Morpheus II: A RISC-V Security Extension for Protecting Vulnerable Software and Hardware

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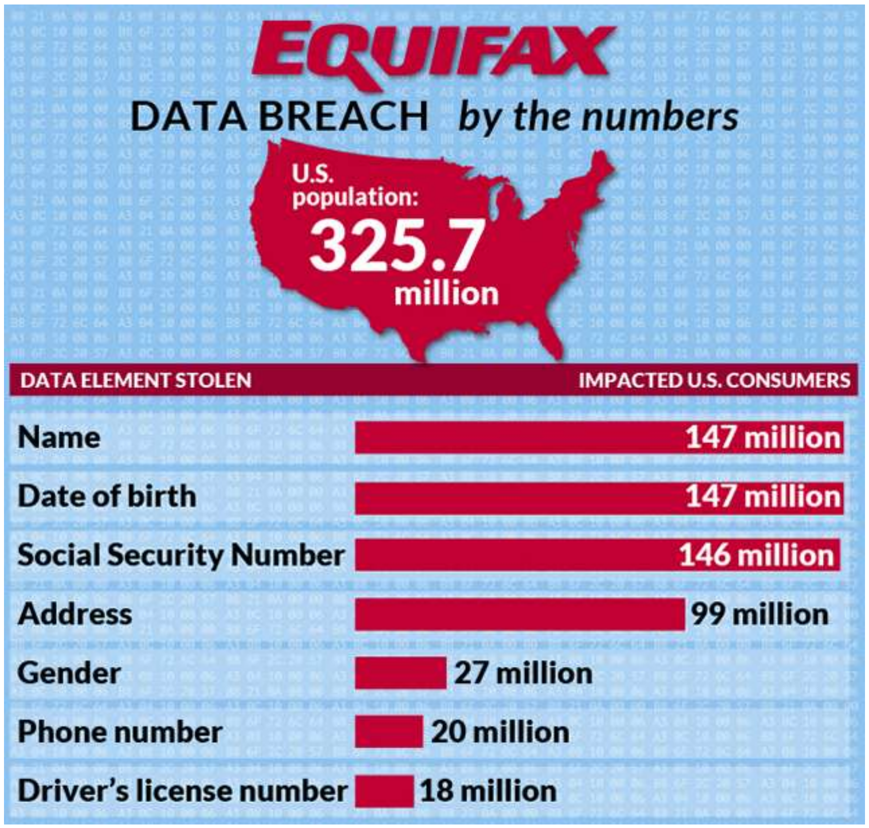
Assessing the (Dour) State of Today's Security Defenses

Who Can We Trust? Attackers Within and Without



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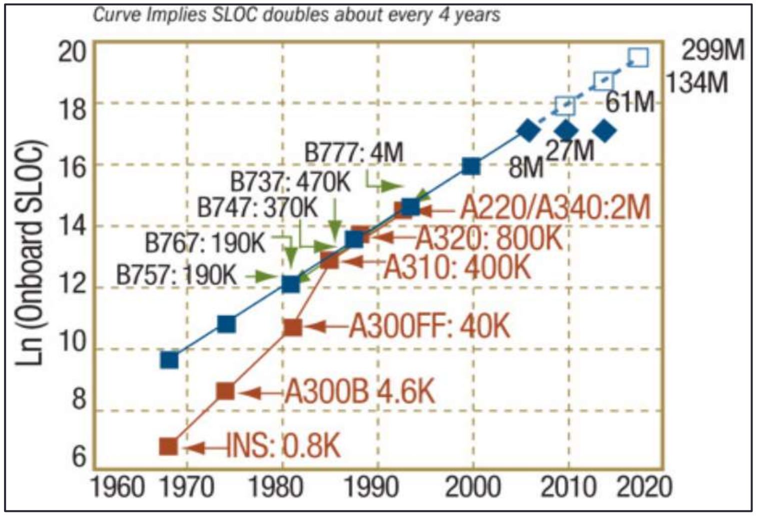
Cambridge Analytica

Because Here There Be Two Powerful Dragons

- Software protects data
  - All software is (eventually) hackable
  - Finding/fixing vulnerabilities doesn't scale
  - E.g., Malicious 7: buffer errors, code injection, numeric errors, permissions, resource mgt
- Side channels abound
  - Control, memory, timing, cache, speculative
  - Performance-centric design creates side channels
  - E.g., Malicious 7: crypto errors, information leakage, resource mgt



Assessing Today's Security Capabilities

- What we do well:
  - Finding and fixing vulnerabilities
  - Deploying system protections that stop well-known attacks
- Where we fail: ***identifying and stopping emergent attacks***

Valgrind

Synopsys' Coverity Tools

ARM's TrustZone

Intel's Control-Flow Enforcement

Can hardware security defenses be built to be more durable?

Morpheus’ Unique Approach to Security

Vulnerabilities + Implementation Assets = Exploit

Attack Detector

- Buffer overflow
- Code pointer arithmetic
- Data pointer logical operation
- Code forgery
- Pointer forgery
- Uninitialized variable access
- Mem permission violation
- Integer overflow
- Shift overflow
- Code read
- Cyclic interference

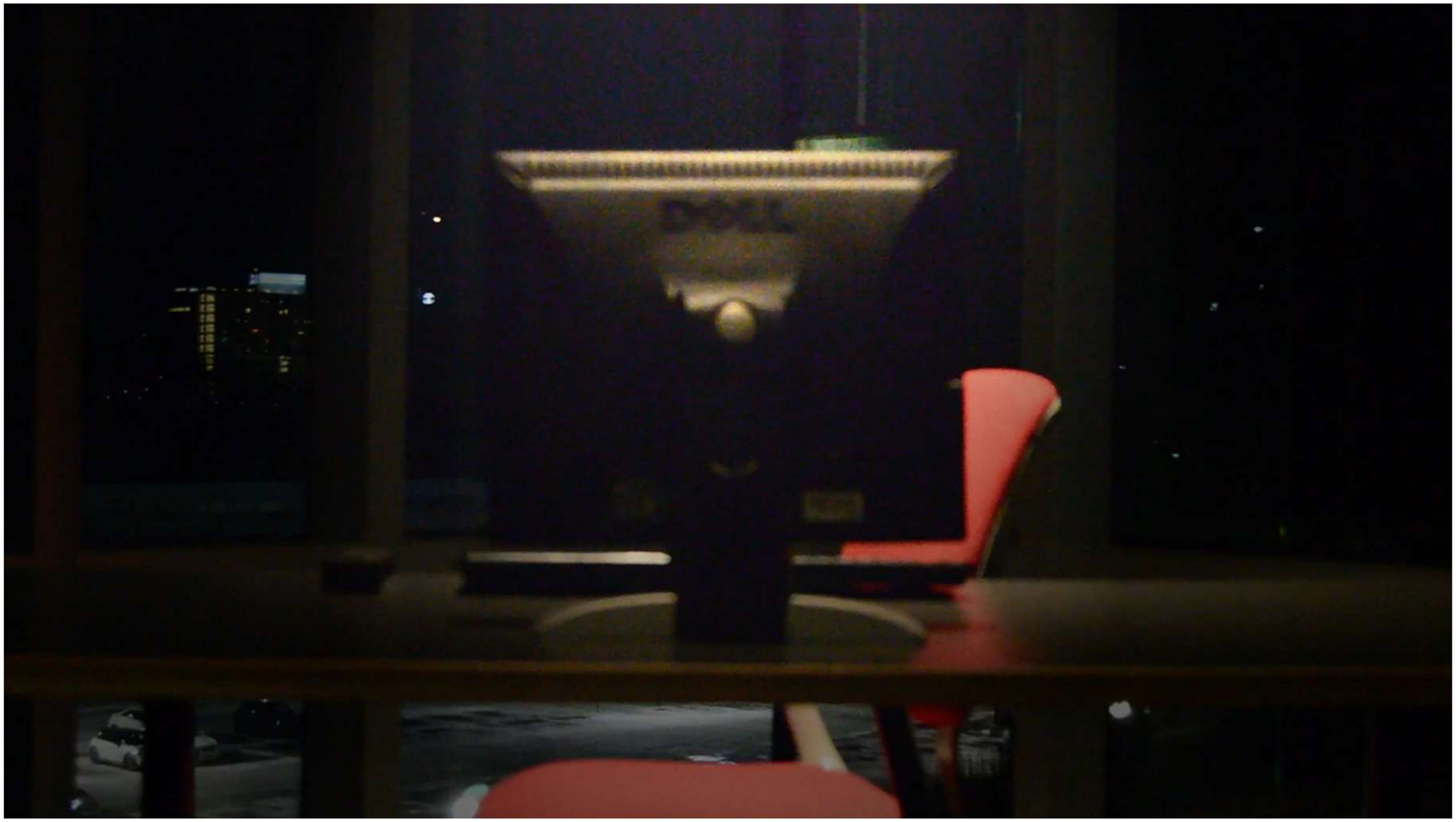
or every 50 ms

Randomization Defenses (w/Churn)

- Code representation
- Code layout (absolute and relative)
- Code pointer representation
- Function pointer representation
- Return pointer representation
- Data pointer representation
- Data layout (absolute and relative)
- Microarchitectural mappings

504 bits of true random entropy

Morpheus: A Puzzle that Computes



Mark Gallagher

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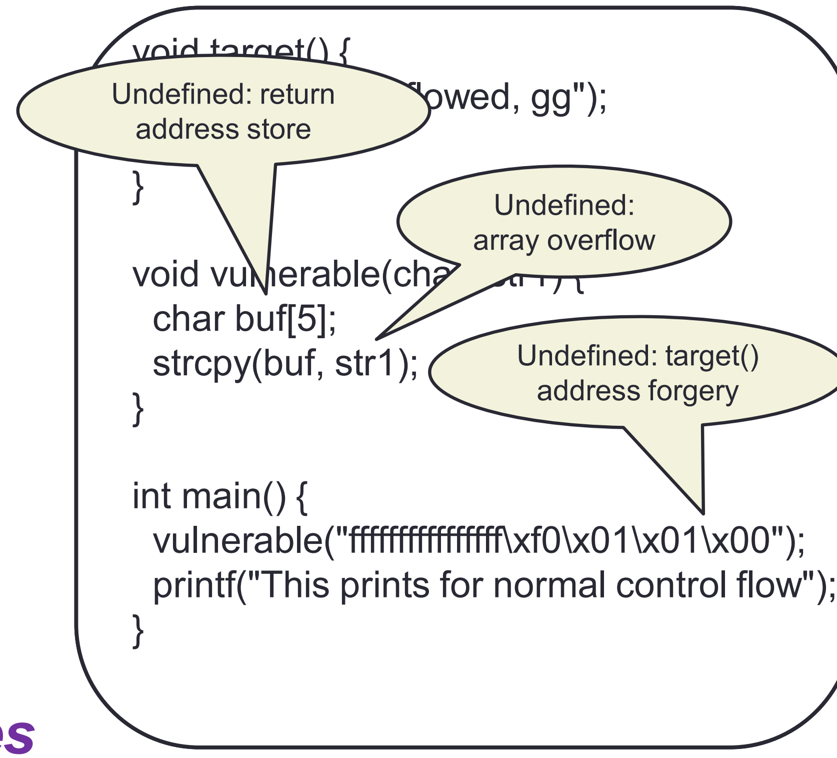
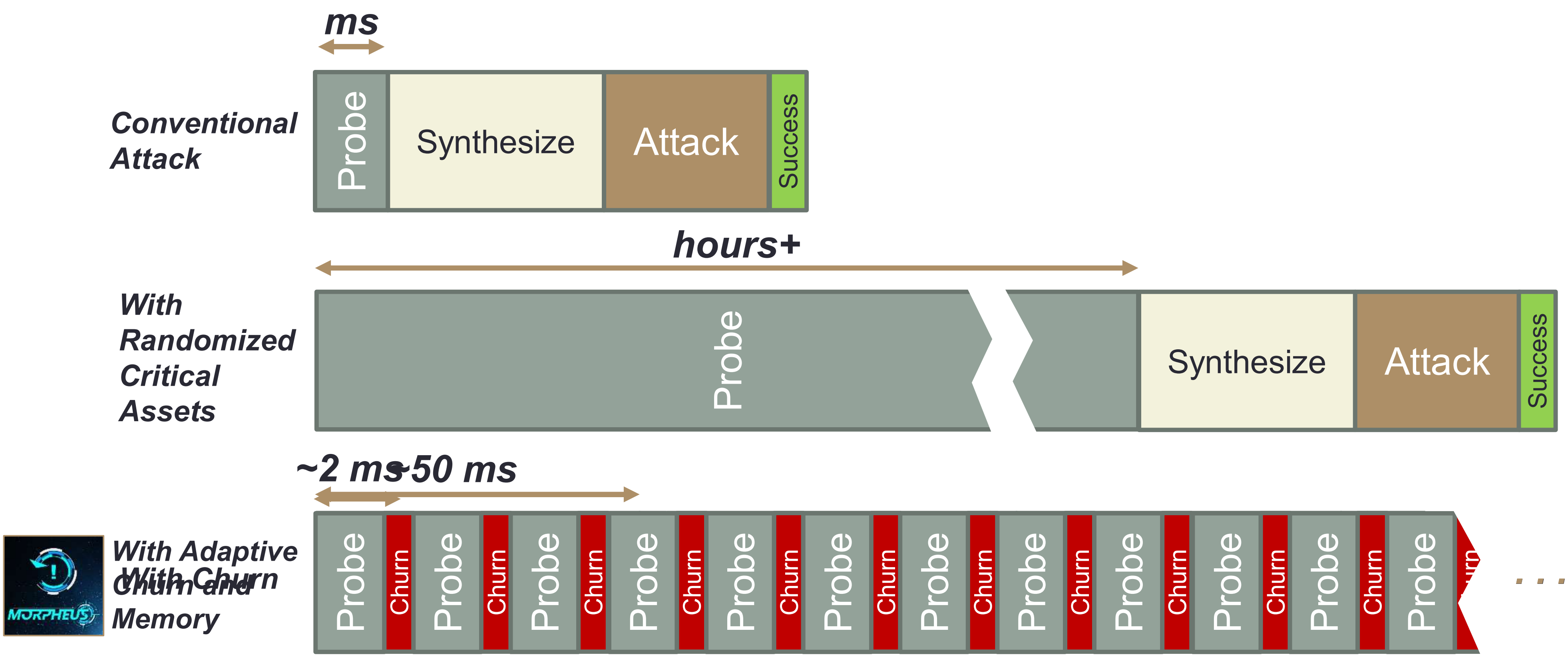
Morpheus Deploys Encryption and Churn

- Morpheus attack detectors discern ***normal*** code from ***malicious*** code, via ***undefined semantics***
- To stop unknown attacks, Morpheus continuously ***encrypts*** undefined program assets, a process called "***churn***"
- Churning undefined assets ***breaks malicious security attacks***, but has no effect on normal software
- Learning mechanisms can ***record and prioritize successful defense strategies*** to speed up protections



Morpheus Breaks Emergent Attacks



Morpheus II RISC-V Extensions and Microarchitecture

Morpheus Code and Pointer Defenses

- ***Always-encrypted code*** is ***physically isolated*** when decrypted

Opcode	Semantics
dst := ptr1 <op> ptr2	Pointer arithmetic: +,-
dst := ptr1 <rel> ptr2	Pointer test: <,>,==, !=,…
dst := load/jump (ptr)	Dereference: ->, *

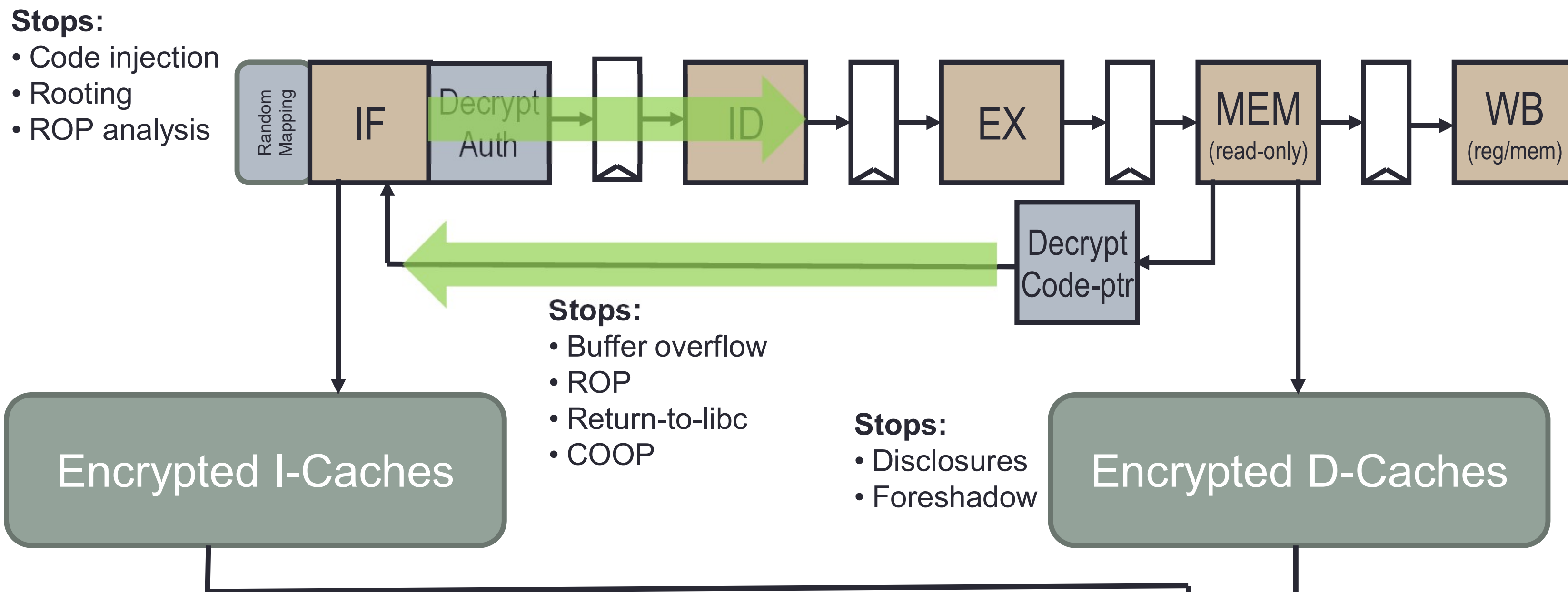
Legend:
Green = decrypted
Red = encrypted

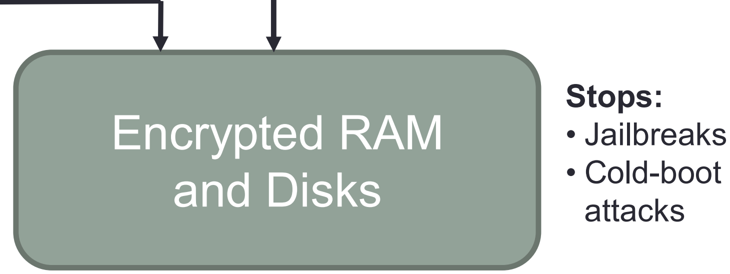
- ***Always-encrypted pointers*** are ***physically isolated*** when decrypted
  - Pointers are accessed with RISC-V instruction set extension
- ***No tagging required*** because we universally change code/pointer format
  - This is ***not*** a problem for normal software
- Pointer tests are leaky, so use ***churn*** to limit utility of side channels
  - Churn re-encrypts program assets while the system is running

Morpheus RISC-V Microarchitecture

Austin Harris

Tarunesh Verma



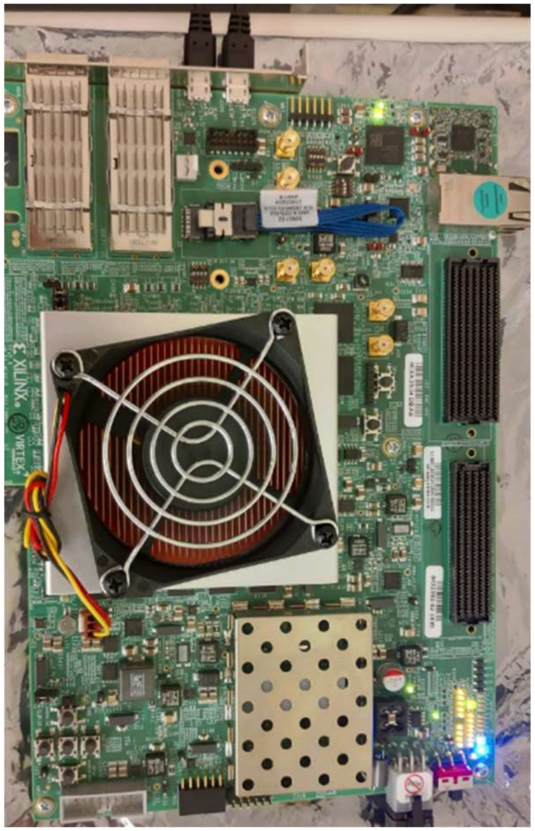


- Built to stop ***remote code execution (RCE)***
  - Built on the RISC-V Rocket Core
  - Always-encrypted code
  - Always-encrypted code pointers

Morpheus II Performance, Area and Security Analysis

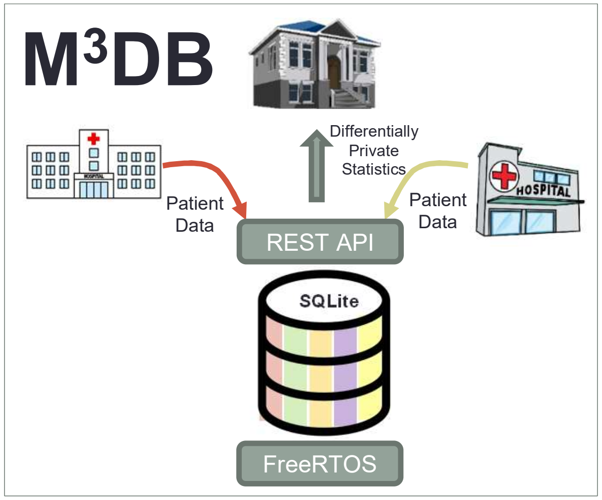
Morpheus Design Overheads

- Integrated into the RISC-V Rocket Core
  - Only 369 lines of Chisel code added
- Deployed in a Xilinx UltraScale+ FPGA
  - Utilized a 12-round Simon cipher
  - < 1% performance overhead
  - 0.2% power overhead
  - 1.3% area overhead
  - Negligible impact to network apps



Putting Morpheus to the Test

- 32-bit Morpheus entered FETT
  - Deployed on AWS F1 FPGAs
  - 535 attackers were recruited for 3 months
  - Worked for sizeable bug bounties
- Running a mock medical DB
  - Only 3 lines of code changes required!
  - Attackers had to penetrate the target (RCE)
- Toward the end of the program, a “high-value payout” was created
  - For a Morpheus SQLite-to-RCE attack
- Morpheus was the second-most engaged target in FETT
- ***Morpheus was penetrated ZERO times***



Morpheus' Evolution and Beyond

- Why is Morpheus hard to hack?
  - Always-encrypted pointers deny attackers ability to forge/analyze code/pointers
  - Churn places a time-limit on replay attacks and probing results
  - Morpheus attacks must be bespoke and lightning-fast (stochastic attacks)
- Lean into secure systems with durable security mechanisms
  - Avoid non-durable mechanisms: software, resource sharing, leaky operations
  - ***Time-Tested Cryptography***, examples: RSA, AES, SHA-2
  - ***Physical Isolation***, examples: TPMs, Intel CAT
- Next-generation Morpheus-derived technology is being deployed
  - Provides highly secure ***secret computation***
  - Based on ***cryptography*** and ***physical isolation*** based defenses
  - Deployed in the Microsoft Azure and Amazon AWS clouds

Shibo Chen

AGITA LABS

Questions?

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