Secure Systems 2.0:

Revisiting and Rethinking the Challenges of Secure System Design

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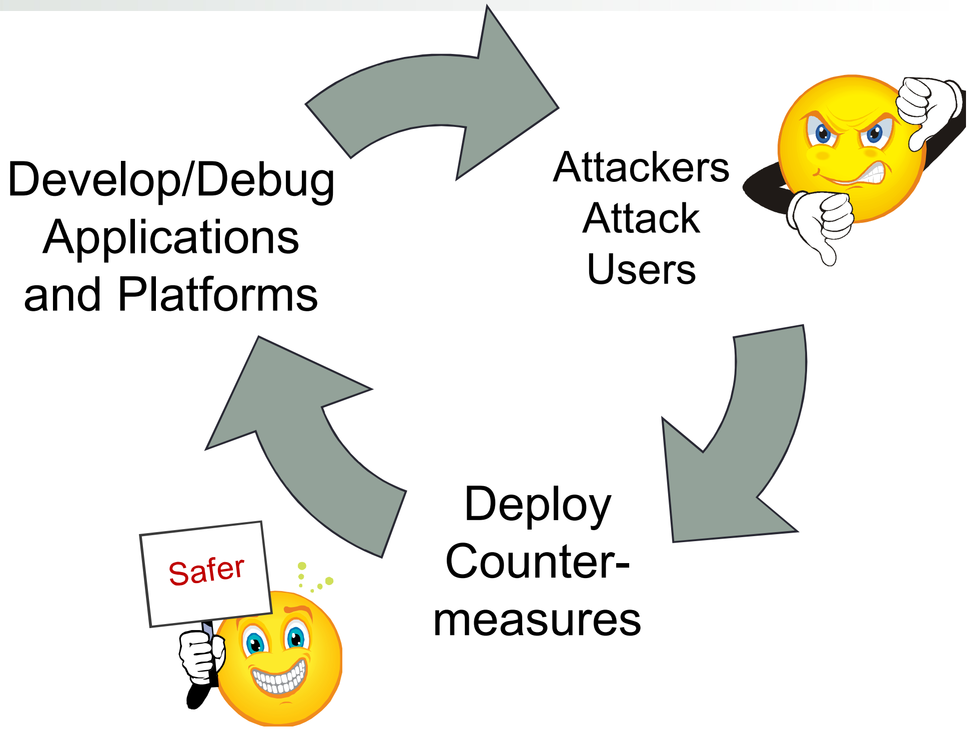
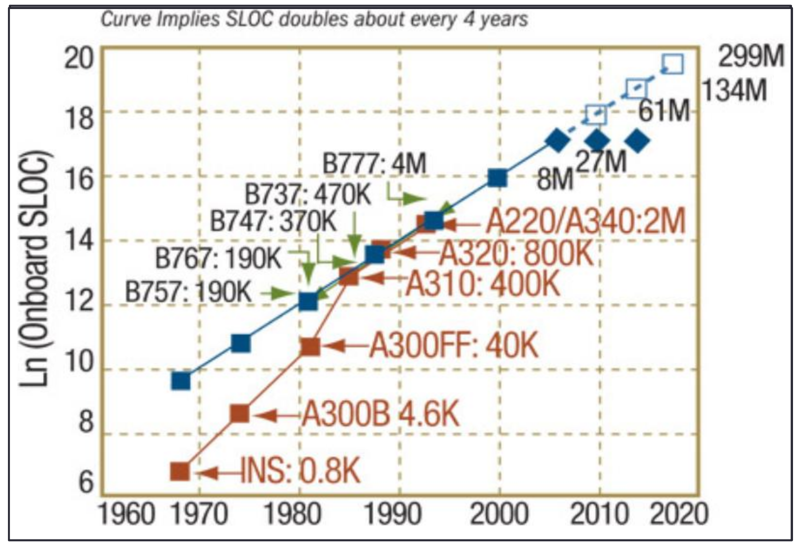
The Security Arms Race

- Question: Why are systems never safe?
  - We deploy our designs
  - Attackers attack
  - We deploy countermeasures
  - Rinse and repeat



Why is Security So Hard to Get Right?

- Industry is based on a patch-based approach to security
  - Find and fix vulnerabilities (*i.e.*, bugs in S/W that can be exploited)
  - S/W and H/W complexity growth ***massively outstrips*** security bug verification capabilities
  - Verifying protections requires a ***nonexistence proof*** vulnerabilities
  - *For all <programs, inputs>, there exists no unchecked vulnerability*
- ***Key unaddressed challenge***: how do we protect against ***unknown (0-day) attacks***?
  - Known vulnerabilities that have not been found and as yet unknown vulnerabilities



How Weak is Security Today?

- Jeep hacked remotely while driving
- DHS attacks Boeing 757, details classified
- Pac
- Mira
- Entire baby monitor market hacked
- Fish tank thermometer data exfiltration

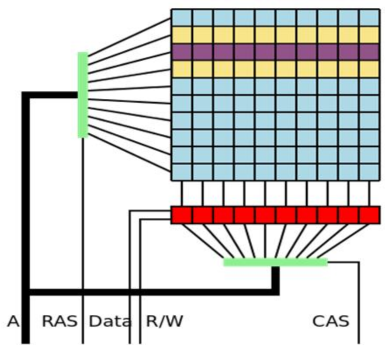
Bruce Schneier:

The growth of IoT is transforming *Computer Security* into *Everything Security*

Hardware is Catching Up Fast

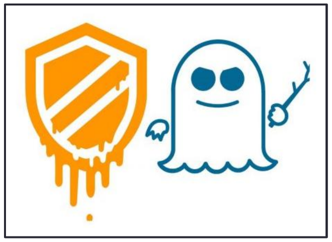
- Growing list of hardware vulnerabilities calls into question the extent to which hardware can establish a ***root of trust***

Rowhammer

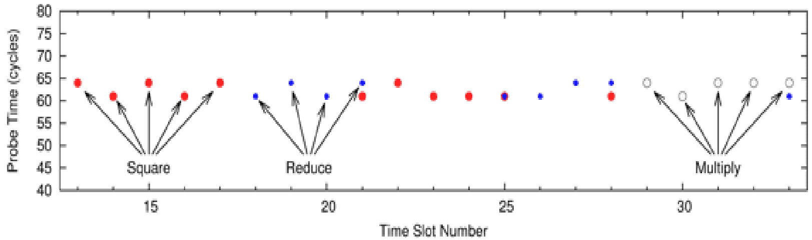


Cold Boot (DDR3/4)

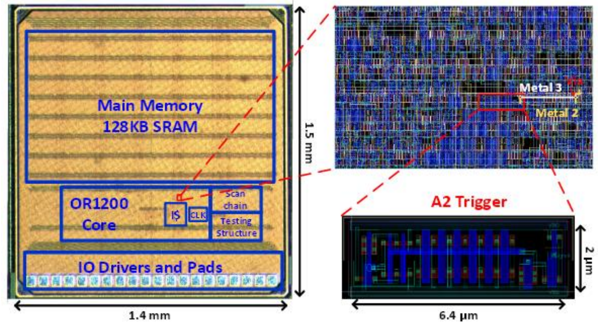
Spectre and Meltdown



Flush+Reload



A2 Malicious Hardware



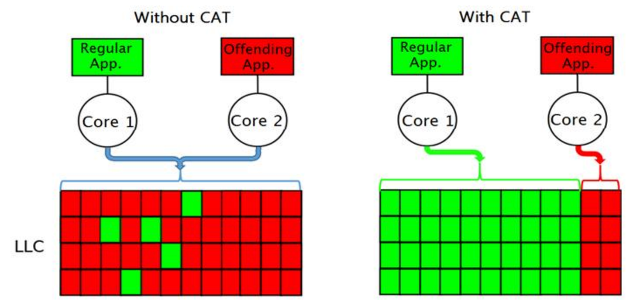
When Good Protections Go Bad: We Have Yet to Address Composability!

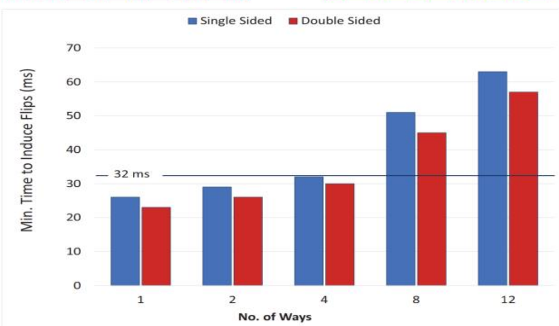
- Current rowhammer protections are effective
  - When used *in tandem*

- CAT technology was made (in part) to prevent VM denial-of-service
  - Works well in this regard
  - Also works well to speed up rowhammer!

- Rowhammer attack approach:
  1. Pose as a VM "noisy neighbor" and get LLC cache access restricted by CAT
  2. Rowhammer using single-ended CFLUSH-free attack mode
- Defenses?
  - Most recent defenses work: ANVIL, PARA

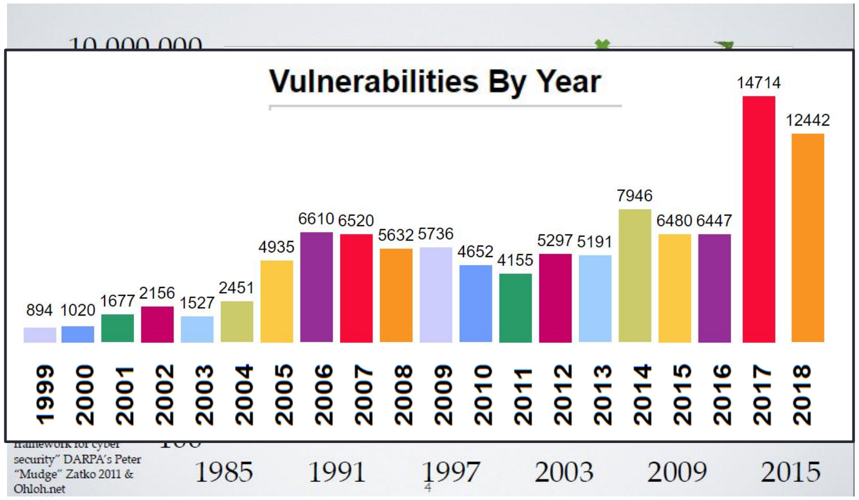
	CLFLUSH-based		CLFLUSH-Free (Aweke et al, ASPLOS 2016, Gruss et al, DIMVA 2016)
	Single-sided (kim et al, ISCA 2014)	**Double-sided** (Seaborn et al, Blackhat 2015)	
Double Refresh Rate	×	✓	×
Restricted Pagemap	✓	×	×
Disabled CLFLUSH	×	×	✓





Today's Security Strategy Favors the Attacker

- ***Attacking is fundamentally easier than protecting*** against attacks
  - Attacking requires ***one*** vulnerability
  - Protecting requires ***100% coverage*** of all vulnerabilities (impractical to achieve)
- Related software growth rates:
  - Protections: ~2x LoC every 2 years
  - Attacks: ~1.4x LoC in 30 years
- Thus, vulnerabilities are on the rise
  - And, rate of attacks is exploding



My Goal Today is to Suggest Better Ways

- Let's work toward ***principled approaches*** for achieving complete coverage of all vulnerabilities for non-trivial systems

- Two approaches
  - ***Subtractive security*** techniques ***remove functionality*** necessary to implement attacks, leaving a ***single-instance constructive proof***
  - ***High-entropy randomization with churn*** uses unspecified semantics randomization to make programs ***impractically difficult to attack***

Subtractive Security

Subtractive Security Techniques

- ***Additive methods*** add protections to thwart attacks
  - Verifying additive measures requires a ***nonexistence proof***
  - *For all <programs, inputs, vulnerabilities>, there exists no unchecked vulnerability*
- ***Subtractive methods*** remove “functionality” needed to implement a class of attacks
  - Rebuild the ***subtractive design*** to work without functionality
  - Implementation is an ***constructive proof*** that approach works
  - ***Optimize subtractive design*** to negate overheads
  - Resulting system is ***immune to targeted class of attacks***
- Why does this work so well?
  - ***Attack functionality differs radically*** from normal activity
  - Constructive proofs are naturally ***scalable and approachable proof*** techniques

Two Examples…

- Control-data isolation (CDI), to stop code injection
- Ozone zero-leakage execution mode, to stop timing side channels

Example: Control-Data Isolation

[CGO'15]

- Code injection ***requires*** indirection
- All ***indirection removed***, uses ***whitelisted*** direct jumps to ***thwart all code injection***
  - ***Direct***, as specified by programmer
  - ***Validated***, via whitelisting
  - ***Complete***, no indirection remains
- System supports run-time code gen and dynamic libraries

Vulnerable Code

```
Int foo() {
  /* fptr */
  fptr = %cx;
  call *fptr;
Work:
  …          }
```

```
Int bar() {
  return; }
```

```
Int baz() {
  return; }
```

Control-Data Isolated Code

```
Int foo() {
  /* fptr */
  fptr = %cx;
  if(*fptr==bar)
    call bar;
Ret_1:
  else if(*fptr==baz)
    call baz;
Ret_2:
  else
    call InvalidCFG!
Work:
  …          }
```

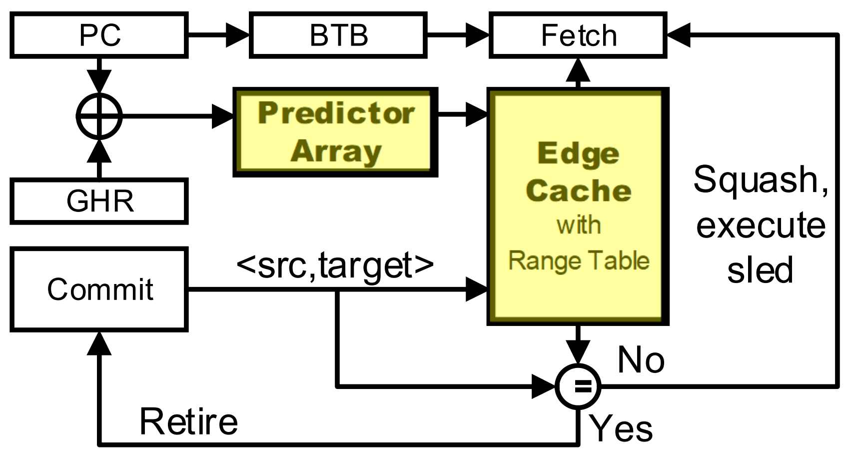
```
Int bar() {
  if([%sp] == Ret_1)
   inc %sp;
   jump Ret_1;
  else
   call InvalidCFG!;}
```

```
Int baz() {
  if([%sp] == Ret_2)
   inc %sp;
   jump Ret_2;
  else
   call InvalidCFG!;}
```

Hardware Support Erases Overheads

[MICRO'15]

- Software-only approach experiences 7% slowdown
  - Due to indirect whitelist validation that occurs at all indirect jumps
- Edge cache memoizes edge validations, doubles as predictor
  - With range table, 6kB ***edge cache reduces slowdowns to 0.3%***
  - Indirect target prediction ***cuts misprediction rate in half*** over simple BTB



Example #2: Ozone Zero-Timing-Leakage Architecture

- Even carefully designed systems leak info about internal computation
  - Example: safes can be cracked by carefully listening to the tumblers
- Clever attackers can utilize leaked information to gain secrets
  - If not directly, use statistical methods
- Current ***protections are additive***
  - ***Add delays*** to the system to hide timing
  - ***Add superfluous activities*** to hide actions
  - Side channels persist despite measures

Ozone Zero-Timing-Leakage Architecture

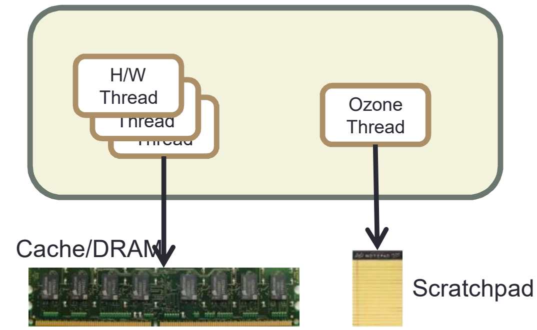
[HOST'17]

- ***Functionality removed:*** all characteristics that create timing channels
  - *Common case **not** optimized*
  - ***No** resource sharing*
  - ***No** fine-grained timing analysis*

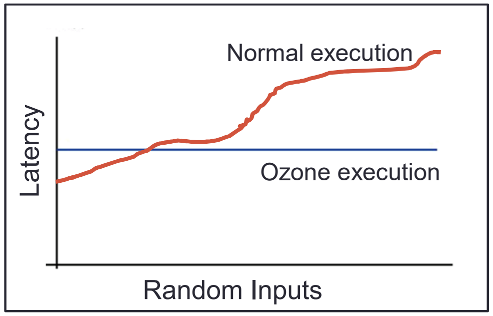
- Implementation approach:
  - Ozone H/W thread runs in fixed time
  - No complex (hammock) control, use static predictor
  - Only access to scratchpad memory
  - Does not share resources
  - Not subject to context switches

- ***Zero timing leakage*** and ***10x faster*** than additive approaches

Ozone Architecture



Execution Characteristics



Challenges and Opportunities

- To what extent can subtractive security stop vulnerabilities?
  - Demonstrated for code injection and timing leakage
  - Could it work for rowhammer, memory side channels, and malicious hardware?
- To what extent will these techniques be composable?
  - prot(code injection) + prot(timing leakage) ?= no code inject, no leakage
- To what extent will these techniques be deployable?
  - Code-data isolation requires complete overhaul of build tool chain
  - Ozone zero-leakage architecture somewhat restricts code expression
  - Will system designers pay for these technologies?

Conclusions

- My challenge to you: let's get the upper hand back from attackers
  - This is simply ***intractable for patch-based security measures***
  - Requires a principled approach that ***shuts down*** vulnerabilities
- ***Subtractive security*** measures are a ***principled approach*** that are simpler to validate
  - Creation of a working system constitutes a constructive proof
  - Has already been demonstrated for multiple vulnerabilities
- ***High-entropy randomization with churn*** make programs ***impractically difficult to attack***
  - By randomizing unspecified program semantics as programs run
  - Breaks today's attacks and makes attackers brute-force search high-entropy spaces