Building Security In

CMSC 330 Spring 2019

Security breaches

<u>Just a few:</u>

- **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 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)

https://www.openhub.net/languages/c

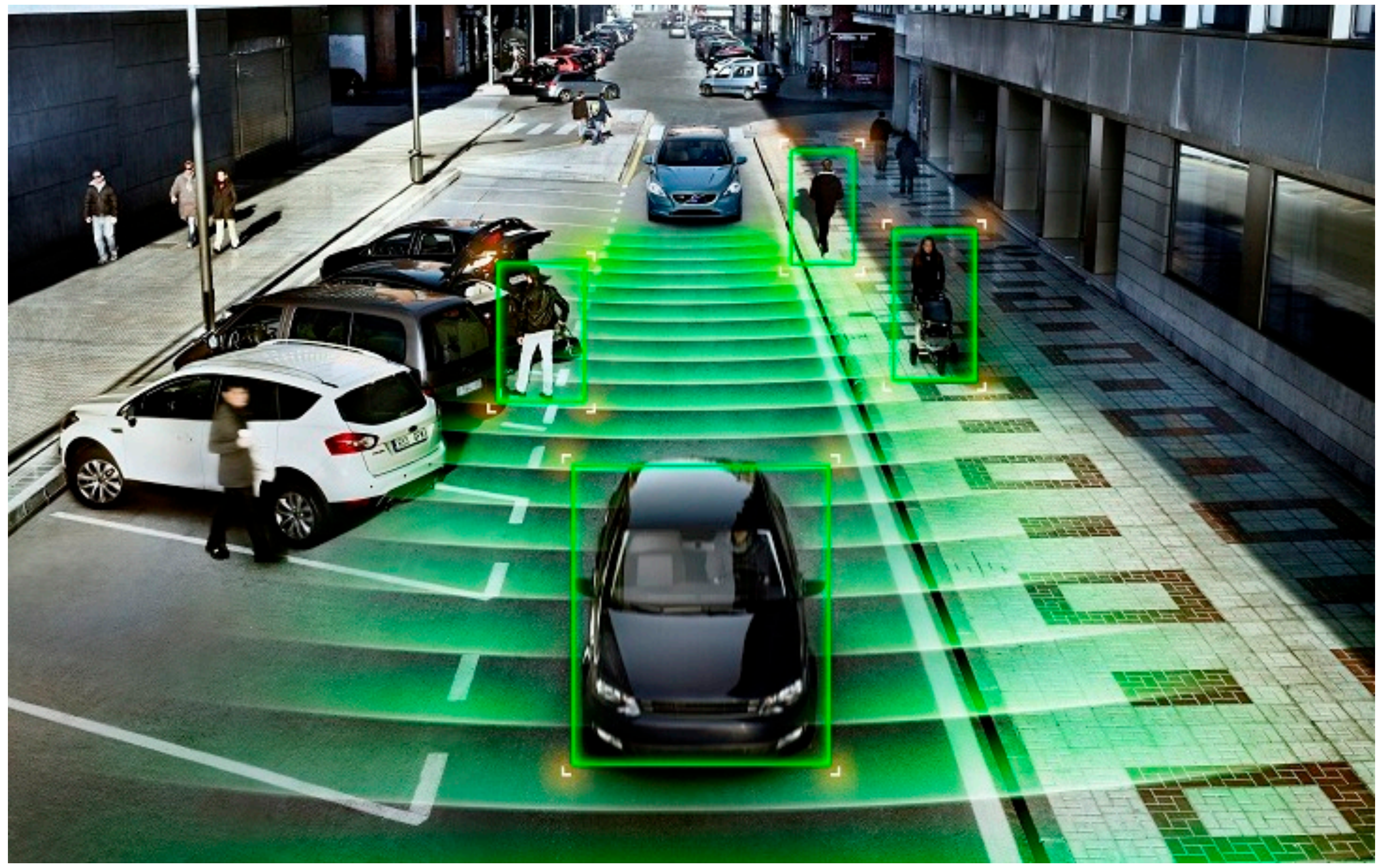
Open Hub	Google	Windows	
5.6B LOC	2B LOC	50M LOC	25M LOC

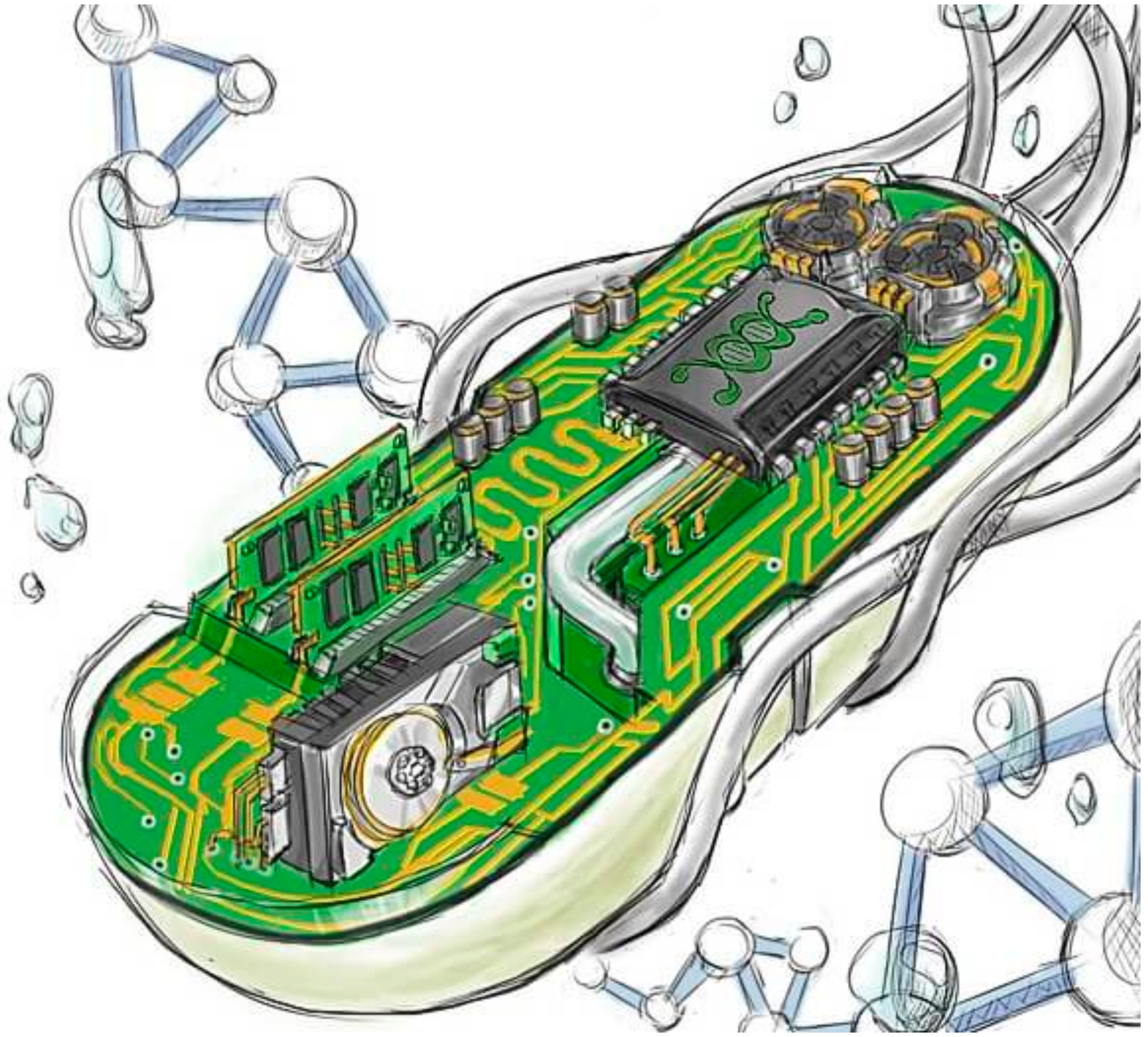
(Lines of code)

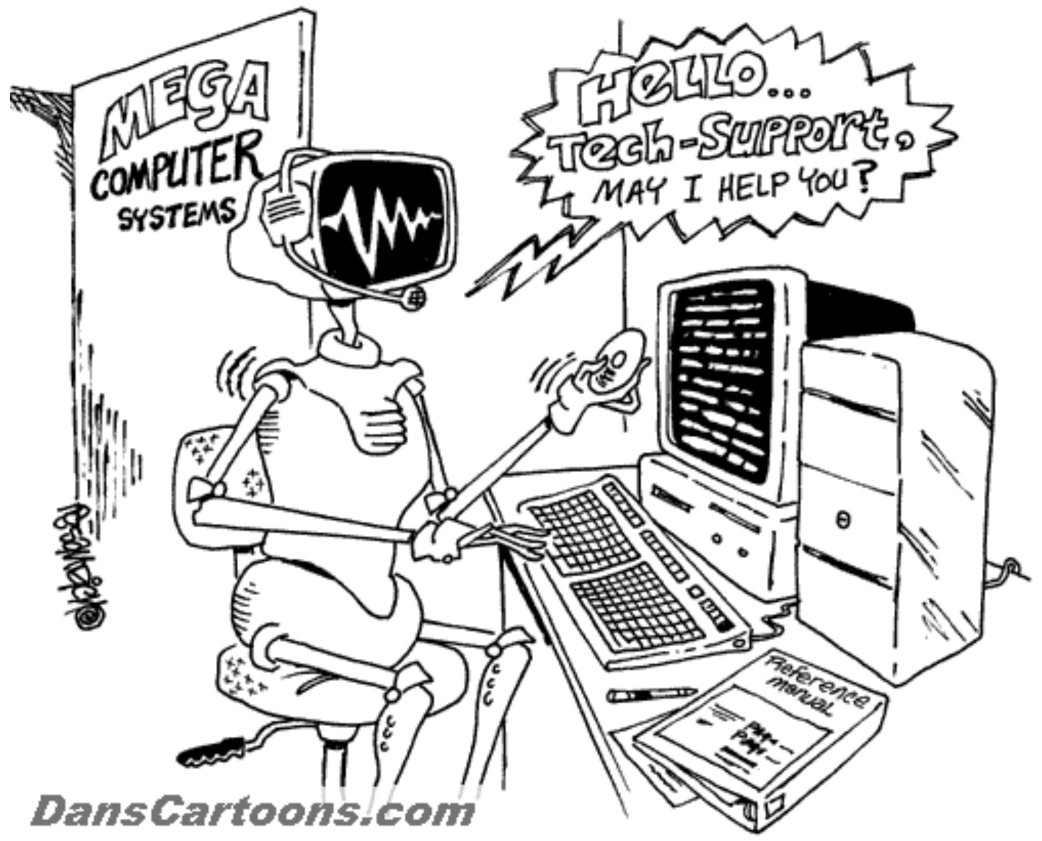
- So: **more bugs and flaws**

ICT* is Proliferating

*Information and Communication Technology







MIDDLE EAST

Iran Fights Malware Attacking Computers

By DAVID E. SANGER SEPT. 25, 2010

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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.

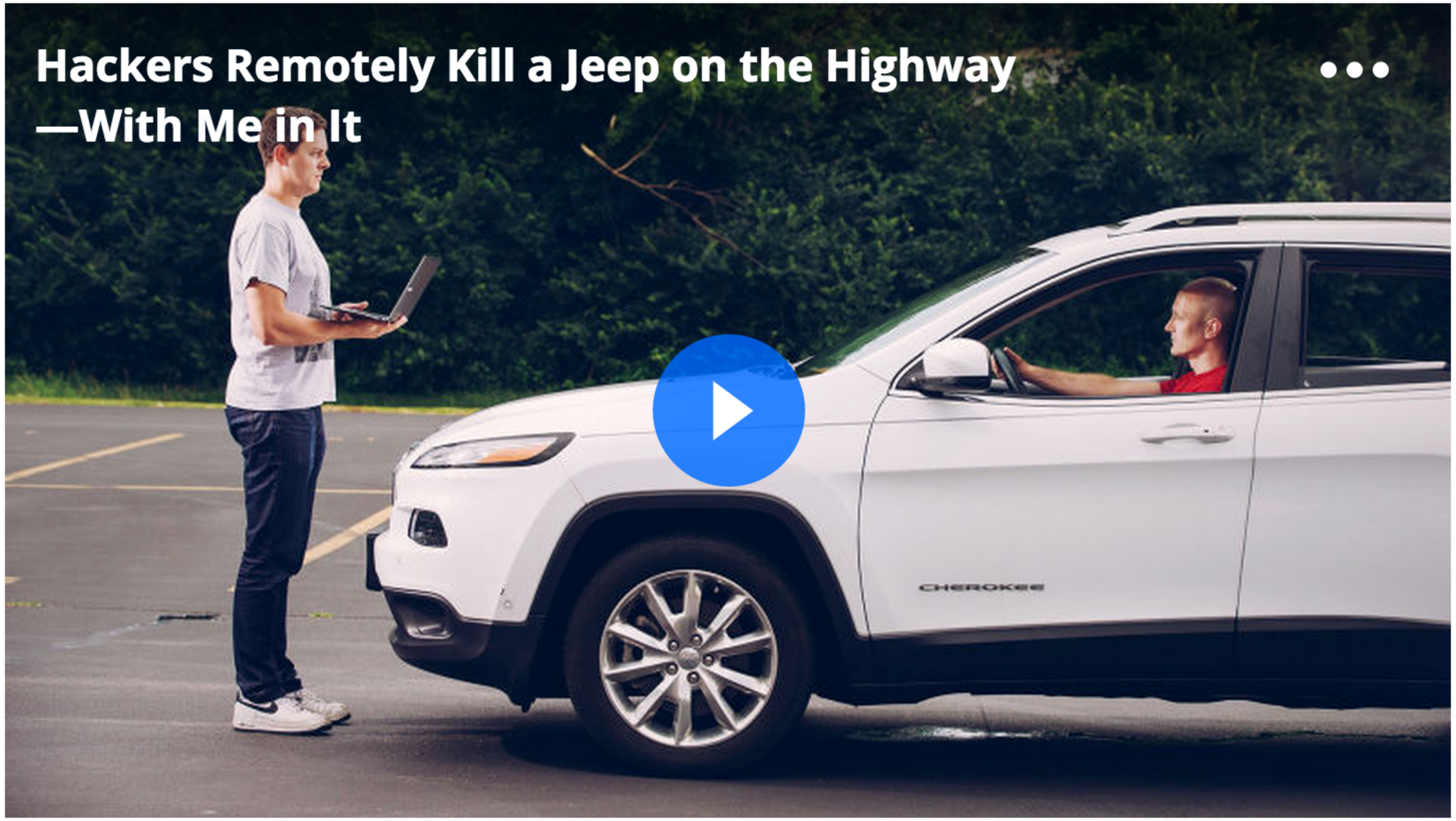
Stuxnet specifically targets … processes such as those used to control … **centrifuges for separating nuclear material**. Exploiting four zero-day flaws, **Stuxnet** functions by targeting machines using the Microsoft Windows operating system …, then seeking out Siemens Step7 software.

http://www.nytimes.com/2010/09/26/world/middleeast/26iran.html

WIRED SUBSCRIBE

ANDY GREENBERG SECURITY 07.21.15 6:00 AM

HACKERS REMOTELY KILL A JEEP ON THE HIGHWAY—WITH ME IN IT



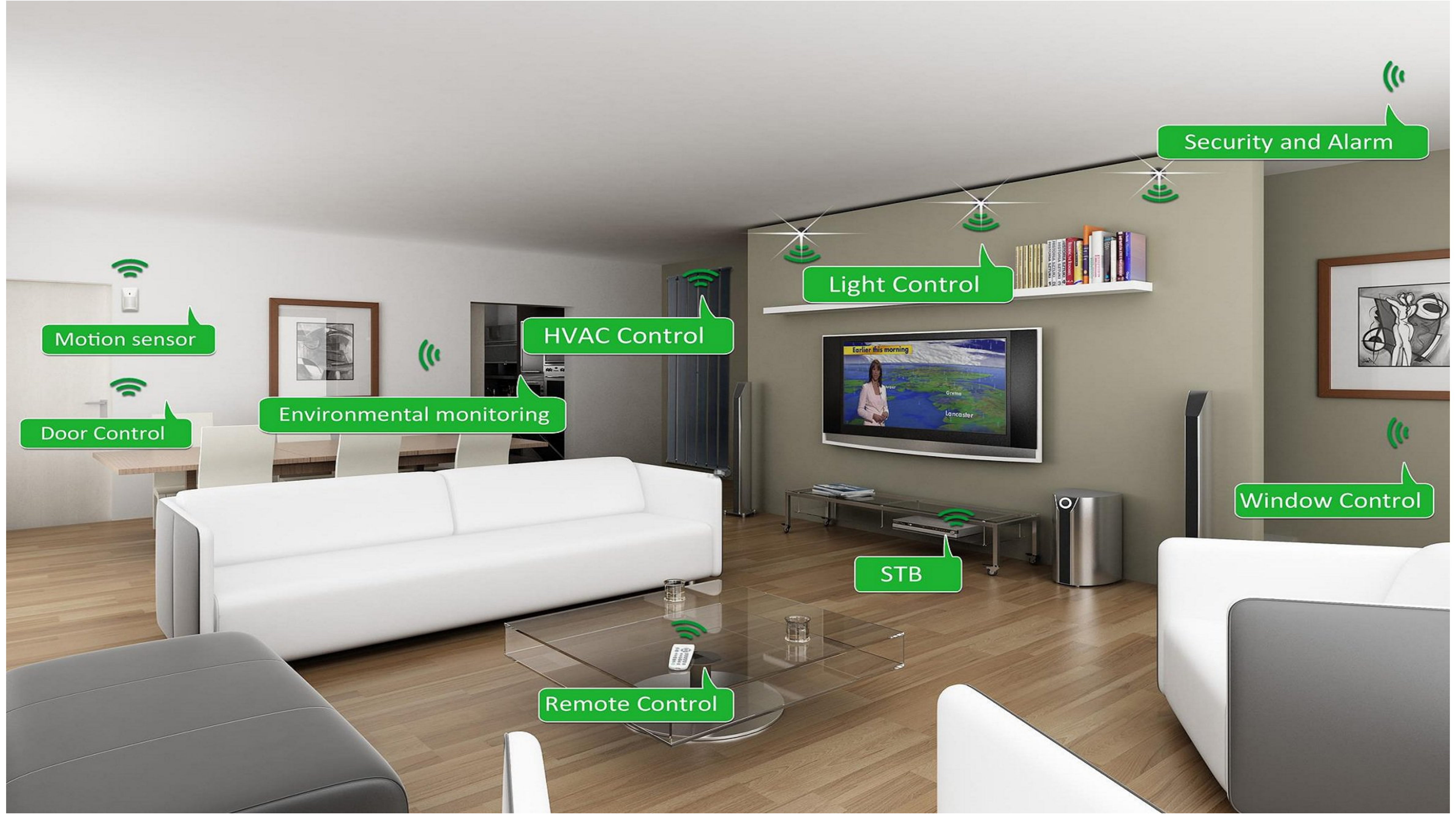
I WAS DRIVING 70 mph on the edge of downtown St. Louis when the exploit began

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)

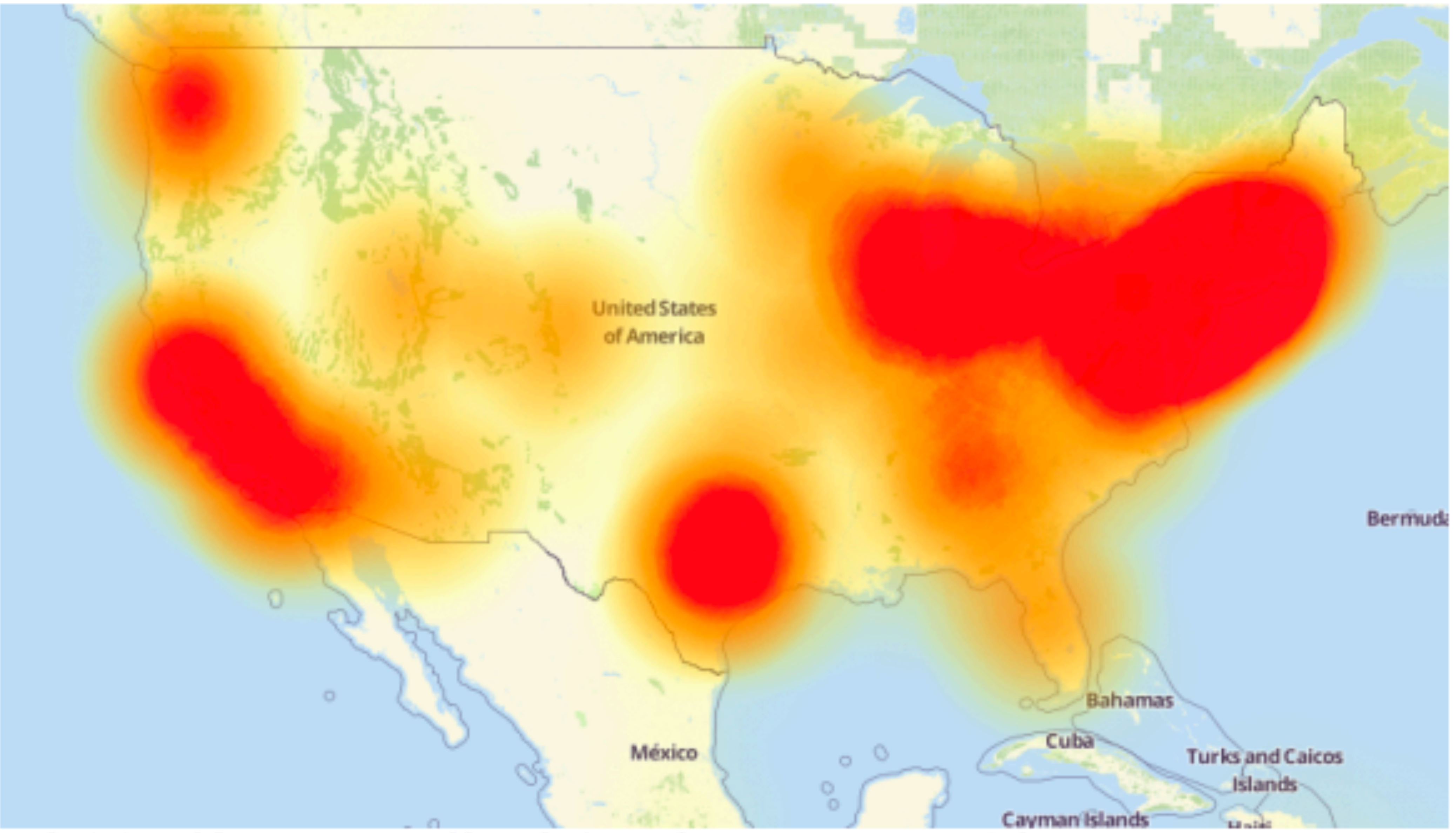
Amazon Alexa



Google Home

21 OCT 16 **Hacked Cameras, DVRs Powered Today’s Massive Internet Outage**

A massive and sustained Internet attack that has caused outages and network congestion today for a large number of Web sites was launched with the help of hacked “Internet of Things” (IoT) devices, such as CCTV video cameras and digital video recorders, new data suggests.



A depiction of the outages caused by today’s attacks on Dyn, an Internet infrastructure company. Source: Downdetector.com.

https://krebsonsecurity.com/2016/10/hacked-cameras-dvrs-powered-todays-massive-internet-outage/

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?

Symantec

McAfee®
An Intel Company

FireEye™
Next Generation Threat Protection

CISCO™

KASPERSKY lab

tenable®
network security

SNORT®

ZDNet | MENU | US

MUST READ THE NIGHT ALEXA LOST HER MIND: HOW AWS OUTAGE CAUSED ECHO MAYHEM

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:

Vulnerabilities in security products too!

Security researcher Tavis Ormandy disclosed the existence of **a vulnerability which impacts on Kaspersky [security] products**.

Hermansen, [another researcher,] publicly disclosed a zero-day **vulnerability within cyberforensics firm FireEye's security product**, complete with proof-of-concept code.

http://www.zdnet.com/article/fireeye-kaspersky-hit-with-zero-day-flaw-claims/

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
  - …

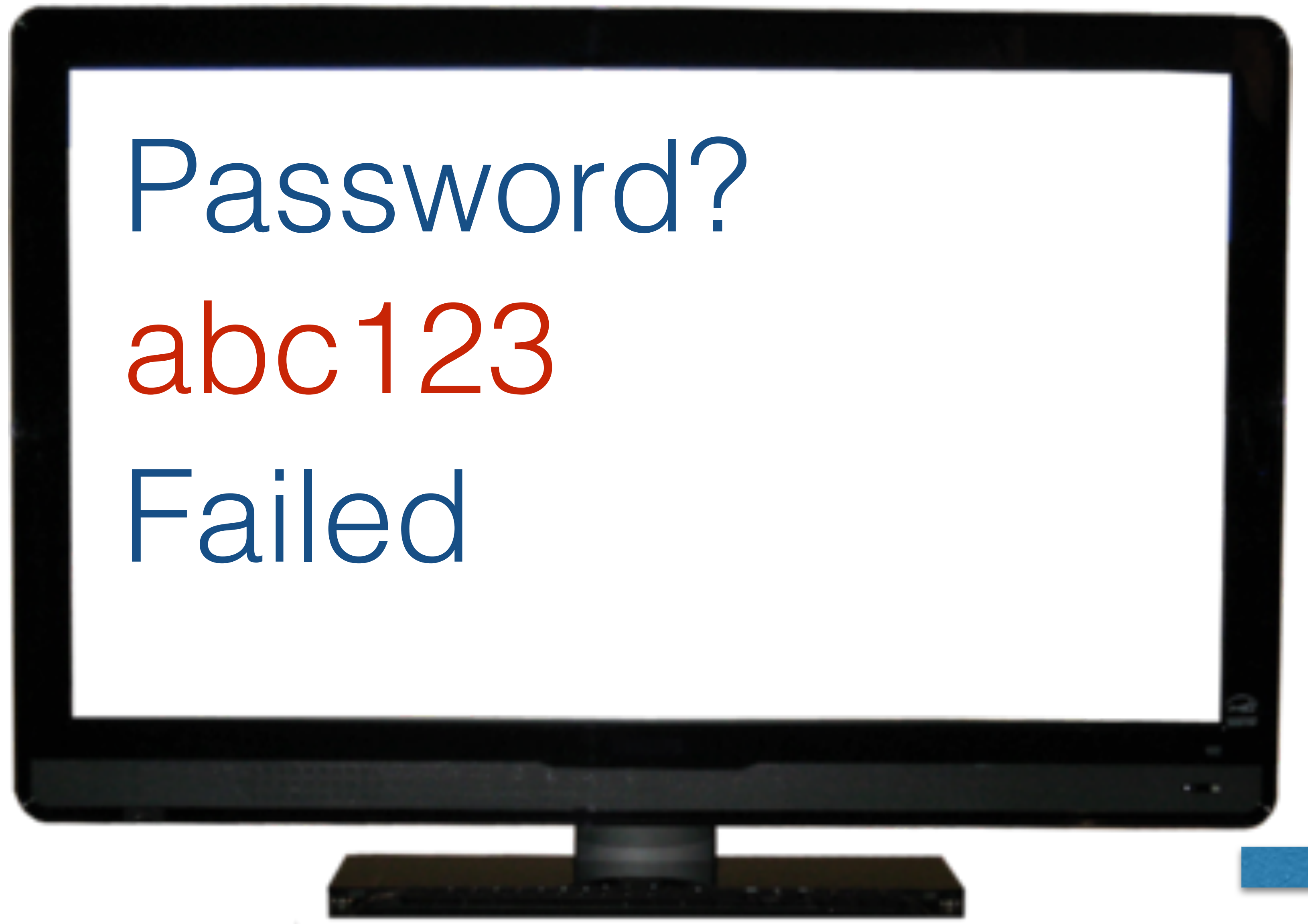
What is a buffer overflow?

- 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!



Normal interaction

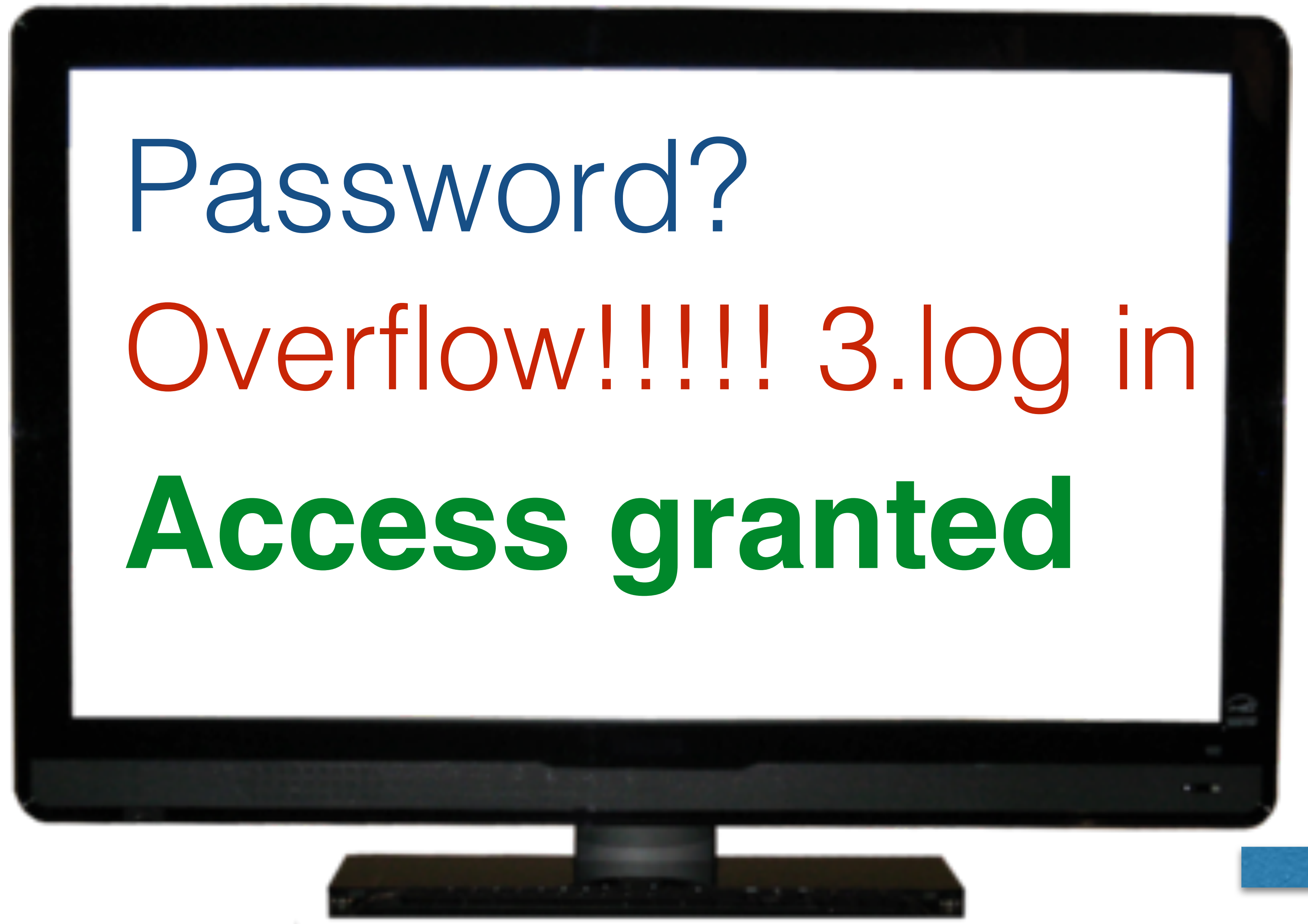
Instructions

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 = $\boxed{\text{abc123}}$

Exploitation



Instructions

1. print “Password?” to the screen

2. read input into variable X

Data

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

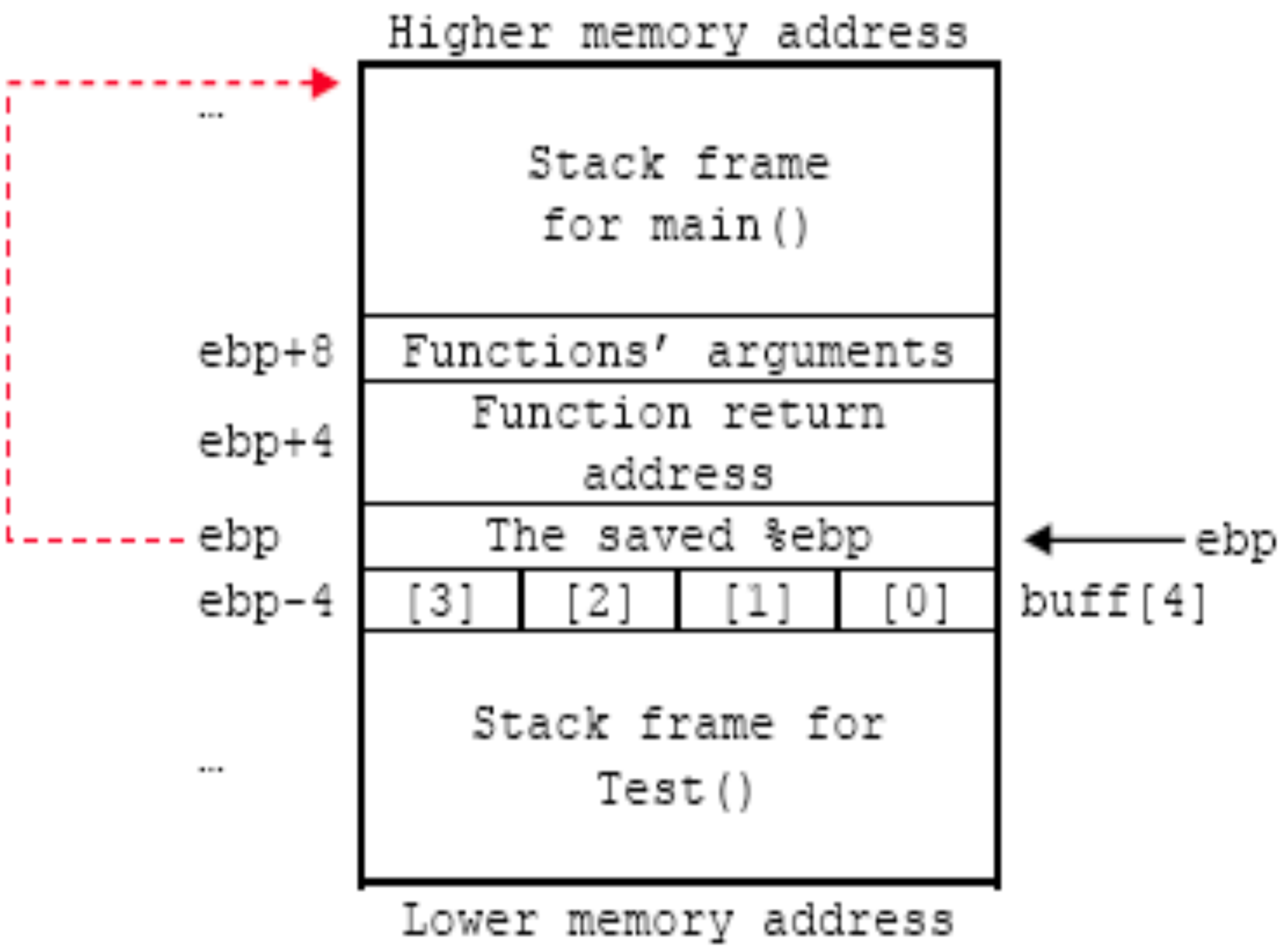
4. else print “Failed” to the screen

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

`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**

Preventing Exploitation

Instructions

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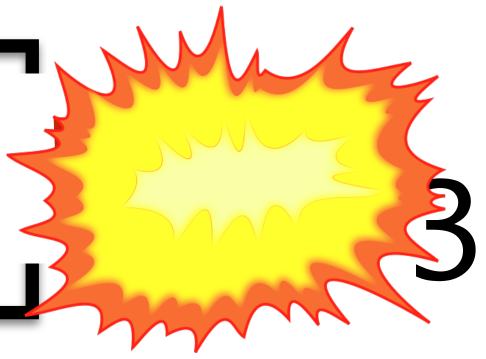
Data

X = Overflow!



Program halted

Key idea

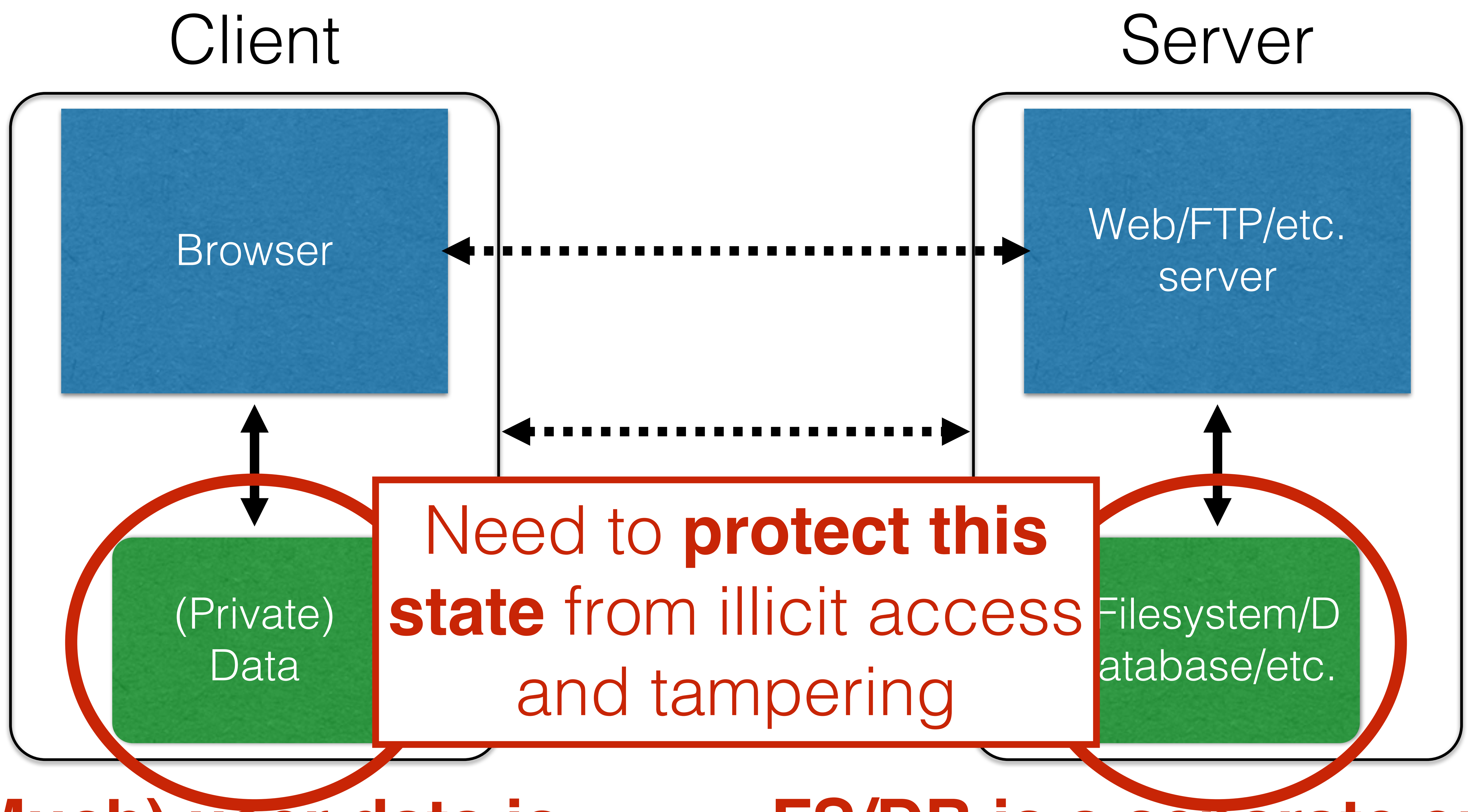
- The key feature of the buffer overflow attack is the attacker getting the application to treat **attacker-provided data** as **instructions (code) or code parameters**

- 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

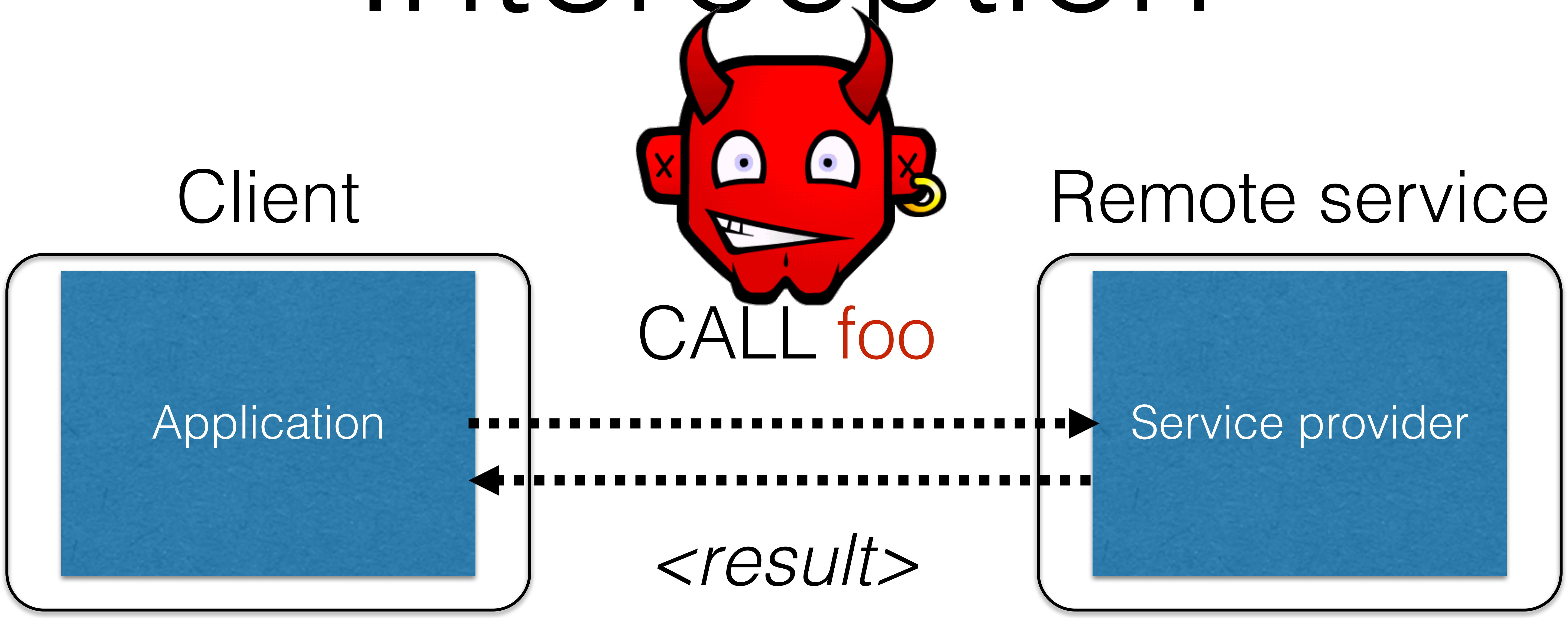
The Internet, in one slide



(Much) user data is part of the browser

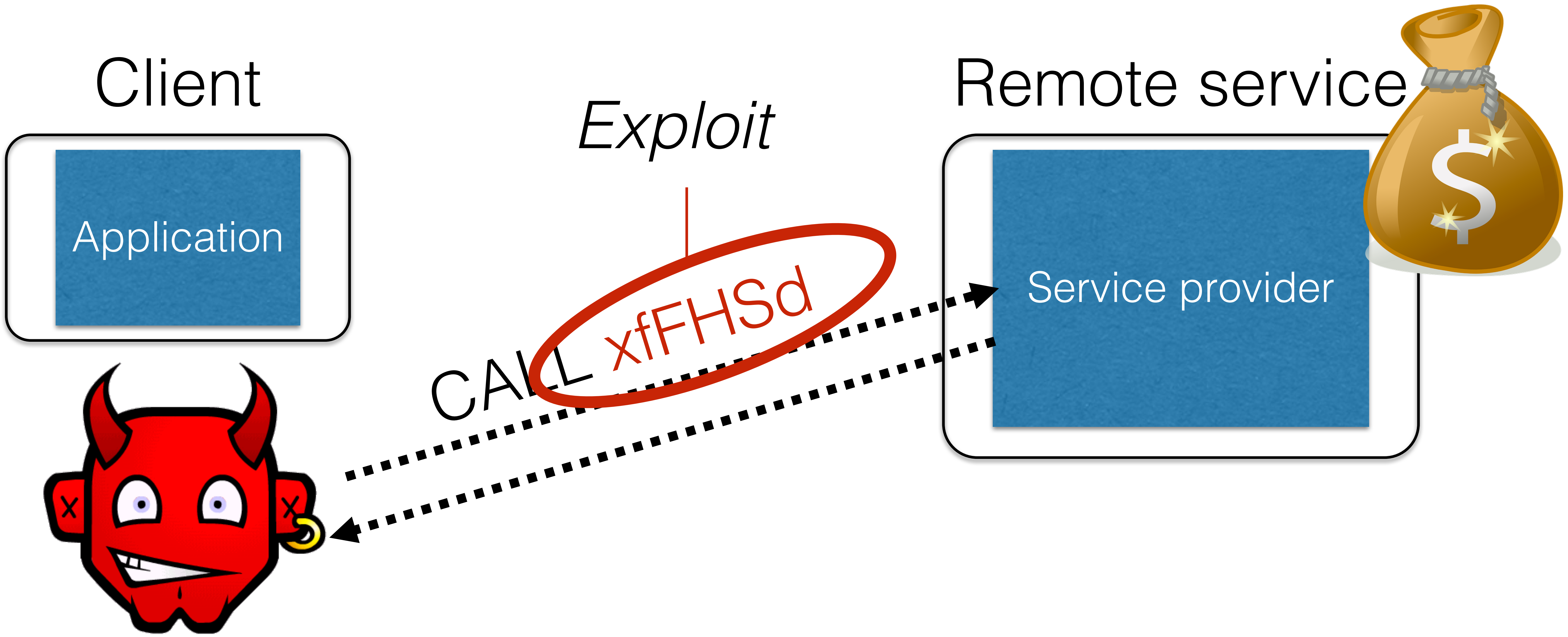
FS/DB is a separate entity, logically (and often physically)

Interception



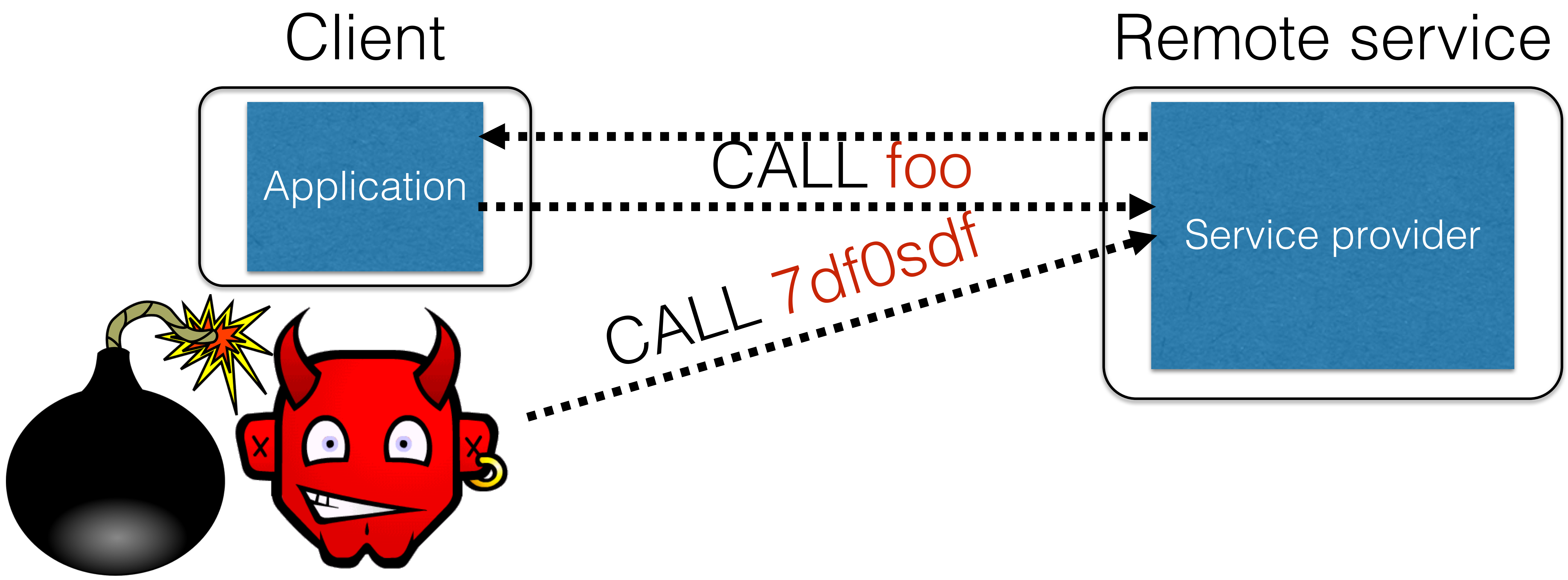
- **Calls** to remote services could be **intercepted** by an adversary
  - **Snoop** on inputs/outputs
  - **Corrupt** inputs/outputs
- Avoid this possibility using **cryptography** (CMSC 414, CMSC 456)

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

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Validating inputs

What’s wrong with this Ruby code?

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
```

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

catwrapper.rb:

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system("cat "+ARGV[0])

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```
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Hello world!
> ls
catwrapper.rb
```

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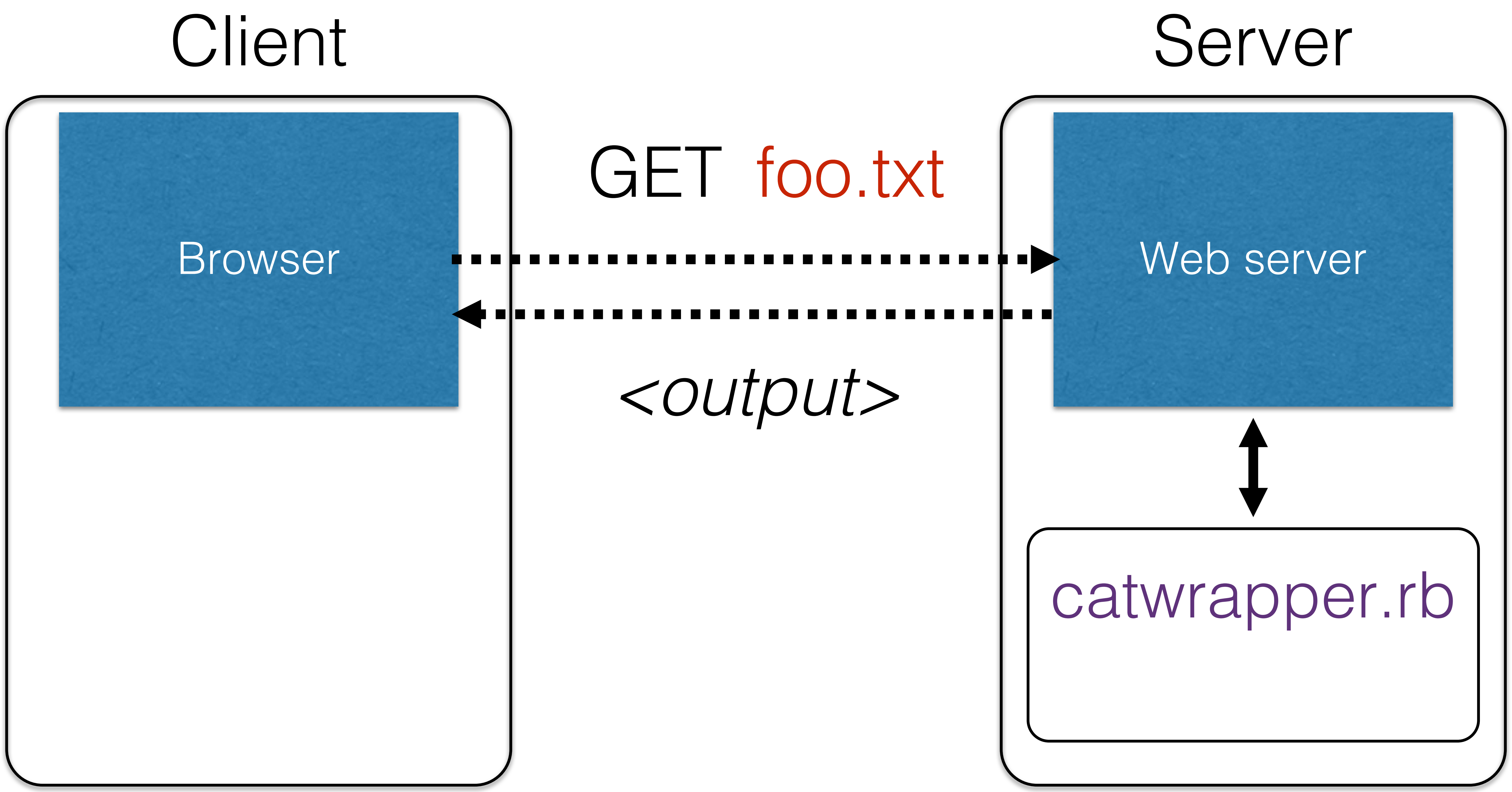
Possible deployment



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

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 it in such a way that the result is correctly formed by construction

Checking: Blacklisting

- **Reject strings with possibly bad chars:** ' ; --

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

reject inputs *that have ; in them*

```
> ruby catwrapper.rb “hello.txt; rm hello.txt”
illegal argument
```

Sanitization: Blacklist Filtering

- **Delete the characters you don't want:** ' ; --

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

delete occurrences *of ; from input string*

```
> 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

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

system(“cat ”+escape_chars(ARGV[0]))
```

escape occurrences *of ‘, “”, ; etc. in input string*

```
> 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

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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*

Checking: Whitelisting

```
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
```

reject inputs *that do not mention a legal file name*

```
> 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