the primitives P1-P3
  - Detect access patterns that could imply that an attack is happening

Supplementary Material

- [Video] CCS 2016 – Drammer: Deterministic Rowhammer Attacks on Mobile Platforms
  - https://www.youtube.com/watch?v=lTaMvBN1PoA
- [Video] Computer Architecture – Lecture 2: RowHammer and Beyond (ETH Zürich, Fall 2018)
  - https://www.youtube.com/watch?v=560JzQ-oeLE