Copy-on-Flip: Hardening ECC Memory Against Rowhammer Attacks

Andrea Di Dio[1], Koen Koning[2], Herbert Bos[1], Cristiano Giuffrida[1]

[1]**Vrije Universiteit Amsterdam**
[2]**Intel**

TL;DR

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  - ECC to detect ongoing Rowhammer attacks
  - Transparent page migration and offlining for vulnerable pages
  - Low overhead with >95% attack surface reduction (including kernel memory)

Background – Rowhammer Attacks

Flipping Bits in Memory Without Accessing Them: An Experimental Study of DRAM Disturbance Errors

Yoongu Kim[1] Ross Daly* Jeremie Kim[1] Chris Fallin* Ji Hye Lee[1]
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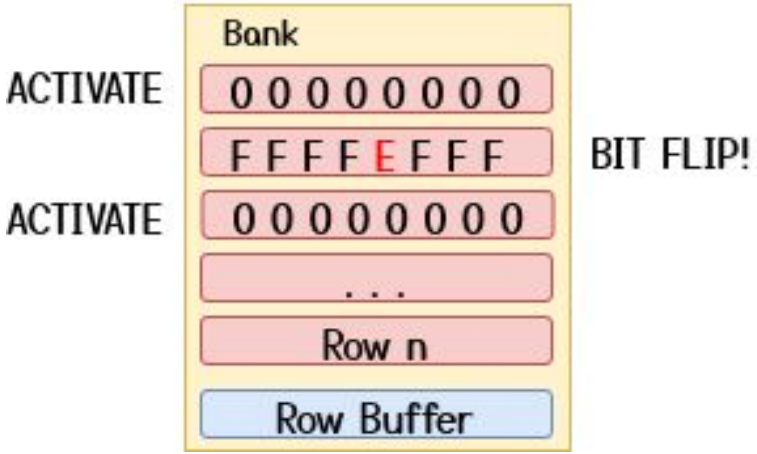

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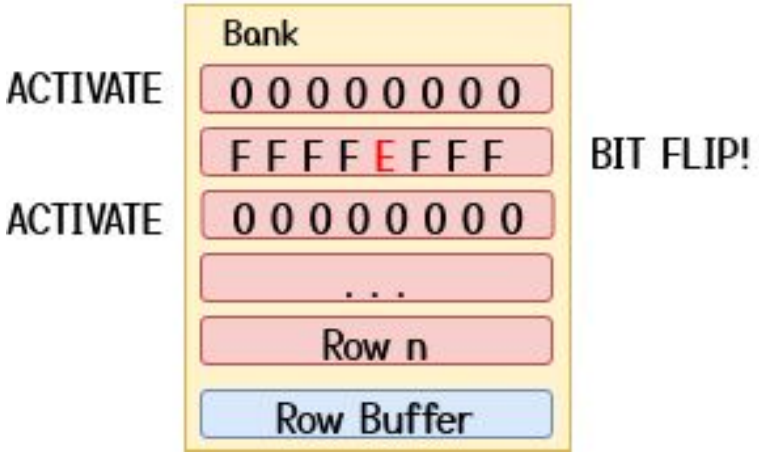

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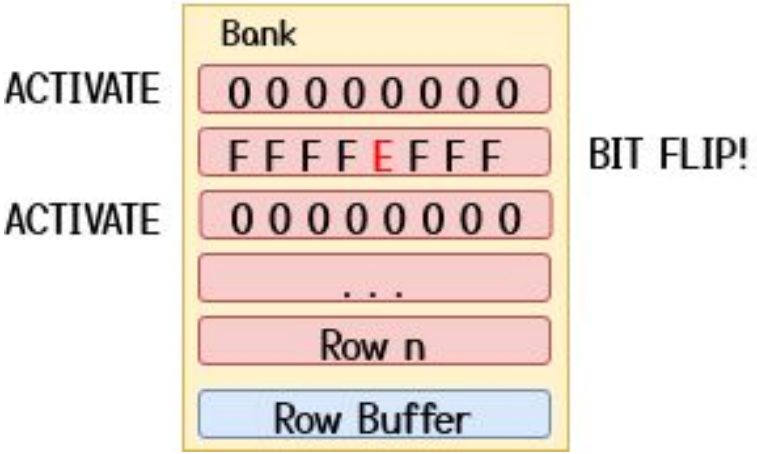

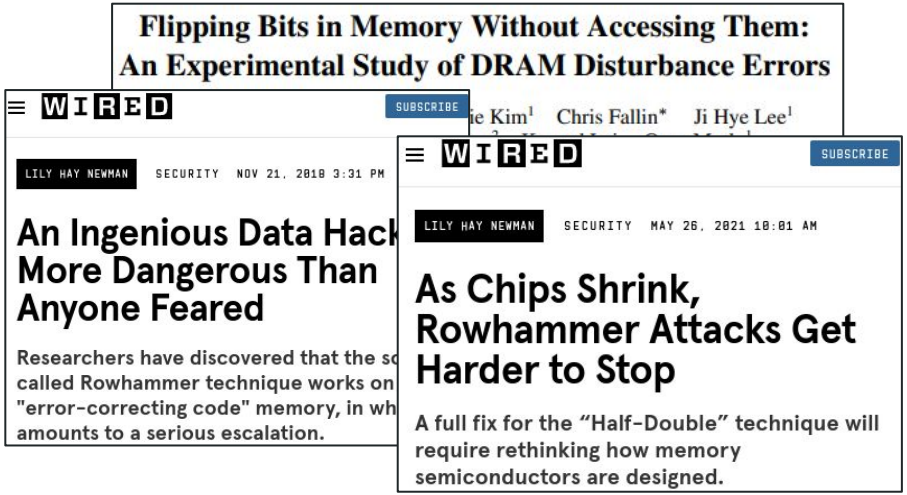

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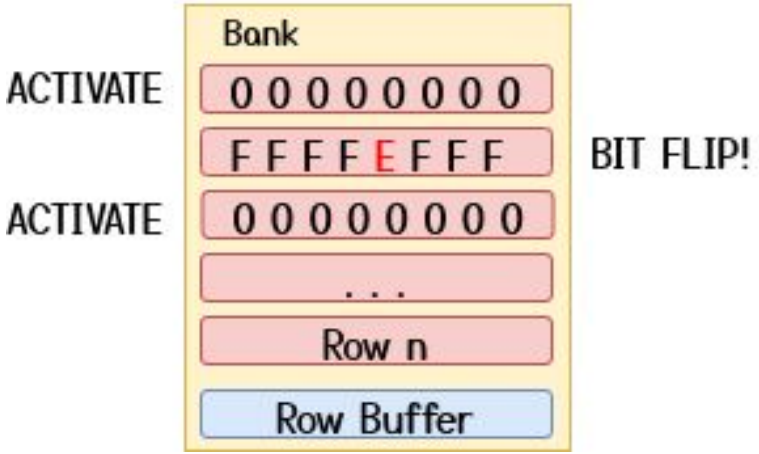

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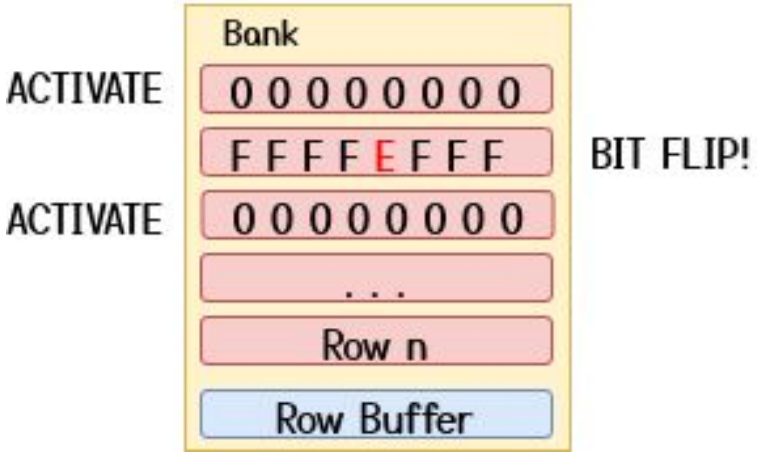

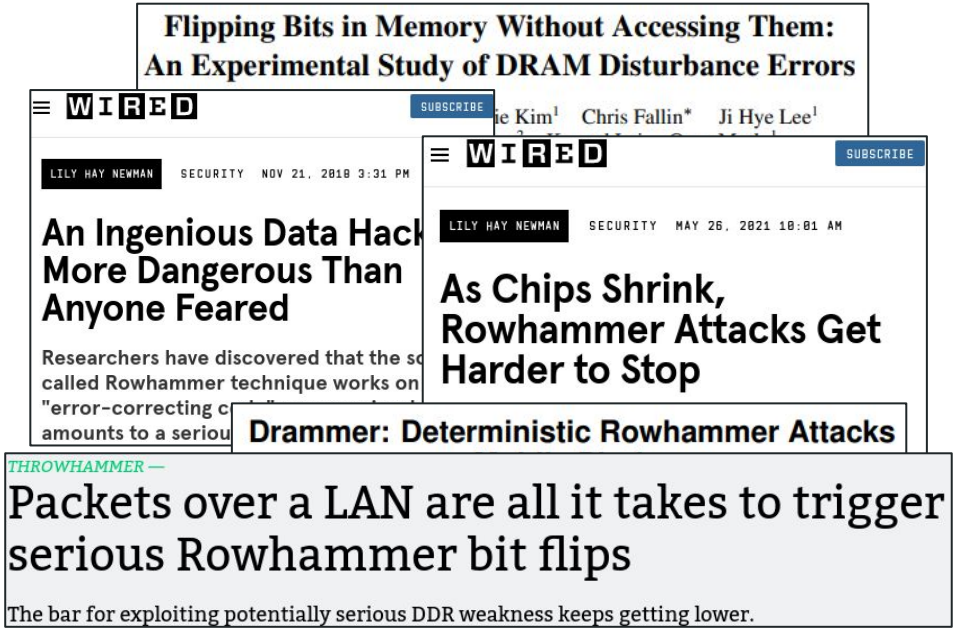

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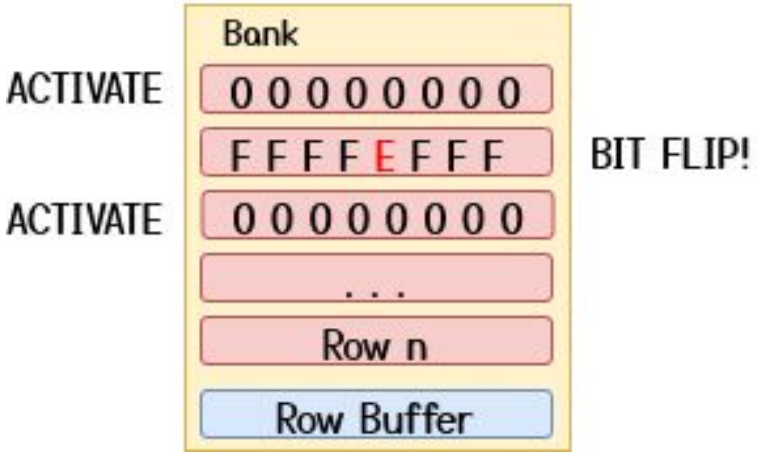

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As Chips Shrink, Rowhammer Attacks Get Harder to Stop

Drammer: Deterministic Rowhammer Attacks

THROWHAMMER —

Packets over a LAN are all it takes to trigger serious Rowhammer bit flips

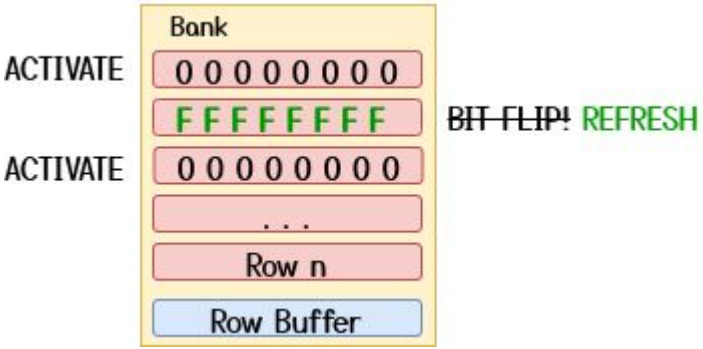
The b

BLACKSMITH —

DDR4 memory protections are broken wide open by new Rowhammer technique

Researchers build "fuzzer" that supercharges potentially serious bitflipping exploits.

Background – Rowhammer Defenses



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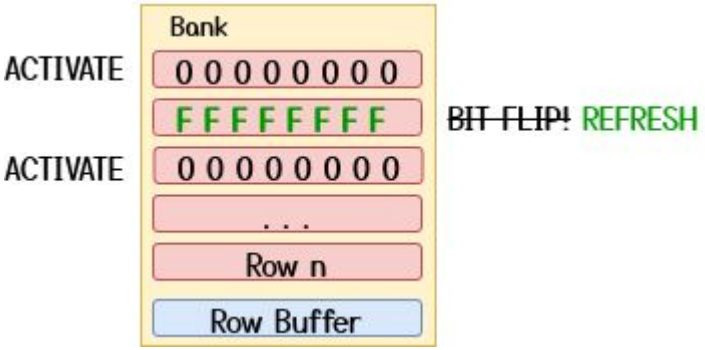

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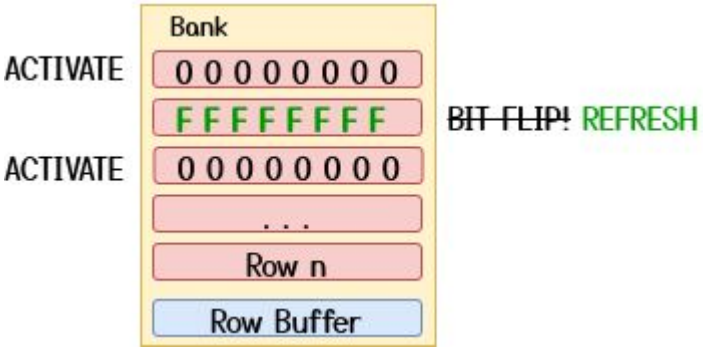

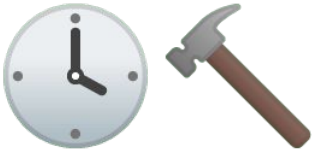

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- One-bit-at-a-time templating
- ≥ 3 bit flips to evade ECC

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  - High overhead
  - Unrealistic assumptions

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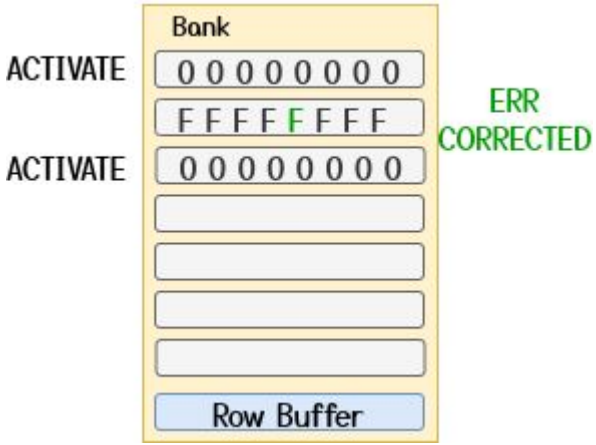

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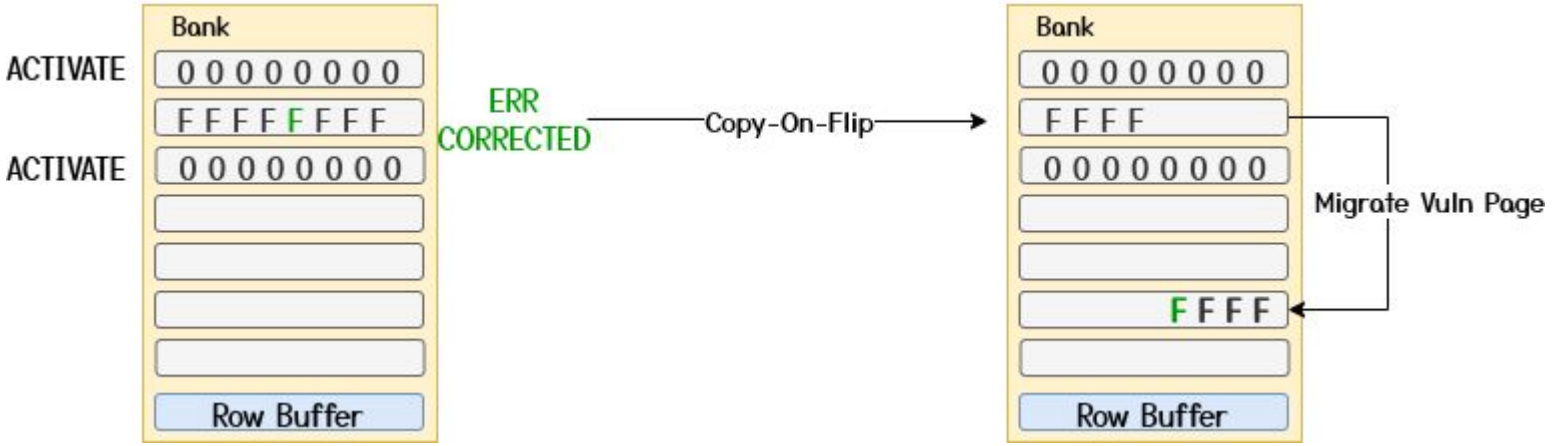

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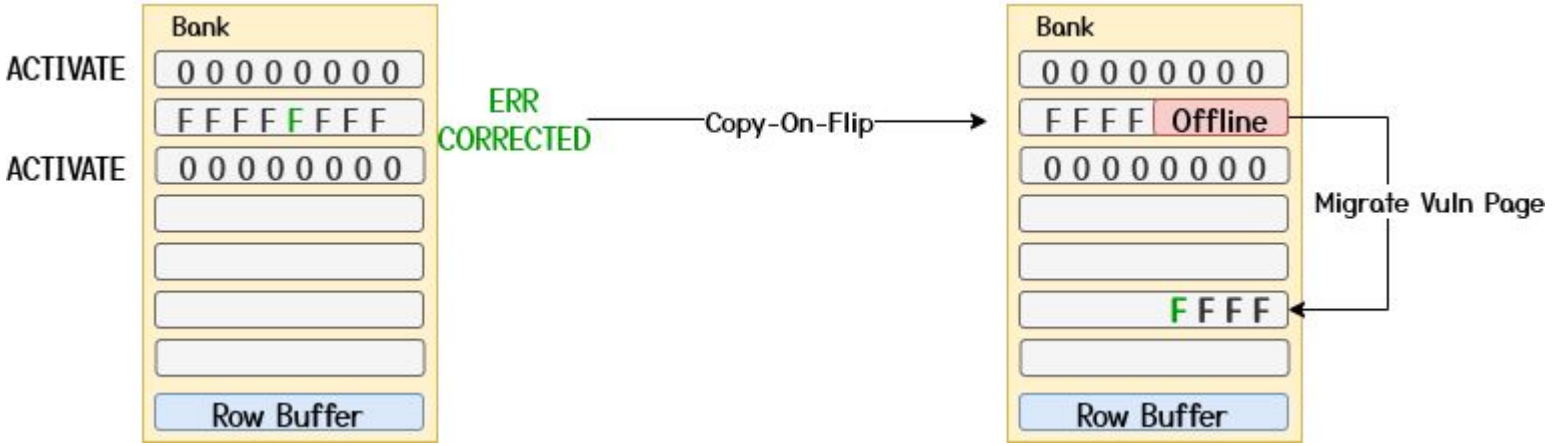

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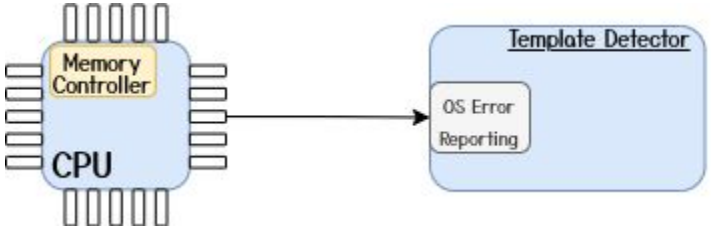

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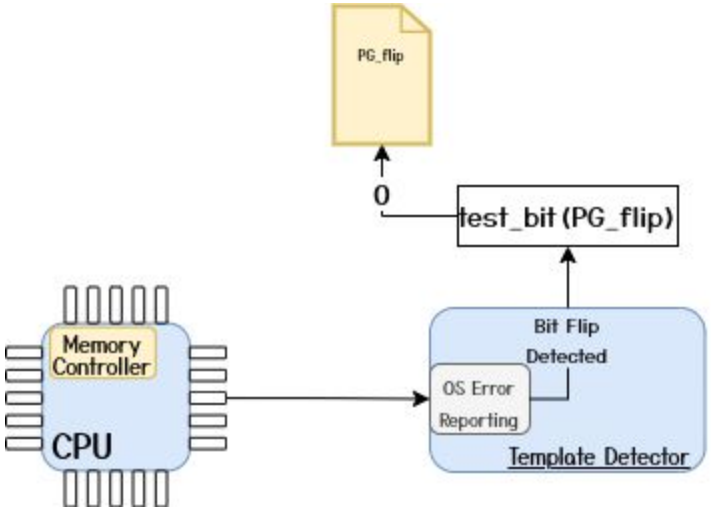

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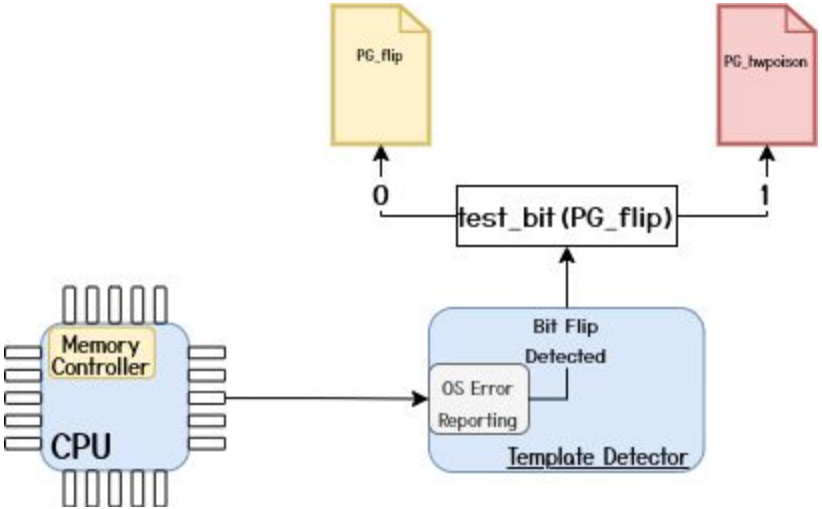

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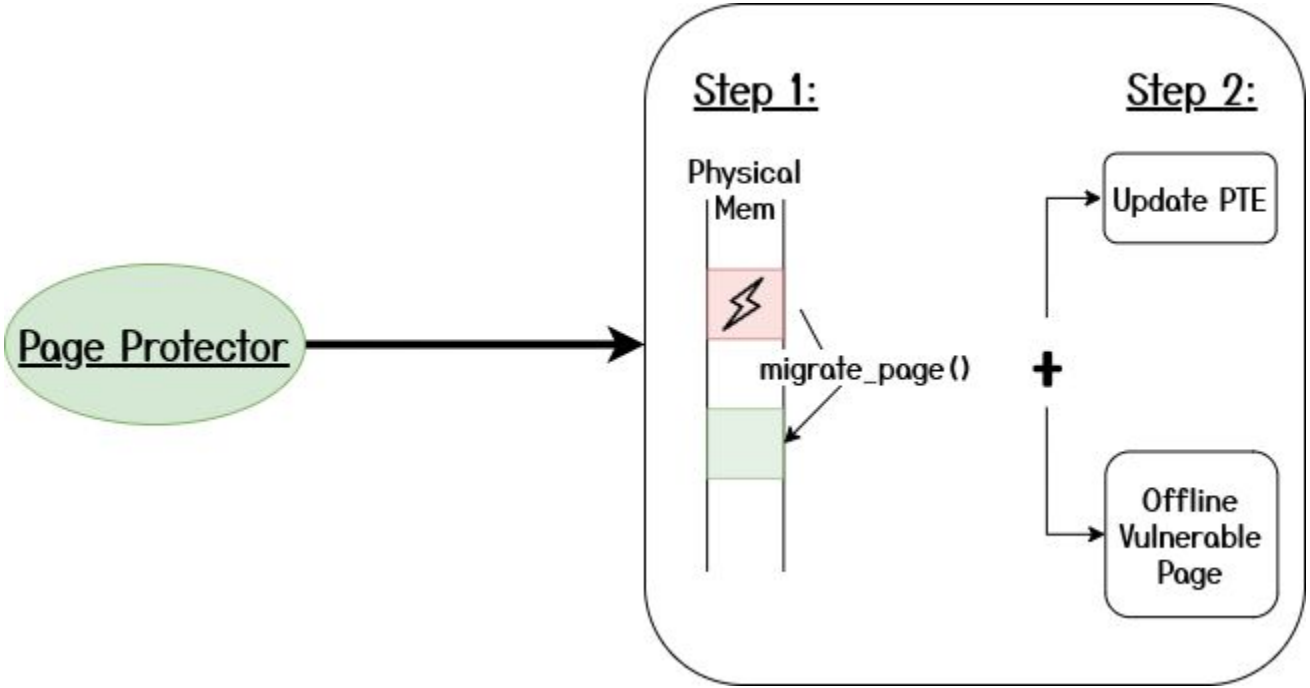

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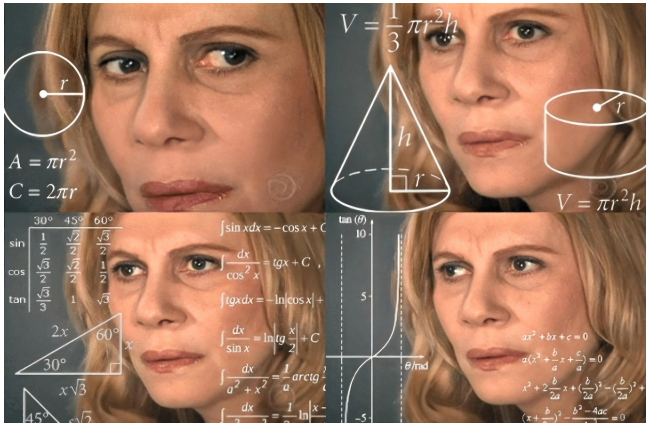

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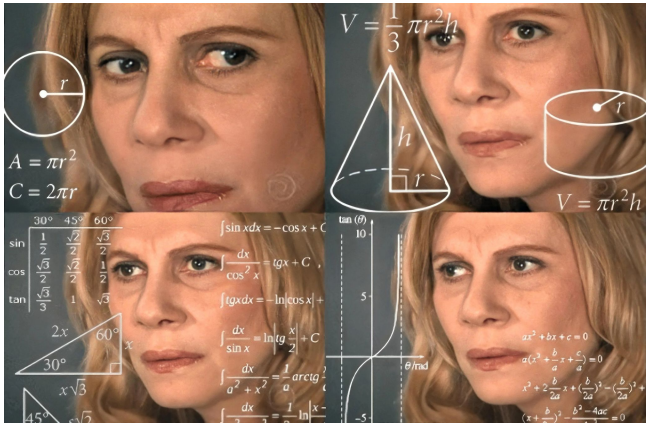

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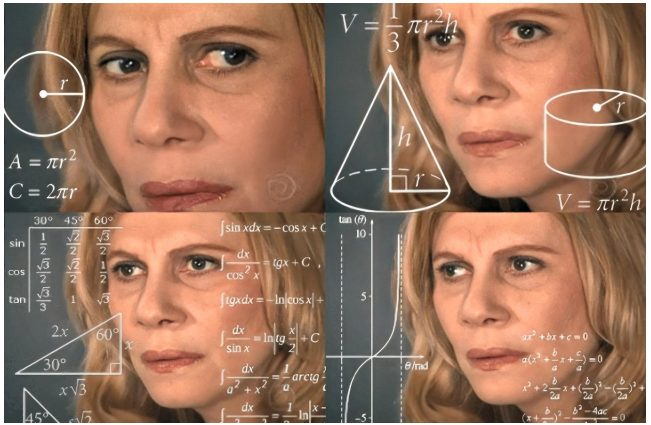

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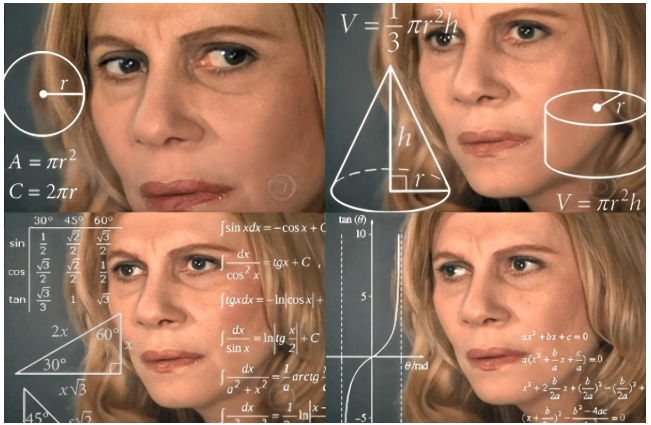

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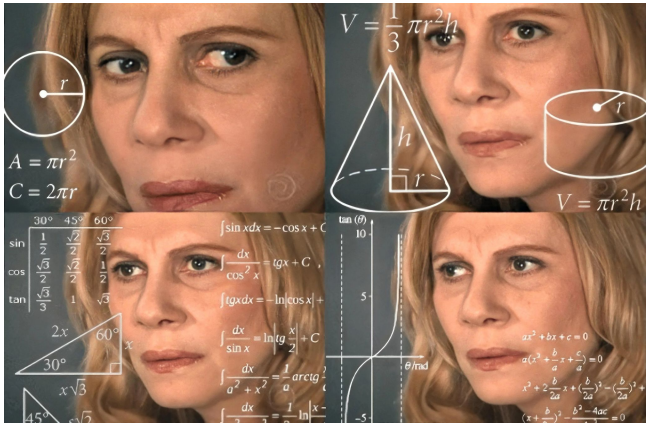

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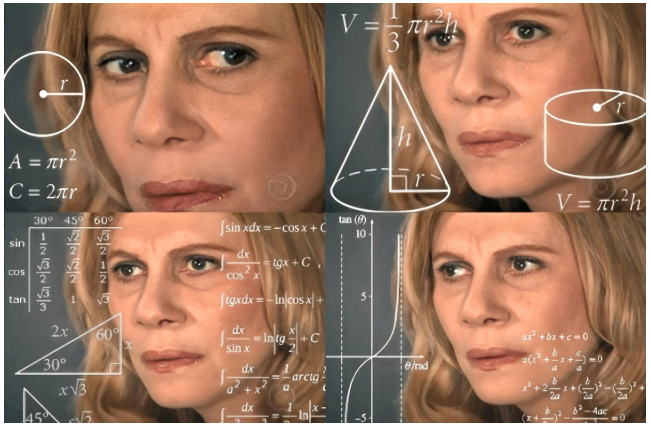

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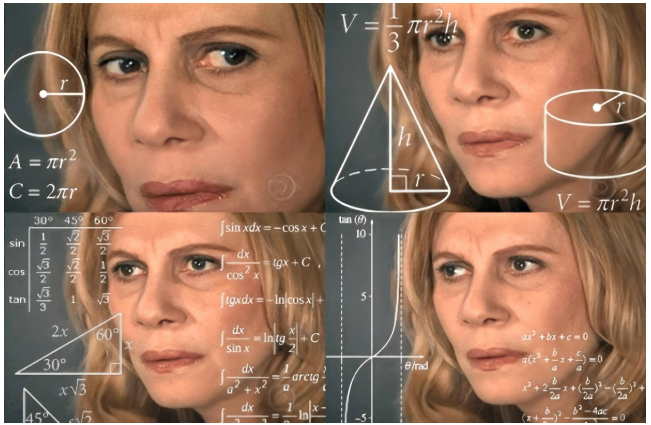

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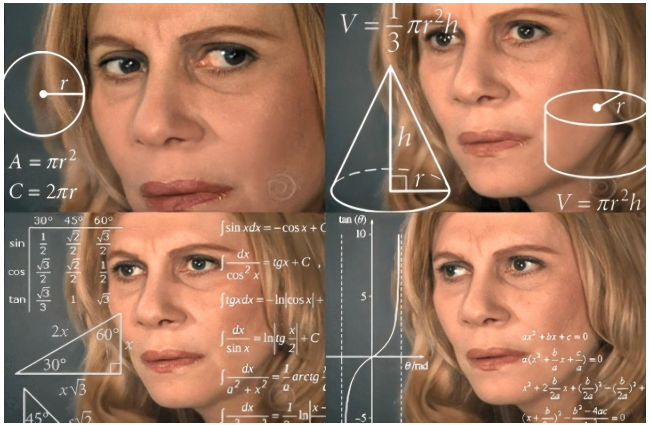

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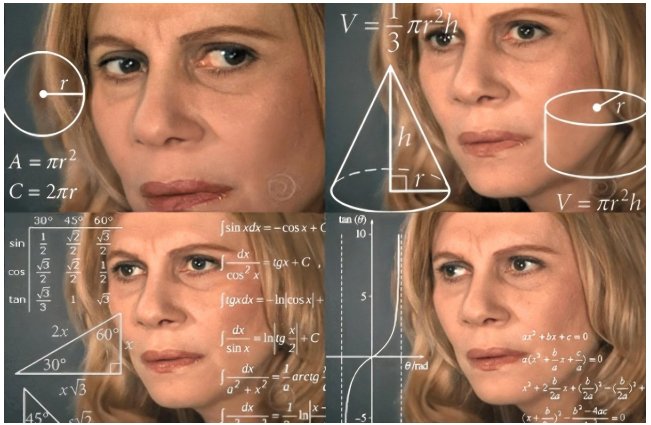


Challenge – Kernel Pages

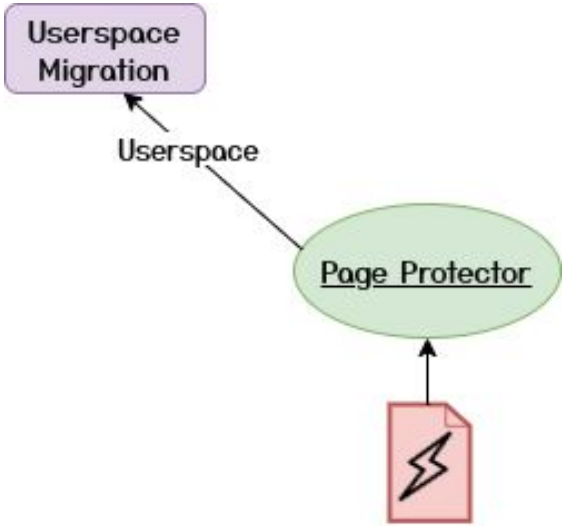
- Existing page offlining implementations in Linux ignore kernel pages

```
886  /*
887   * Error hit kernel page.
888   * Do nothing, try to be lucky and not touch this instead. For a few cases we
889   * could be more sophisticated.
890   */
891  static int me_kernel(struct page_state *ps, struct page *p)
892  {
893          unlock_page(p);
894          return MF_IGNORED;
895  }
```

mm/memory-failure.c

Copy-on-Flip - Page Protector

- Transparent page migration and offlining



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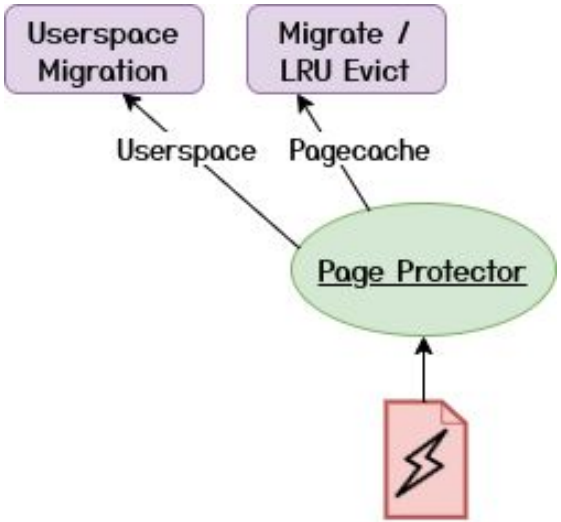

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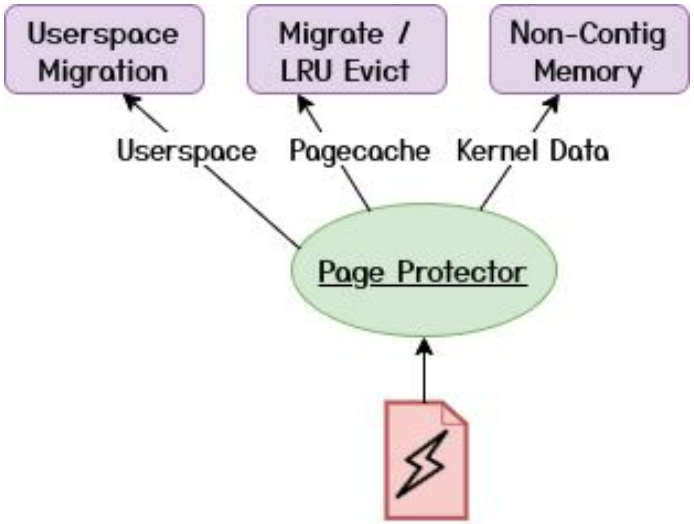

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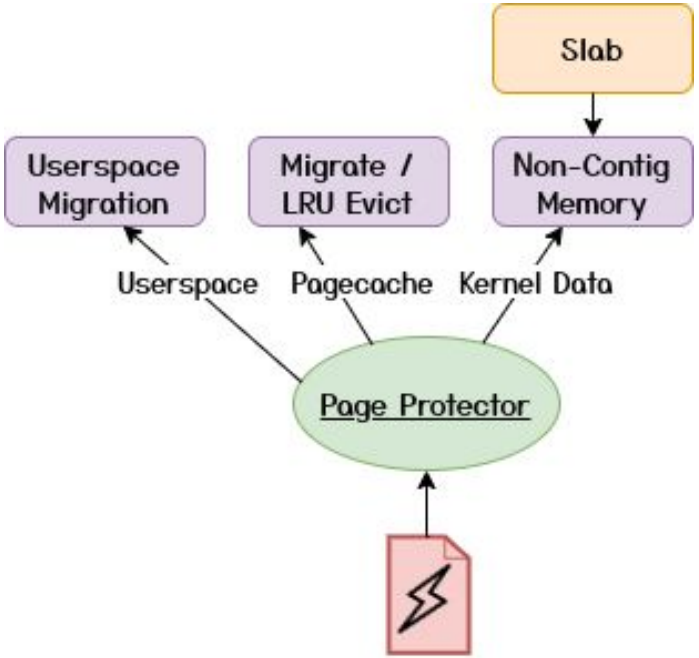

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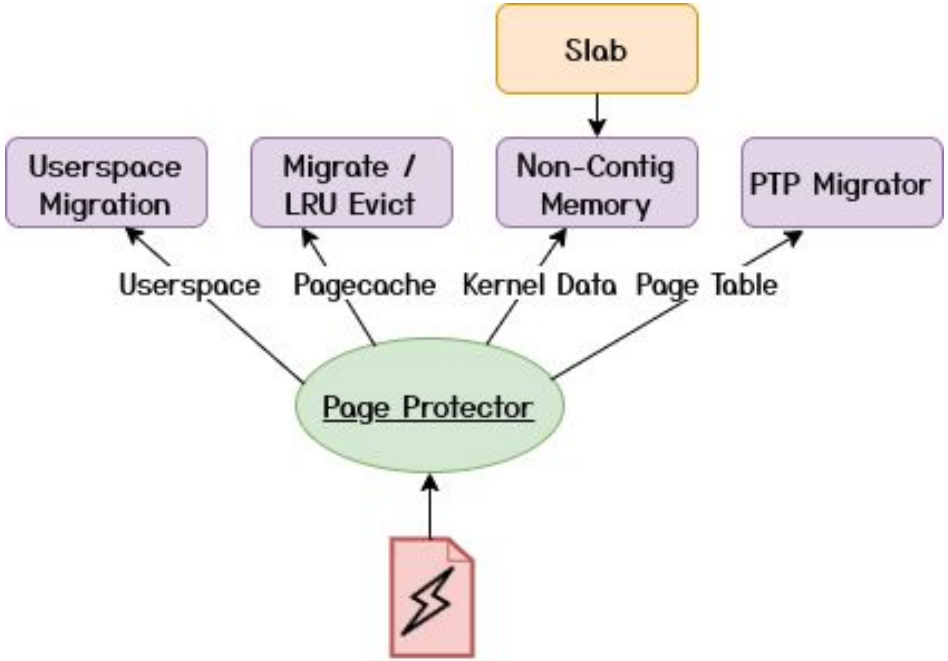

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- HW Error Injection to test defense
- >95% of memory is movable
- System-wide protection
- No assumptions on Rowhammer variant

Evaluation – Performance

- SPEC CPU2017 geometric mean overhead: 0.2%
- LMBench geometric mean overhead: 1.9%
- Kraken on Google Chrome geometric mean overhead: 1.1%

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- SPEC CPU2017 geometric mean overhead: 0.2%
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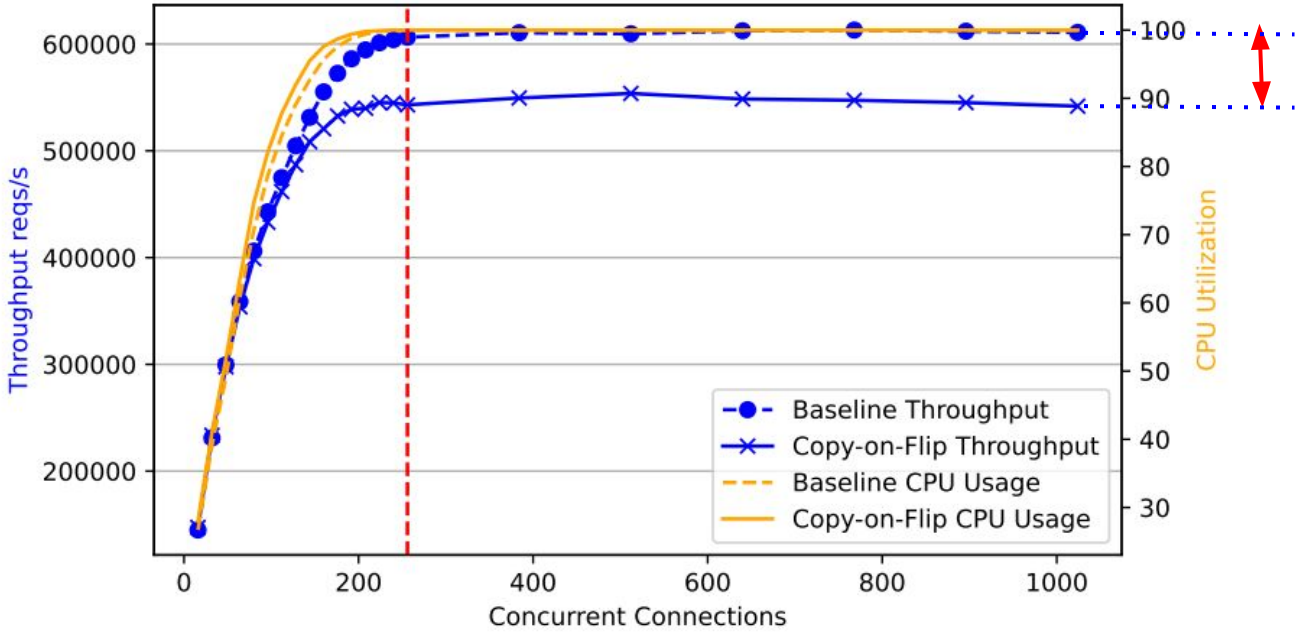
- Negligible memory overhead under normal conditions

Evaluation – Nginx



~10% median overhead

Conclusion

- Modern systems are still vulnerable to Rowhammer
- Copy-on-Flip design + open-source implementation
- Low overhead and high attack surface reduction

More in The Paper

- Linux implementation details
- More evaluation results
- Discussion on other OSes
- Paper: https://download.vusec.net/papers/cof_ndss23.pdf
- Code: https://github.com/vusec/Copy-on-Flip

@hammertux @vu5ec

Evaluation - Residual Attack Surface

- >95% pages are now protected in Copy-on-Flip
- Non-movable pages
  - DMA
  - Direct Linear Mapping

Evaluation – Performance Under Attack