Security breaches

Just a few:

- **Equifax** (2017) - 145 million consumers’ records*
- **Adobe** (2013) - 150 million records, 38 million users
- **eBay** (2014) - 145 million records
- **Anthem** (2014) - Records of 80 million customers
- **Target** (2013) - 110 million records
- **Heartland** (2008) - 160 million records

*containing SSNs, birth dates, addresses, other private info

https://www.privacyrights.org/data-breaches
Defects and Vulnerabilities

- Many of these breaches begin by exploiting a **vulnerability**

- This is a *security-relevant software defect* (bug) or **design flaw** that can be **exploited** to effect an undesired behavior

- **Lots of software out there** (and growing)

  ![Open Hub](https://www.openhub.net/languages/c)
  - 5.6B LOC
  - 2B LOC
  - 50M LOC
  - 25M LOC

  *Lines of code*

- So: **more bugs and flaws**
ICT* is Proliferating

*Information and Communication Technology
WASHINGTON — The Iranian government agency that runs the country’s nuclear facilities, including those the West suspects are part of a weapons program, has reported that its engineers are trying to protect their facilities from a sophisticated computer worm that has infected industrial plants across Iran.

The agency, the Atomic Energy Organization, did not specify whether the worm had already infected any of its nuclear facilities, including Natanz, the underground enrichment site that for several years has been a main target of American and Israeli covert programs.

But the announcement raised suspicions, and new questions, about the origins and target of the worm, Stuxnet, which computer experts say is a far cry from common computer malware that has affected the Internet for years. A worm is a self-replicating malware computer program. A virus is malware that infects its target by attaching itself to programs or documents.

Stuxnet specifically targets … processes such as those used to control … centrifuges for separating nuclear material. Exploiting four zero-day flaws, Stuxnet functions by targeting machines using the Microsoft Windows operating system …, then seeking out Siemens Step7 software.
The result of their work was a hacking technique—what the security industry calls a zero-day exploit—that can target Jeep Cherokees and give the attacker wireless control, via the Internet, to any of thousands of vehicles.

http://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/
“Internet of Things” (IOT)

Amazon Alexa

Google Home

Considering Correctness

- **All software is buggy**, isn’t it? Haven’t we been dealing with this for a long time?
- A **normal user never sees most bugs**, or figures out how to **work around** them
- Therefore, **companies fix the most likely bugs**, to save money
Considering Security

Key difference:

*An attacker is not a normal user!*

• The attacker *will actively attempt to find defects*, using unusual interactions and features

• A *typical interaction* with a bug results in a *crash*

• An attacker will work to *exploit* the bug to do *much worse*, to achieve his goals
Cyber-defense?
FireEye, Kaspersky hit with zero-day flaw claims

Researchers have disclosed severe security flaws within the firm’s products over the holiday weekend.

By Charlie Osborne for Zero Day | September 8, 2015 -- 09:45 GMT (02:45 PDT) | Topic: Security

Researchers have revealed the existence of zero-day vulnerabilities within Kaspersky and FireEye's systems which could compromise customer safety.

Over the holiday weekend, security researcher Tavis Ormandy disclosed the existence of a vulnerability which impacts on Kaspersky products. Ormandy, known in the past for publicly revealing security flaws in Sophos and ESET antivirus products, said the vulnerability is "about as bad as it gets." In a tweet, the researcher said:

Building Security In

The long-term solution is to prevent all exploitable bugs before deploying. Avoid the holes to start with!
Outline

- **Vulnerability**: A kind of software bug that can be exploited by an attacker to manipulate the software to violate a desired security property
  - What kinds of **bugs are exploitable**?
  - Examples: **Buffer overflow, command injection**

- **Input validation**: Confirming that input does not violate software assumptions, or making it so
  - Rules out many kinds of exploits
  - Examples: **escaping, filtering, blacklisting, whitelisting**

- Next time: Applying these **principles to web-based software**
Exploitable bugs

• Some bugs can be exploited
  • An attacker can control how the program runs so that any incorrect behavior serves the attacker

• Many kinds of exploits have been developed over time, with technical names like
  • Buffer overflow
  • Use after free
  • SQL injection
  • Command injection
  • Privilege escalation
  • Cross-site scripting
  • Path traversal
  • …
What is a buffer overflow?

- A buffer overflow is a dangerous bug that affects programs written in C and C++

- **Normally**, a program with this bug will simply **crash**

- But an **attacker** can alter the situations that cause the program to **do much worse**
  - **Steal** private information
  - **Corrupt** valuable information
  - **Run code** of the attacker’s choice
Buffer overflows from 10,000 ft

• **Buffer** =
  • Block of memory associated with a variable

• **Overflow** =
  • Put more into the buffer than it can hold

• **Where does the overflowing data go?**

*Learn more in CMSC 414!*
1. print “Password?” to the screen
2. read input into variable X
3. if X matches the password then log in
4. else print “Failed” to the screen
**Instructions**

1. print “Password?” to the screen
2. read input into variable X
3. if X matches the password then log in
4. else print “Failed” to the screen

**Data**

Password?
Overflow!!!!! 3.log in

Access granted

X = Overflow!!!!! 3.log in

Exploitation
What happened?

- For C/C++ programs
  - A buffer with the password could be a local variable
- Therefore
  - Input is too long, and overruns the buffer
  - Input includes machine instructions
  - The overrun rewrites the return address to point into the buffer, at the machine instructions
  - When the call “returns” it executes the attacker’s code

```c
strcpy(buff, "abc");
```
Stopping the attack

• **Buffer overflows** rely on the ability to **read or write outside the bounds of a buffer**

• **C and C++** programs expect the **programmer** to ensure this never happens
  • But humans (regularly) make mistakes!

• Other languages (like **Python, OCaml, Java**, etc.) ensure buffer sizes are respected
  • The **compiler** inserts checks at reads/writes
  • Such checks can halt the program
  • But will **prevent a bug from being exploited**
Instructions

1. print “Password?” to the screen
2. read input into variable X
3. if X matches the password then log in
4. else print “Failed” to the screen

Data

X = Overflow!!

Preventing Exploitation

Program halted
Key idea

• The key feature of the buffer overflow attack is the attacker getting the application to treat attacker-provided data as instructions (code) or code parameters

• This feature appears in many other exploits too
  • SQL injection treats data as database queries
  • Cross-site scripting treats data as browser commands
  • Command injection treats data as operating system commands
  • Etc.

• Sometimes the language helps (e.g., type safety)
  • Sometimes the programmer needs to do more work
Attack Scenarios
The Internet, in one slide

(Much) user data is part of the browser

FS/DB is a separate entity, logically (and often physically)

Need to protect this state from illicit access and tampering

(Private) Data

Filesystem/D Database/etc.
Interception

- **Calls** to remote services could be intercepted by an adversary
  - **Snoop** on inputs/outputs
  - **Corrupt** inputs/outputs

- Avoid this possibility using **cryptography** (CMSC 414, CMSC 456)
Malicious clients

- Server needs to **protect itself against malicious clients**
  - Such clients won’t run standard software (e.g., typical web browser)
  - Such clients will probe the limits of the interface
Planting a bomb

- **Server needs to protect good clients** from malicious clients that will try to launch attacks via the server
  - They corrupt the server state (e.g., uploading malicious files or code)
  - Good client interaction affected as a result (e.g., getting the malware)
Defensive measures

• Two key actions the server can take:
  
  • **Validate that client inputs are well formed**
    • Fallacy: Focus on testing that good inputs produce good behavior
    • Must (also) ensure that malformed inputs result in benign behavior
  
  • Mitigate harm that might result by **minimizing the trusted computing base**
    • Isolate trusted components, or minimize privilege to precisely what is needed, in case something goes wrong
Quiz 1: What are reasonable assumptions?

Suppose you are writing a PDF viewer that is leaner and better than Acrobat Reader. Which can you assume?

A. PDF files given to your reader will always be well-formed
B. PDF files will never exceed a particular size
C. You viewer will never be used as part of an Internet-hosted service
D. None of the above
Quiz 1: What are reasonable assumptions?

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D. None of the above
Validating inputs
What’s wrong with this Ruby code?

`catwrapper.rb`:

```ruby
if ARGV.length < 1 then
  puts "required argument: textfile path"
  exit 1
end

# call cat command on given argument
system("cat "+ARGV[0])

exit 0
```
Possible Interaction

> ls
  catwrapper.rb
  hello.txt

> ruby catwrapper.rb hello.txt
Hello world!

> ruby catwrapper.rb catwrapper.rb
if ARGV.length < 1 then
  puts "required argument: textfile path"
...

> ruby catwrapper.rb "hello.txt; rm hello.txt"
Hello world!

> ls
  catwrapper.rb
Quiz 2: What happened?

A. `cat` was given a file named `hello.txt`; `rm hello.txt` which doesn’t exist

B. `system()` interpreted the string as having two commands, and executed them both

C. `cat` was given three files – `hello.txt`; and `rm` and `hello.txt` – but halted when it couldn’t find the second of these

D. `ARGV[0]` contains `hello.txt` (only), which was then catted

```ruby
# catwrapper.rb:
if ARGV.length < 1 then
  puts "required argument: textfile path"
  exit 1
end

# call cat command on given argument
system("cat "+ARGV[0])
exit 0
```

```bash
> ruby catwrapper.rb "hello.txt; rm hello.txt"
Hello world!
> ls
```

Quiz 2: What happened?

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D. `ARGV[0]` contains `hello.txt` (only), which was then catted

---

```ruby
# catwrapper.rb

if ARGV.length < 1 then
  puts "required argument: textfile path"
  exit 1
end

# call cat command on given argument
system("cat " + ARGV[0])
exit 0
```

> ruby catwrapper.rb “hello.txt; rm hello.txt”

Hello world!

> ls

```
catwrapper.rb
```
Possible deployment

Client

Browser

Server

Web server

GET foo.txt

<output>

catwrapper.rb
Consequences?

- If `catwrapper.rb` is part of a web service
  - Input is **untrusted** — could be anything
  - But we only want requestors to read (see) the contents of the files, not to do anything else
  - Current code is too powerful: vulnerable to

  *command injection*

- How to fix it?

  **Need to validate inputs**

  [https://www.owasp.org/index.php/Command_Injection](https://www.owasp.org/index.php/Command_Injection)
Equifax: What happened

• Equifax used Struts which failed to properly vet input prior to using deserialization. Ruby had a similar bug sometime back.

• Vulnerability was discovered in a popular open-source software package Apache Struts, a programming framework for building web applications in Java

• The framework’s popular REST plugin is vulnerable. The REST plugin is used to handle web requests, like data sent to a server from a form a user has filled out.

• The vulnerability relates to how Struts parses that kind of data and converts it into information that can be interpreted by the Java programming language.

• When the vulnerability is successfully exploited, malicious code can be hidden inside of such data, and executed when Struts attempts to convert it.

• Intruders can inject malware into web servers, without being detected, and use it to steal or delete sensitive data, or infect computers with ransomware, among other things.
Input Validation

• We expect input of a certain form
  • But we cannot guarantee it always has it
    - it’s under the attacker’s control
  • So we must validate it before we trust it

• **Making input trustworthy**
  • **Check it** has a valid form, and reject it if not
  • **Sanitize it** by modifying it or using it in such a way that the result is correctly formed by construction
Checking: Blacklisting

- **Reject** strings with possibly bad chars: ``, `;`, `--`

```ruby
if ARGV[0] =~ /;/ then
  puts "illegal argument"
  exit 1
else
  system("cat "+ARGV[0])
end
```

```bash
> ruby catwrapper.rb "hello.txt; rm hello.txt"
illegal argument
```
Sanitization: Blacklist Filtering

- **Delete** the characters you don’t want: `
  ;`  

```ruby
system("cat "+ARGV[0].tr(";",""))
```

```bash
> ruby catwrapper.rb "hello.txt; rm hello.txt"
Hello world!
cat: rm: No such file or directory
Hello world!
> ls hello.txt
hello.txt
```
Sanitization: Escaping

- **Replace problematic characters with safe ones**
  - change `' to `\`
  - change `;` to `;`
  - change `-` to `--`
  - change `\` to `\`

- Which characters are problematic depends on the interpreter the string will be handed to
  - Web browser/server for URIs
    - `URI::escape(str,unsafe_chars)`
  - Program delegated to by web server
    - `CGI::escape(str)`
Sanitization: Escaping

Regexes are very handy for specifying dangerous inputs, both for checking and sanitizing.

```ruby
def escape_chars(string)
  pat = /('"|\.|\*|\/|\-|\s)/
  string.gsub(pat){|match|"\" + match}
end

system("cat "+escape_chars(ARGV[0]))
```

> ruby catwrapper.rb "hello.txt; rm hello.txt"

```
cat: hello.txt; rm hello.txt: No such file or directory
```

> ls hello.txt

```
hello.txt
```
Quiz 3: Is this escaping sufficient?

A. No, you should also escape character &
B. No, some of the escaped characters are dangerous even when escaped
C. Both of the above
D. Yes, it’s all good

catwrapper.rb:

```ruby
def escape_chars(string)
  pat = /('|"|\.\.|\*|\|\|-|--|;|--|s)/
  string.gsub(pat){|match|"\" + match}
end
system("cat "+escape_chars(ARGV[0]))
```
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```ruby
def escape_chars(string)
  pat = /(/|"|\.|\*|\|\|\|\|\-|\|\|\;|\|\|\s)/
  string.gsub(pat){|match|"\" + match}
end
system(“cat ”+escape_chars(ARGV[0]))
```
Escaping not always enough

> ls ../passwd.txt
passwd.txt
> ruby catwrapper.rb "../passwd.txt"
bob:apassword
alice:anotherpassword

- A web service probably only wants to give access to the files in the current directory
  - the .. sequence should have been disallowed

- Previous escaping doesn’t help because . is replaced with \., which the shell interprets as .
Path traversal

This is called a path traversal vulnerability. Solutions:

- Delete all occurrences of the . character
  - Will disallow legitimate files with dots in them (hello.txt)

- Delete occurrences of .. sequences
  - Safe, but disallows foo/../hello.txt where foo is a subdirectory in the current working directory (CWD)

- Ideally: Allow any path that is within the CWD or one of its subdirectories

https://www.owasp.org/index.php/Path_Traversal
Checking: Whitelisting

- **Check that the user input is known to be safe**
  - E.g., only those files that exactly match a filename in the current directory

- **Rationale**: Given an invalid input, **safer to reject than to fix**
  - “Fixes” may result in wrong output, or vulnerabilities
  - **Principle of fail-safe defaults**
files = Dir.entries(".").reject { |f| File.directory?(f) }

if not (files.member? ARGV[0]) then
   puts "illegal argument"
   exit 1
else
   system("cat "+ARGV[0])
end

> ruby catwrapper.rb "hello.txt; rm hello.txt"
illegal argument
Validation Challenges

- **Cannot always delete or sanitize problematic characters**
  - You may want dangerous chars, e.g., “Peter O’Connor”
  - How do you know if/when the characters are bad?
  - Hard to think of all of the possible characters to eliminate

- **Cannot always identify whitelist cheaply or completely**
  - May be expensive to compute at runtime
  - May be hard to describe (e.g., “all possible proper names”)

Key Questions

- **Which inputs in my program should not be trusted?**
  - These start from input from untrusted sources
  - And these inputs influence ("taint") other data that flows through my program
    - And could be stored in files, databases, etc.

- **How to ensure that untrusted inputs, no matter what they are, will produce benign results?**
  - Sanitization, checking, etc. as early as possible
    - How to do this depends on the program, and how the inputs are used
Quiz 4: As a developer, security is

A. Something I can help address by writing better code
B. Something that writing better code can do little to address
C. Something that is the purview of the government, e.g., DHS
D. Something that will never be solved so long as market forces do not value security

(Pick an answer you think is best)
Summary

- Securing software requires **understanding your adversary**
  - **Threat models** help you think through how your code could be manipulated to do the wrong thing

- Key defense: **Input validation**
  - Method to make sure adversary-influence input is valid – safe & trustworthy – before using it

- Two validation methods
  - **Checking**: methods that accept or reject and don't modify the input.
    - Whitelisting - checking against a positive list (regex)
    - Blacklisting - checking against a negative list (regex)
  - **Sanitizing**: methods that modify the input before passing it on
    - Escaping - replacing bad chars with good ones
    - Blacklist filtering - filtering out (removing) bad chars