ESE532: System-on-a-Chip Architecture

Day 26: April 24, 2017

Security

Today

- Security Issues
- Memory
- Input
- Output
- Cryptography

Message

- SoC Designers need to be concerned about security
- Hazards are real, understandable
  - Avoidable, tricky…
- Things that make it easier and harder than general-purpose, best-effort
- Consider CIS331, CIS551

Security Issues

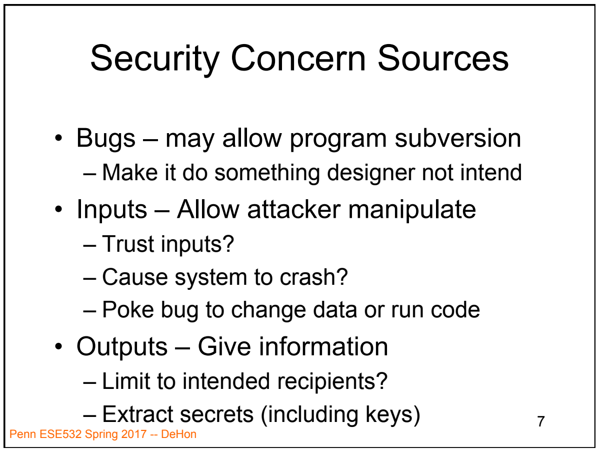
- What security issues arise for the SoC designer and applications?
- What make easier / less of an issue?
- What make harder or more important?

Sensationalism

- Target data breach
  - Millions of credit cards; enter through HVAC
- Car Hacks
  - Take over brakes, speed, …
- DDoS
  - Through networks devices/IoT

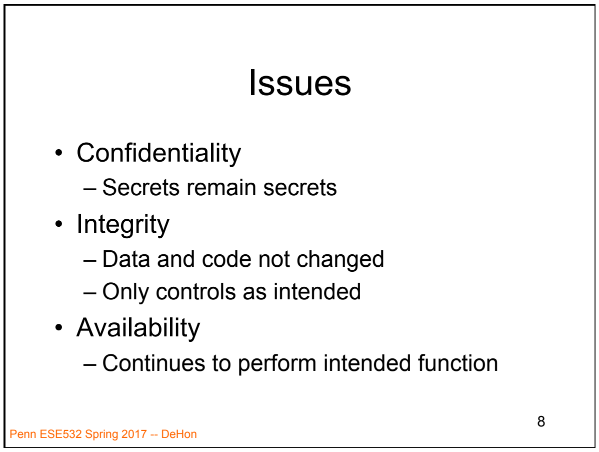
Potential Security Concerns Arise

- Bug free program
  - with no input
  - and no output,
  - might have no security concerns
- …but could it do anything?
- …uintended outputs?



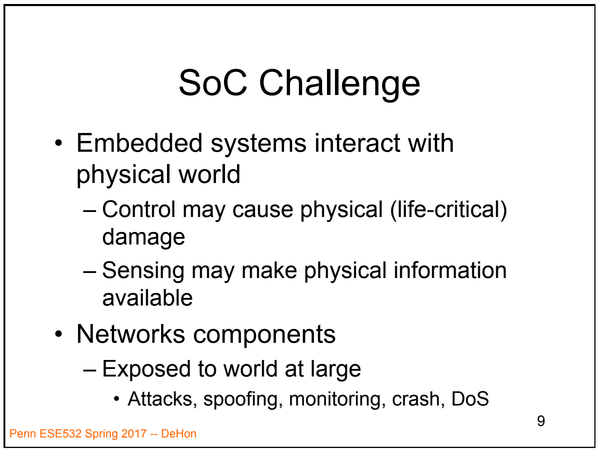
Security Concern Sources

- Bugs – may allow program subversion
  - Make it do something designer not intend
- Inputs – Allow attacker manipulate
  - Trust inputs?
  - Cause system to crash?
  - Poke bug to change data or run code
- Outputs – Give information
  - Limit to intended recipients?
  - Extract secrets (including keys)



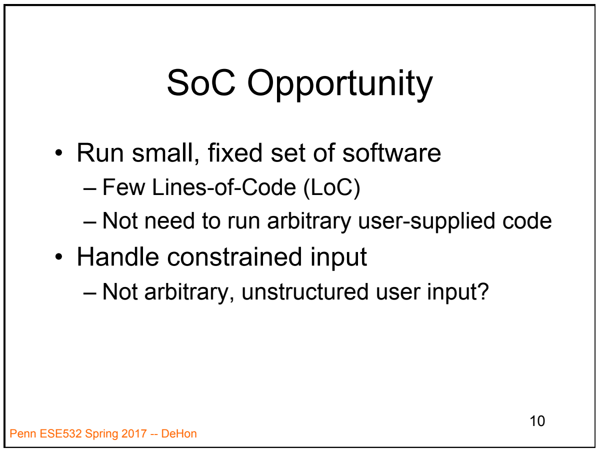
Issues

- Confidentiality
  - Secrets remain secrets
- Integrity
  - Data and code not changed
  - Only controls as intended
- Availability
  - Continues to perform intended function



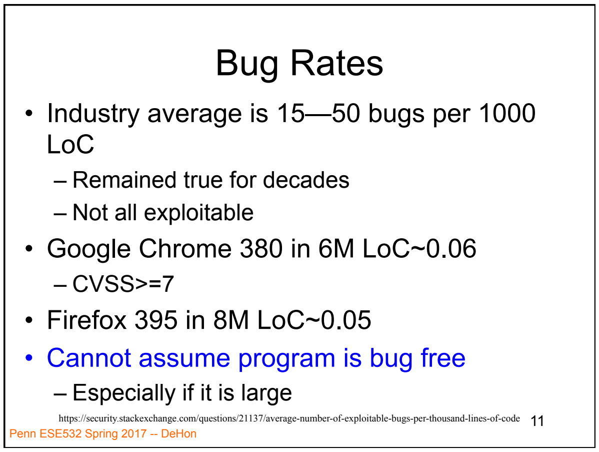
SoC Challenge

- Embedded systems interact with physical world
  - Control may cause physical (life-critical) damage
  - Sensing may make physical information available
- Networks components
  - Exposed to world at large
    - Attacks, spoofing, monitoring, crash, DoS



SoC Opportunity

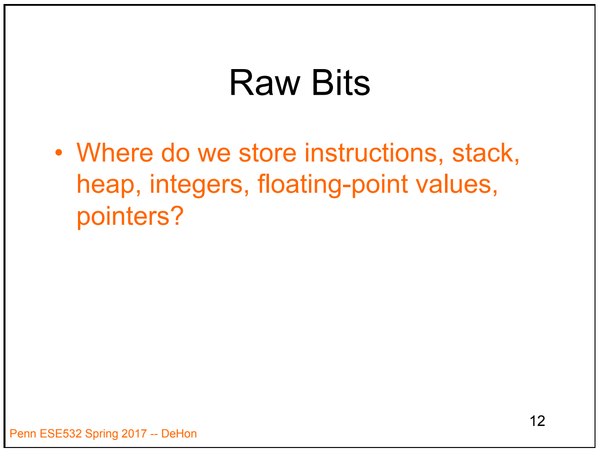
- Run small, fixed set of software
  - Few Lines-of-Code (LoC)
  - Not need to run arbitrary user-supplied code
- Handle constrained input
  - Not arbitrary, unstructured user input?



Bug Rates

- Industry average is 15—50 bugs per 1000 LoC
  - Remained true for decades
  - Not all exploitable
- Google Chrome 380 in 6M LoC~0.06
  - CVSS>=7
- Firefox 395 in 8M LoC~0.05
- Cannot assume program is bug free
  - Especially if it is large

https://security.stackexchange.com/questions/21137/average-number-of-exploitable-bugs-per-thousand-lines-of-code



Raw Bits

- Where do we store instructions, stack, heap, integers, floating-point values, pointers?

Memory

Memory Contents

- Instructions
- Data
- Data structures
  - Pointers
- Program call graph
  - Stack

Memory Contents

- Instructions
- Data
- Data structures
  - Pointers
- Program call graph
  - Stack

- How tell them apart?

Stored Program Processor

- Instructions stored in memory
- One big, undifferentiated memory
  - Containing instructions, data, stack, heap…
- Powerful
  - Loading in new programs
  - Generating new code at runtime
  - Flexible division of memory space
- Dangerous…

C

- C allows construction of arbitrary pointers

```
int *ptr = (int *)0x1000;
ptr[3]=0x0773;
```

- …and references beyond the end of pointers

```
int data[100];
data[2376]=0x0aa734;
data[-578]=0xffff348c;
```

Dangerous

- Bugs may scribble over memory
  - Violate integrity of code or data
- …or, allow attacker to access or write memory
- Pointer that points to unexpected location
- Out-of-bounds reference

Very Dangerous

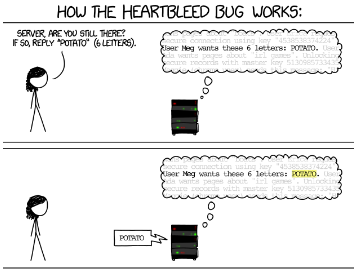
```
int data[128];
which=read_input();
write_output(data[which]);
```

- What does this allow?

Heartbleed

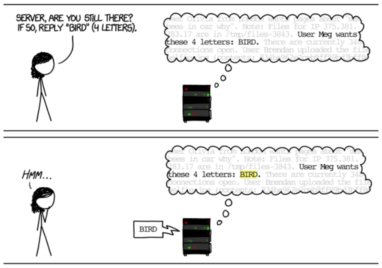
- Attack on SSL
  - CVE-2014-0160
- Could use
  - User input + lack of bounds checks
- To get computers to export secrets
  - Like cryptography keys

xkcd Heartbleed Explanation


HOW THE HEARTBLEED BUG WORKS:
SERVER, ARE YOU STILL THERE? IF SO, REPLY "POTATO" (6 LETTERS).
secure connection using key "4538538374224". User Meg wants these 6 letters: POTATO. User Ada wants pages about "irl games". Unlocking secure records with master key 5130985733435
POTATO

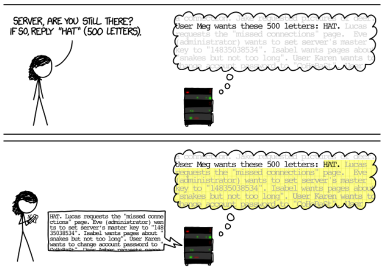
https://xkcd.com/1354/

xkcd Heartbleed Explanation


SERVER, ARE YOU STILL THERE? IF SO, REPLY "BIRD" (4 LETTERS).
bees in car why". Note: Files for IP 375.381.283.17 are in /tmp/files-3843. User Meg wants these 4 letters: BIRD. There are currently 348 connections open. User Brendan uploaded the file
HMM...
BIRD

https://xkcd.com/1354/

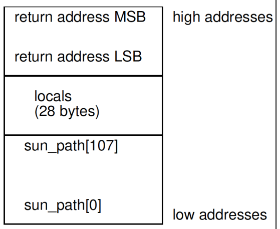
xkcd Heartbleed Explanation


SERVER, ARE YOU STILL THERE? IF SO, REPLY "HAT" (500 LETTERS).
User Meg wants these 500 letters: HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to
HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to change account password to "

https://xkcd.com/1354/

Buffer Attack

```
int ud_connect(const char *name) {
    int fd;
   struct sockaddr_un {
      sa_family_t sun_family;
      char sun_path[108];
   } addr;
    ...
    sprintf(addr.sun_path, "%s", name);
     ...
    return fd;
}
```



return address MSB

return address LSB

locals (28 bytes)

sun_path[107]

sun_path[0]

high addresses

low addresses

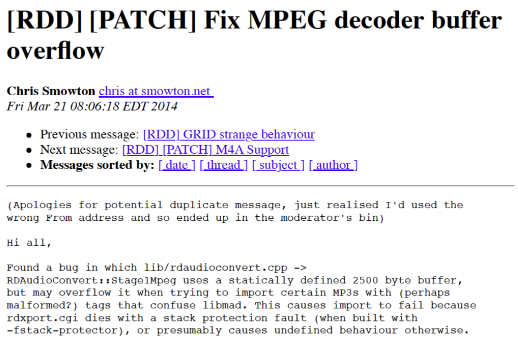
What happens if name>108 characters?

> 136?

[Avgerinos, CACM 2014]

Buffer Overflow

- Unchecked buffers allow insertion/ overwrite of data
- Unchecked buffers on stack allow overwrite of data controlling what code you execute
  - …and maybe even code to execute



[RDD] [PATCH] Fix MPEG decoder buffer overflow

Chris Smowton chris at smowton.net
Fri Mar 21 08:06:18 EDT 2014

- Previous message: [RDD] GRID strange behaviour
- Next message: [RDD] [PATCH] M4A Support
- **Messages sorted by:** [date] [thread] [subject] [author]

```
(Apologies for potential duplicate message, just realised I'd used the
wrong From address and so ended up in the moderator's bin)

Hi all,

Found a bug in which lib/rdaudioconvert.cpp ->
RDAudioConvert::Stage1Mpeg uses a statically defined 2500 byte buffer,
but may overflow it when trying to import certain MP3s with (perhaps
malformed?) tags that confuse libmad. This causes import to fail because
rdxport.cgi dies with a stack protection fault (when built with
-fstack-protector), or presumably causes undefined behaviour otherwise.
```

http://caspian.paravelsystems.com/pipermail/rivendell-dev/2014-March/020437.html

Defenses

- Modern virtual memory systems will set code pages to be unwritable
- Can still control which code gets run
- Embedded systems without VM don't have this option
- Modern compilers (like gcc) can be instructed to add sanity check code
  - Stack Guard: Canary data to catch overwrites
  - Attacker not change canary…

Memory Vulnerability

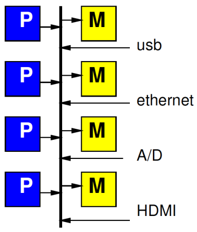
- Raw, undifferentiated memory
- Holding code, data, control structures
- Accessible from every memory operation
- Relying only on absence of out-of-bounds reference bugs to maintain integrity
- …enables a host of security vulnerabilities

SoC

- Small, differentiated memories in SoC may help
  - Not live in single, unified address space
  - Tasks have access to limited, local memory (not everything)
- Hardware functions cannot be overwritten

DMA Master

- What can a DMA Master do to memory?



DMA

- May give USB/firewire/PCI DMA access to memory
- Without care can read/write anywhere in memory
- Allow malicious peripheral to
  - Steal data
  - Compromise integrity

ThunderStrike

Available for: OS X Yosemite v10.10 and v10.10.1,for: MacBook Pro Retina, MacBook Air (Mid 2013 and later), iMac (Late 2013 and later), Mac Pro (Late 2013)

Impact: A malicious Thunderbolt device may be able to affect firmware flashing

Description: Thunderbolt devices could modify the host firmware if connected during an EFI update. This issue was addressed by not loading option ROMs during updates.

CVE-2014-4498 : Trammell Hudson of Two Sigma Investments

https://trmm.net/Thunderstrike_FAQ

Input

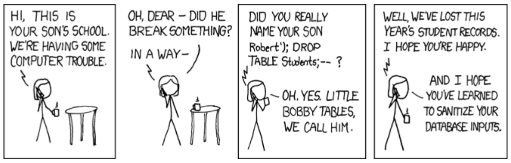
Input

- Provides an opportunity to poke at system
  - Exploit vulnerabilities
  - Directly control system?
- Can mislead system
  - Lie to it

Input and Memory

- Memory section illustrates unchecked inputs can exploit vulnerabilities

Input Integrity (xkcd)


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR – DID HE BREAK SOMETHING?
IN A WAY–
DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students;-- ?
OH. YES. LITTLE BOBBY TABLES, WE CALL HIM.
WELL, WE'VE LOST THIS YEAR'S STUDENT RECORDS. I HOPE YOU'RE HAPPY.
AND I HOPE YOU'VE LEARNED TO SANITIZE YOUR DATABASE INPUTS.

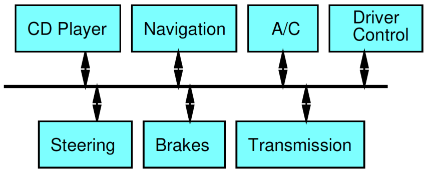
https://xkcd.com/327/

Input Data Integrity

- Bobby Tables illustrates
  - Must take care with any inputs that may be used in control
    - Interpret commands, where branch, specify what operate upon…
- As does
  - data[user_input()]
  - Heartbleed
  - Buffer bounds checks

Input Validity

- What happens if the CD-player sends a message to the brakes to stop?



CD Player

Navigation

A/C

Driver Control

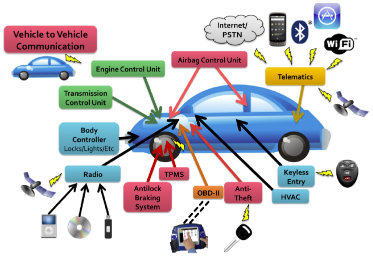
Steering

Brakes

Transmission

Cars

- Modern cars contain many embedded controllers



[Checkoway, Usenix Security 2011]

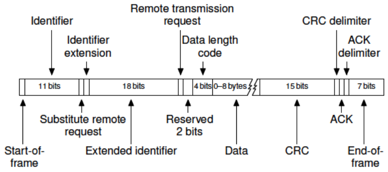


Figure 5. CAN packet structure. Extended frame format is shown. Base frame format is similar.

breaking the network this way, adversarially-controlled hardware would not need to exercise such precautions.

No Authenticator Fields. CAN packets contain no authenticator fields — or even any source identifier fields — meaning that any component can indistinguishably send a packet to any other component. This means that any single compromised component can be used to control all of the other components on that bus, provided those components themselves do not implement defenses; we consider the

[Koscher, IEEE Security&Privacy 2010]

Result

- If you can compromise any unit on the bus (like the MP3 player), can send control messages to any unit

Impact

- Were able to control the car
- More recent demo 2015 on 60 Minutes
- https://news.cs.washington.edu/2015/02/09/watch-uw-cse-and-darpa-hack-a-car-driven-by-60-minutes-leslie-stahl/

[Koscher, IEEE Security&Privacy 2010]

Input Integrity

- What could we do to protect against this?

Input Lessons

- Need to carefully consider where our inputs come from
  - and how we know that
- If comes from untrustworthy source
  - Need to validate before use

Output

Output

- Who should be able to see the outputs produced?
- What outputs is the system producing you may not have intended?
  - Radio-frequency, power, timing, audio…

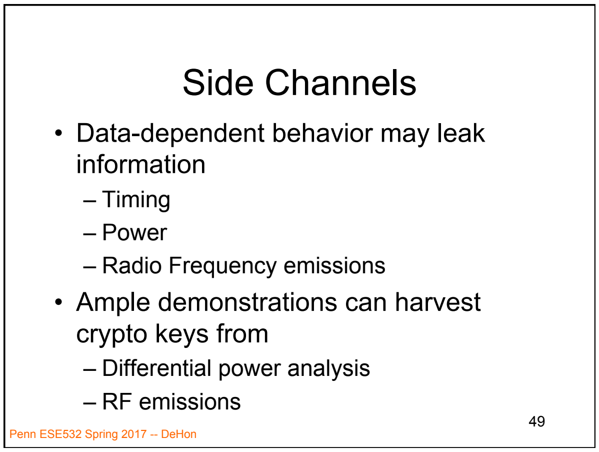
AUTHOR: NOAH SHACHTMAN AND DAVID AXE.
NOAH SHACHTMAN AND DAVID AXE
SECURITY DATE OF PUBLICATION: 10.29.12.
10.29.12
TIME OF PUBLICATION: 4:00 AM.
MOST U.S. DRONES OPENLY BROADCAST SECRET VIDEO FEEDS

FOUR YEARS AFTER discovering that militants were tapping into drone video feeds, the U.S. military still hasn't secured the transmissions of more than half of its fleet of Predator and Reaper drones, Danger Room has learned. The majority of the aircraft still broadcast their classified video streams "in the clear" — without encryption. With a minimal amount of equipment and know-how, militants can see what America's drones see.

https://www.wired.com/2012/10/hack-proof-drone/

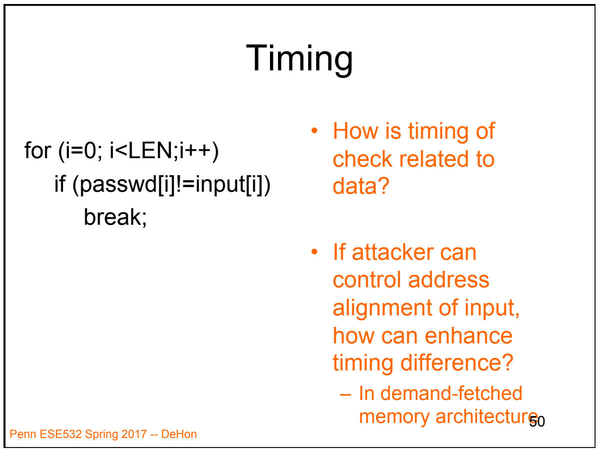
Open Datastreams

- …and this is true of most internet connected cameras
  - Including baby monitors
  - https://arstechnica.com/security/2015/09/9-baby-monitors-wide-open-to-hacks-that-expose-users-most-private-moments/



Side Channels

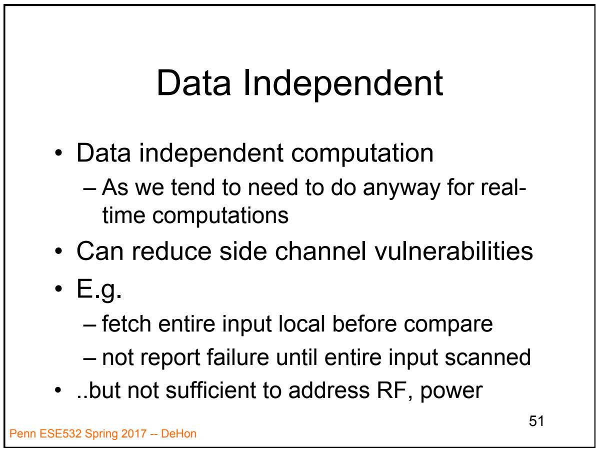
- Data-dependent behavior may leak information
  - Timing
  - Power
  - Radio Frequency emissions
- Ample demonstrations can harvest crypto keys from
  - Differential power analysis
  - RF emissions



Timing

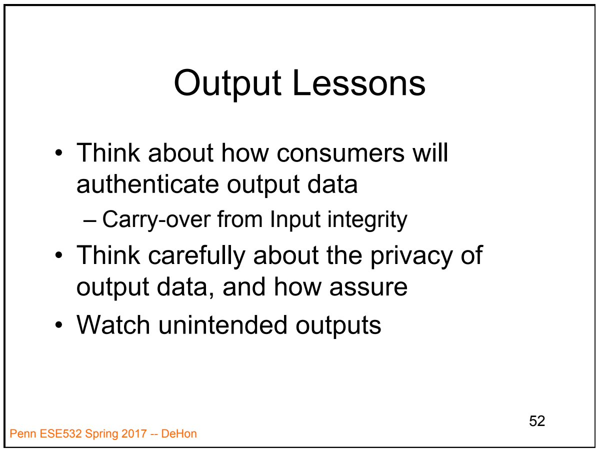
```
for (i=0; i<LEN;i++)
   if (passwd[i]!=input[i])
      break;
```

- How is timing of check related to data?
- If attacker can control address alignment of input, how can enhance timing difference?
  - In demand-fetched memory architecture



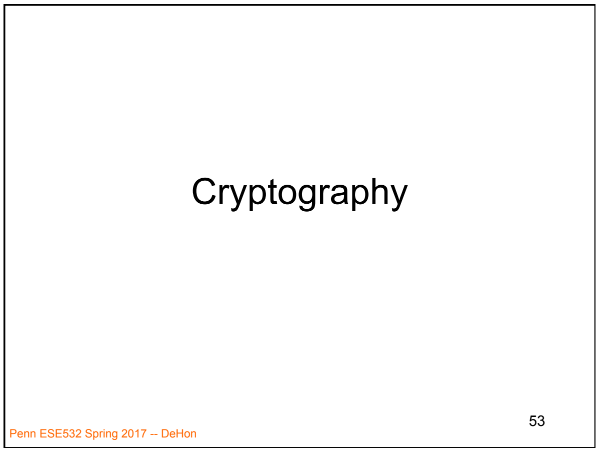
Data Independent

- Data independent computation
  - As we tend to need to do anyway for real-time computations
- Can reduce side channel vulnerabilities
- E.g.
  - fetch entire input local before compare
  - not report failure until entire input scanned
- ..but not sufficient to address RF, power

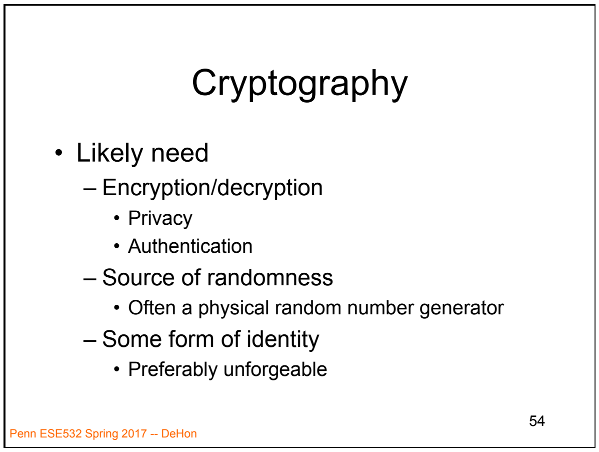


Output Lessons

- Think about how consumers will authenticate output data
  - Carry-over from Input integrity
- Think carefully about the privacy of output data, and how assure
- Watch unintended outputs



Cryptography



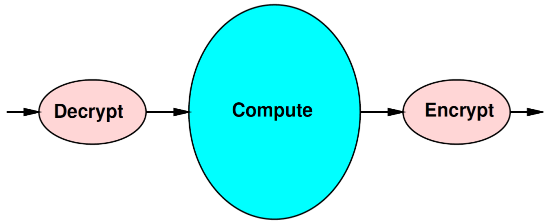
Cryptography

- Likely need
  - Encryption/decryption
    - Privacy
    - Authentication
  - Source of randomness
    - Often a physical random number generator
  - Some form of identity
    - Preferably unforgeable

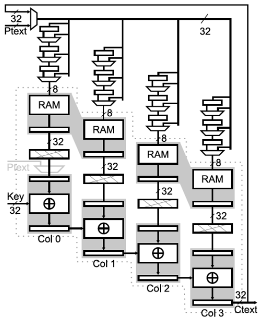
Easy to screw it up

- Roll own insecure crypto algorithms
- Use weak algorithms or keys
- Use insufficiently random data
- Leak key-related data
  - (see memory, output)

Natural Streaming



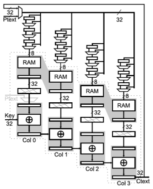
Natural for spatial hardware



[Drimer, FCCM 2008]

Natural for spatial hardware

Design	Dec[a]	Key sch.	Device	Resources[b]						f	Throughput[c]
				slices	LUT	FF	d.RAM	BRAM	DSPs	(MHz)	(Gbit/s)
Basic	○	○	Virtex-5	93	245	274	7838	2×36K	4	550	1.76
Round	○	○	Virtex-5	277	204	601	1432	8×36K	16	485	6.21
Unrolled	●	○	Virtex-5	428	672	992	1696	80×36K	160	430	55



[Drimer, FCCM 2008]
[Drimer, TRETS 2010]

Big Ideas

- SoC Designers need to be concerned about security
  - Confidentiality, integrity, availability
  - Important for many applications
- Hazards are real, understandable
  - Avoidable, tricky…

Admin

- Collect Zed Boards
  - Class Monday 4/24
- Final: Monday, May 1 9am—11am
- One more class on Wednesday