CMPSC 447
History of Software Attacks

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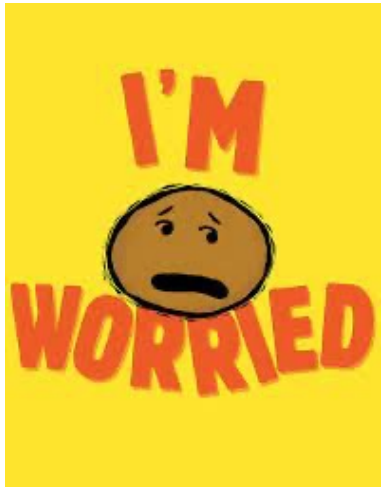
Early Concerns

- Even in the early days of computing, people were worried about attacks on computer systems
  - Why were they concerned?



Early Concerns

- Significant early (1960s) computer systems were funded for government use
  - From single-user systems to timesharing, multi-user systems
  - Leakage of secrets was critical to the Allies success in World War II – Still at a high point in the Cold War
- Inspired the US government to find the development of a general purpose, reliable, multi-user operating system
  - Consider security issues as a first-class concept

Multics Project

- Major operating systems research project
- Information about the project is available online
  - https://multicians.org/history.html

Multics Project

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- Participants: MIT, Bell Labs, General Electric
  - Bell Labs dropped out in 1969
    - Later did a system you may be familiar with
  - General Electric sold out to Honeywell in 1970
- Started in 1965 and funded by the US government (DARPA) for over $2M per year at the time
  - Delivered systems to US Air Force
  - Later sold to various governments and to auto makers, universities, and commercial data processing services
  - Last Multics system was shut down in 2000 (Canada)

Multics Project

- Why are we discussing a system that is no longer in use?
  - And only sold 80 installations
  - But, at about $7M each

Multics Security

- Due to the interest in government deployments, security was a key goal of the Multics project from the outset
- They were concerned about two main problems
  - Secrecy
    - Prevent the unauthorized access to sensitive data
  - Integrity
    - Prevent the illicit modification of sensitive data
- Multics researchers already had a good idea about the software security problems we would face

Process Compromise

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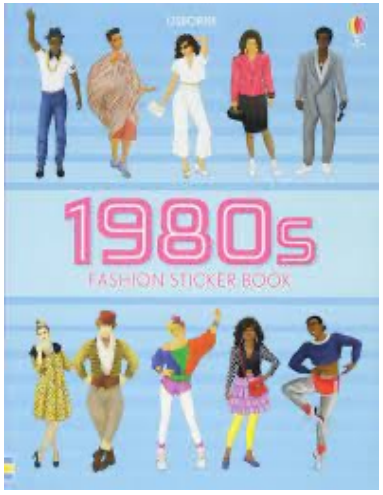
- Can an adversary provide an input payload that enables the adversary to run hijack your program?
  - Multics researchers knew this was possible in theory
  - And demonstrated such attacks were possible in a vulnerability analysis of Multics in 1974
    - See retrospective in https://www.acsac.org/2002/papers/classic-multics-orig.pdf
    - Among other attacks
- Would such attacks ever be used maliciously?

Commercial Systems

- With the Personal Computer (IBM PC) and Workstation (Sun) revolutions of the 1980s
  - Two operating systems became dominant
  - Which were…?



Commercial Systems

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- With the Personal Computer (IBM PC) and Workstation (Sun) revolutions of the 1980s
  - Two operating systems became dominant
- UNIX and Windows
  - UNIX was a follow up to Multics by Bell Labs that emphasized simplicity and extensibility (note the name)
  - Windows also wanted to provide application access to computing resources easily to speed development
- Unlike Multics, both UNIX and Windows had a limited focus on security, allowing freedom to code running on the system

Morris Worm

- Robert Morris, a 23-year-old Cornell PhD student
  - Wrote a small (99 line) program
  - Launched on November 3, 1988
  - Simply disabled the Internet
- Used a buffer overflow in a program called *fingerd*
  - To get adversary-controlled code running
- Then spread to other hosts – cracked passwords and leveraged open LAN configurations
- Covered its tracks in a variety of ways

Morris Worm

- Fingerd
  - A UNIX program you can use to determine who is logged into a computer
  - Send a network request to the daemon, which responds with who is logged in and some other metadata
  - I used this program to see if other students or my advisor was online in grad school
- The fingerd program was known to have a flaw that permitted an input payload to hijack execution
  - We'll learn this cause and its prevention later

Morris Worm

- Hijack Fingerd
  - Caused to act as a malicious program that came to be called a "computer worm"
  - The computer worm hijacks the fingerd process
    - Runs code chosen by the worm writer instead of fingerd
    - To download other malicious programs to propagate the attack to other computers in the same network (easy then)
    - And then to other networks
- Computer worm: a malware program that replicates itself to spread to multiple computers

Morris Worm

- Hijack Fingerd
  - Besides the worm behaviors, the Morris worm used multiple techniques to evade identification and ensure its propagation was not thwarted
    - These techniques worked too well for the time
  - Change the name of the processes created by a hijacked fingerd to "sh", avoid creating accurate "cores"
  - Tried to propagate to the same computer multiple times
- Basically, created an Internet-scale denial-of-service attack because many computers were running many copied of the Morris worm simultaneously

Morris Worm

- Other than stealing CPU cycles galore,
  - The Morris Worm did not perform any operations that stole data or modified existing data on a compromised host
    - I.e., did not attack the secrecy and integrity of host data
    - Although it certainly impacted the integrity of the fingerd process
- Nonetheless, Morris faced punishments in the forms of fines and prohibitions on computer use for time period

Morris Worm Reaction

- It was Morris's fault
  - Hands were rung, Morris was punished, few tangible security changes happened in commercial systems
    - Exception: Network security research (e.g., crypto and firewalls)
  - And computer systems took more risks
    - E.g., executable email attachments

The Internet

- Then, the Internet "happened"
  - Actually, the World Wide Web took over in 1995 or so
- Everyone is (well, many people are) connected
  - Not everyone is nice
- It didn't take too long for new attacks like the Morris worm to emerge
  - But, these truly had malicious intent

Code Red

- Worm from 2001
  - Attacked the Windows IIS web server
  - Exploited a publicly known vulnerability
    - A patch had been available a month before
- Same type of vulnerability as the Morris worm
  - Called a buffer overflow
- Malicious activities
  - Defaced websites and launched a DDoS against several IPs, including the White House
- Code Red II later used the same vulnerability

SQL Slammer

- Worm from 2003
  - Attacked the Windows SQL server (database)
  - Compromised approximately 75,000 hosts worldwide
    - In about 10 minutes
  - Also, exploited a publicly known vulnerability
    - A patch had been available for six months
- Also used a buffer overflow
- Malicious activities
  - None really – impact was mainly a denial of service
    - And concern that a bad actor could "own" all Internet hosts

Worm Reactions

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- Problem: known vulnerabilities are exploited on unpatched machines
  - Firewall and antivirus rules target such information
- Problem: one vulnerability enables an adversary to control a host completely
  - Significantly reduce use of an all-powerful identity, such as "root" or "admin"
- Problem: buffer overflow allows an adversary to "inject" their code into a compromised process
  - Prevent executing data on the stack and locating variables on the stack – more later

Results

- Did these defenses stop the problems?

Results

- Did these defenses stop other attacks from being successful?

Results

- Did these defenses stop the problems?
  - These defenses did address these issues partially
    - Do not see attacks on one known vulnerability enabling compromise of all the Internet hosts
- Instead, adversaries switch approaches
  - Exploit "zero-day" vulnerabilities to circumvent defenses based on known vulnerabilities
  - Exploit multiple vulnerabilities
  - Exploit other types of attack vectors
- So, plenty of attack options remain

Other Attack Vectors

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- Adversaries have identified several other attack vectors that they can use to launch attacks
- Other attack vectors (there are several more)
  - Code-reuse attacks (e.g., return-oriented programming)
  - Heartbleed (i.e., buffer overread)
  - Shellshock (i.e., information flow with buffer overflow)
  - SQL Injection (i.e., attacks on input sanitization)
  - Heap spraying (i.e., attacks on memory allocation)
- We will learn about how software flaws enable these attacks to motivate their reduction

Multiple Vulnerabilities

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- Multiple vulnerabilities can still be used to exploit a host in many cases
- Consider the attack on Penn State in 2015
  - Started with a user's password
  - Led to the adversary embedding in a Penn State network for approximately 18 months
- Once an adversary has code running on your host, there are many ways that adversary can gain control
  - In this course, we will learn about how to prevent flaws that allow "local attacks" from other host processes

Zero-Day Vulnerabilities

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- A zero-day vulnerability is a vulnerability that was unknown prior to its use in an attack
- Often vulnerabilities are caused by software flaws
  - Unfortunately, software development is complex and software flaws are often created unwittingly
- An aim in this course is to introduce you to techniques to prevent the creation of and detect such flaws
  - Another important issue is whether an adversary can exploit a flaw

Penn State Cyberattack

- In 2015, two cyberattacks against Penn State's College of Engineering (not CSE) were discovered
  - Advanced Persistent Threats (APTs)
- At least one of the attacks started with a student account
  - OK, but that is not supposed to be secure anyway
- But, from there, the adversaries were able to launch attacks against privileged host processes
  - To obtain "root" privilege

Penn State Cyberattack

- While Penn State data appeared to be largely unchanged, further attacks were launched
  - Stepping Stones
- And data leakage was possible
  - Inventions and user information
- The adversaries hid on the system for a while
  - Hence the APT
- The main identifiable change was 2FA

Penn State Cyberattack

- Attack was possible because the adversaries could
  - Exploit multiple vulnerabilities
    - Stolen passwords and software vulnerabilities in privileged programs
  - Exploit "zero-day" vulnerabilities
    - Not sure which exact vulnerabilities were exploited, but no one was looking for these exploits
  - Exploit other types of attack vectors
    - Lots of attack vector options are available once an adversary has code running on your machine
- Critical for software flaws to be removed

Take Away

- The history of software attacks rather complex
- Early systems designers were aware of the importance of preventing software attacks (Multics)
  - But, the commercial systems that were broadly adopted emphasized extensibility, performance, and ease of programming over security
- After the worm attacks of the early 2000s, commercial vendors improved security
  - Albeit in a limited way relative to old (1980s) attacks
- We have been in reactive mode ever since