

# Software Foundations of Security & Privacy

## 15316 Fall 2020

### Lecture 1:

### Introduction

Matt Fredrikson  
mfredrik@cs

August 31, 2020

# Course Staff



Matt Fredrikson  
Instructor



Urvi Agarwal  
TA

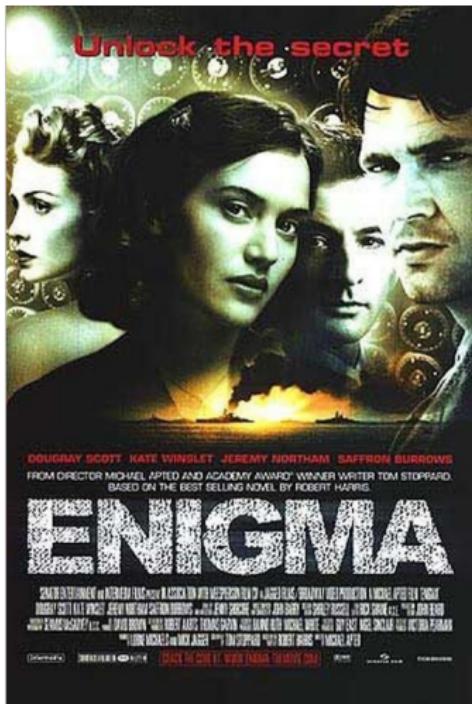
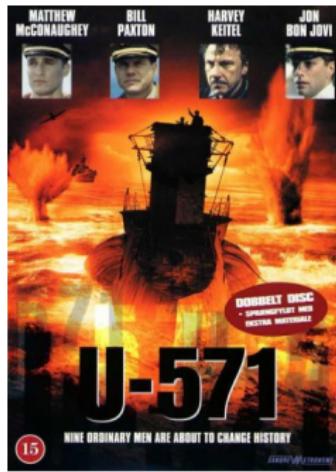


Ryan Chen  
TA

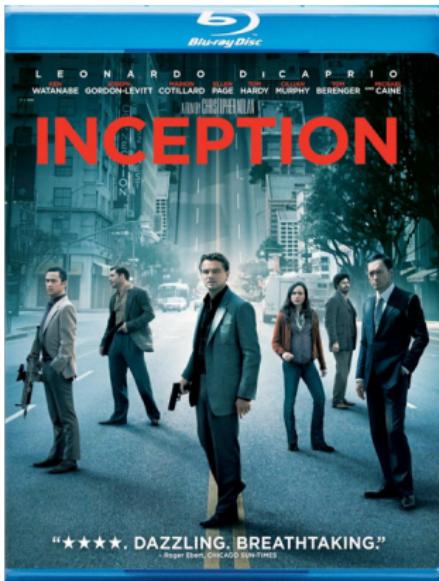
# Themes and anti-themes

What is this course about?

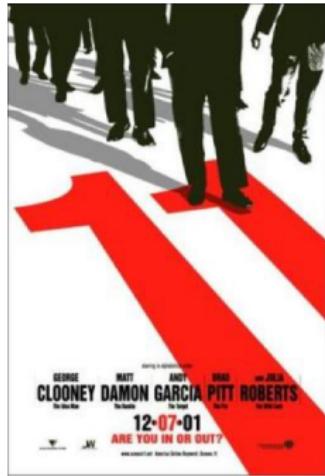
# This is not a course about encryption...



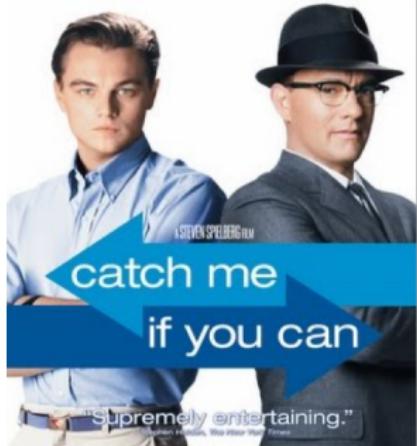
# Not a course about hacking...



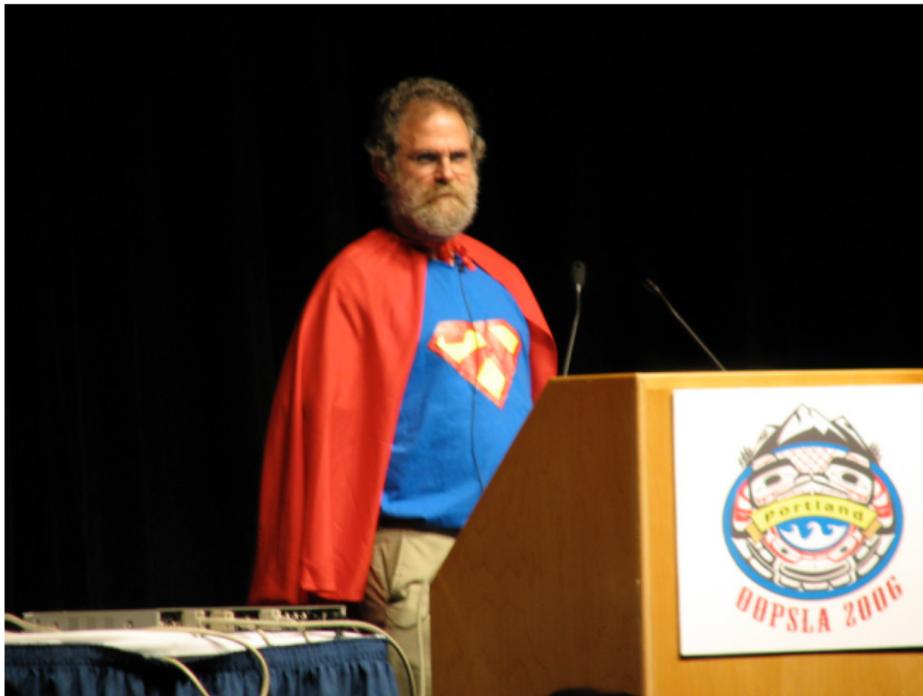
# Not a course about social engineering...



leonardo dicaprio tom hanks



# This course is about...



How logic and languages will save us (and make software secure)

# Project Zero

News and updates from the Project Zero team at Google

Wednesday, January 3, 2018

Reading privileged memory with a side-channel

Posted by Jann Horn, Project Zero

# Spectre & Meltdown

What's the big deal?

# Spectre & Meltdown

## What's the big deal?

- ▶ “Efficiently” leak information via mis-speculated execution
- ▶ Read arbitrary virtual memory regions (including kernel)
- ▶ Bypass explicit bounds checks
- ▶ Violate browser sandboxing
- ▶ ...?

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“Every Intel processor that implements out-of-order execution is potentially affected”

# Timing channels

```
1 struct array {
2     unsigned long length;
3     unsigned char data[];
4 };
5 struct array *arr1 = ...; /* small array */
6 struct array *arr2 = ...; /* array of size 0x400 */
7 unsigned long untrusted_offset = network_read(...);
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Step 1. Read some data from an arbitrary memory location

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## Step 2. Isolate a bit of data from the read

- ▶ index2 is 0x200 if bit is 0
- ▶ Otherwise, index2 is 0x300

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Step 3. Read from a location dependent on extracted bit

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This last step is a result of the processor's data cache!

# Progress

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Keeping track of assumptions:

1. Code doesn't check bounds on memory access
2. Code reads memory using untrusted, attacker-controlled index  
`untrusted_offset`
3. Targeted memory location won't cause segfault

# Defensive programming: bounds checks

```
1 struct array {
2     unsigned long length;
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5 struct array *arr1 = ...; /* small array */
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7 unsigned long untrusted_offset = network_read(...);
8 if (untrusted_offset < arr1->length) {
9     unsigned char value = arr1->data[untrusted_offset];
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- ▶ If `arr1->length` is not in cache, 100 cycles until it fetches
- ▶ Processor may begin executing inside branch anyway...
- ▶ If condition is false, results are rolled back like a transaction
- ▶ But not the cache!

# Speculative cache leaks

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**Attacker-controlled reads make measurable changes to the processor cache**

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Keeping track of necessary assumptions:

1. ~~Process code doesn't check bounds on memory access~~
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- ▶ Triggered by sending data to associated socket

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bytecode that opens a side-channel vulnerability*

- ▶ Upshot: unprivileged processes can read all kernel memory
- ▶ Proof of concept demonstrated 2000 bytes/second

# Javascript Interpreters

```
1 if (index < simpleByteArray.length) {  
2     index = simpleByteArray[index | 0];  
3     index = (((index * 4096)|0) & (TABLE1_BYTES-1))|0;  
4     localJunk ^= probeTable[index|0]|0;  
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**Upshot:** Untrusted websites can read memory of other sites  
(passwords, CC #'s, emails, ...), extension data, browser settings, ...

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But there are software-based mitigations

1. Disable speculative execution (*expensive!*)
2. Disable the cache (*way more expensive!*)
3. Don't index arrays on untrusted values (*hard?*)

# Ongoing research: provable side-channel security

## Vale: Verifying High-Performance Cryptographic Assembly Code

Barry Bond\*, Chris Hawblitzel\*, Manos Kapritsos†, K. Rustan M. Leino\*, Jacob R. Lorch\*,  
Bryan Parno†, Ashay Rane‡, Srinath Setty\*, Laure Thompson¶

\* Microsoft Research      † University of Michigan      ‡ Carnegie Mellon University  
§ The University of Texas at Austin      ¶ Cornell University

## Verifying and Synthesizing Constant-Resource Implementations with Types

Van Chan Ngo      Mario Dehesa-Azuara      Matthew Fredrikson      Jan Hoffmann

*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*

*Email: channgo@cmu.edu, mdehazu@gmail.com, mfredrik@cs.cmu.edu, jhoffmann@cmu.edu*

## Verifying Constant-Time Implementations

José Bacelar Almeida      Manuel Barbosa  
*HASLab - INESC TEC & Univ. Minho*      *HASLab - INESC TEC & DCC FCUP*

Gilles Barthe      François Dupressoir      Michael Emmi  
*IMDEA Software Institute*      *IMDEA Software Institute*      *Bell Labs, Nokia*

# Spectre & Meltdown: Takeaways

Security problems are numerous, can be subtle and challenging

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This course will teach you how to deal with hard security problems

- ▶ Understand the general principles behind vulnerabilities
- ▶ Design and critically evaluate potential solutions
- ▶ Learn a set of rigorous defense strategies, implement some
- ▶ Hopefully, write code that isn't vulnerable to begin

# Making software secure: desiderata

Central theme: *security & correctness are often two sides of a coin*

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- ▶ Under what circumstances can a program execute?
- ▶ ...and what do we expect of its outputs?
- ▶ How should information flow through a system?

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A way to ensure that software adheres to policy, i.e. *enforcement*

- ▶ With **provable guarantees**, not ad-hoc arguments
- ▶ Often, without trusting developers or users

# What logic & languages gives us

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Rigorous means: we can *prove* that policy is obeyed

# Formalism & security

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- ▶ For security, formality means *no surprises!*

Focus on refutable claims of security

- ▶ Use math to exhaust the relevant space of attacks
- ▶ Rely on formalism to make it clear what remains unknown
- ▶ Ideal: break out of vuln/patch arms race

# Course topics

Some of the topics that we will cover include:

- ▶ Policy models: safety, information flow, statistical privacy
- ▶ Runtime policy enforcement, reference monitoring
- ▶ Security type systems
- ▶ Isolation (SFI, CFI, hardware protections)
- ▶ Privacy for individuals
- ▶ Trusted computing, authorization logic
- ▶ Web app security & best practices
- ▶ Side channel vulnerabilities and defenses
- ▶ ...

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3. Understand the role of key principles like least privilege, small trusted computing base, and complete mediation in formulating effective defenses
4. Be able to use formal proof and deductive systems to reason about the security of software systems

# Logistics

**Website:** <https://15316-cmu.github.io>

**Course staff contact:**

15-316-course-staff@lists.andrew.cmu.edu

**Lecture:** Tuesdays & Thursdays, 8:00-9:20 on Zoom

Matt Fredrikson

- ▶ Location: CIC 2126
- ▶ Office Hours: **answer Piazza poll on good times**

# Grading

## Breakdown:

- ▶ 35% labs
- ▶ 35% written homework
- ▶ 30% exams (15% each, midterm and final)

2-3 labs

Written homework most weeks

Exams open-book, some additional time for scanning/typesetting

## Participation:

- ▶ Come to lecture if you can
- ▶ Contribute to discussion
- ▶ Answer questions on Piazza
- ▶ Ask questions **early!**

# Written homework (35% of grade)

Written homeworks focus on theory and fundamental skills

Grades are based on:

- ▶ Correctness of your answer
- ▶ How you present your reasoning

Strive for **clarity & conciseness**

- ▶ Show each step of your reasoning
- ▶ State your assumptions
- ▶ Answers without well-explained reasoning don't count!

# Labs (35% of grade)

Extend HTTP server to serve answers to data queries

Incrementally add functionality while maintaining security

Grades are based on:

- ▶ Whether you implemented correct functionality
- ▶ Robustness to relevant attacks

Partial credit depending on:

- ▶ How close your impl. is to the functional spec
- ▶ How many attacks your security measures prevent

# What to do before Thursday

1. Make sure that you are enrolled in the Gradescope, Canvas, Piazza sections for this course
  - ▶ Canvas: <https://canvas.cmu.edu/courses/19932>
  - ▶ Gradescope entry code: **9GNPXE**
  - ▶ Piazza signup link: <https://piazza.com/class/keisqg3c2w43jr>
2. Answer the Piazza poll about office hours time slots
3. Read the syllabus on the webpage carefully
4. Get started on homework (if you can)