CS5412: DANGERS OF CONSOLIDATION

Lecture XXIII

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Are Clouds Inherently Dangerous?

- Gene Spafford, famous for warning that the emperor has no clothes fears that moving critical information to the cloud could be a catastrophe

- His concern?
  - Concentration of key resources creates a "treasure chest" that adversaries can focus upon and attack
  - Risk of a virus spreading like wildfire

- Core issue: Clouds create *monocultures*

What Constitutes a “Monoculture”?

monoculture: An environment in which the predominance of systems run apparently identical software components for some or all services.

- Such systems share vulnerabilities, hence they are at risk to rapid spread of a virus or other malware vector.

Cloned babies

Cloned plants

Forms of monocultures

- Large numbers of instances of identical programs or services (includes applications, not just the O/S)
- Wide use of the same programming language or scripting tool
- Any standard defines a kind of monoculture

Taking the larger view

Three categories of attack

- **Configuration** attacks.
  - Exploit aspects of the configuration. Vulnerability introduced by system administrator or user who installs software on the target.
  - Includes compiling SNDMAIL with the back door enabled
- **Technology** attacks.
  - Exploit programming or design errors in software running on the target. Vulnerability introduced by software builder.
  - Here hacker breaks in via buggy code
- **Trust** attacks.
  - Exploit assumptions made about the trustworthiness of a client or server. Vulnerability introduced by system or network architect.
  - Hacker abuses legitimate access, like a hospital worker who peeks at Lindsey Lohan's medical records

Monoculture: A *defense* for configuration attacks.

A carefully constructed, fixed, system configuration would be an effective defense against configuration attacks.

- System configuration (today) is hard to get right and thus is best done by experts. Having one or a small number of "approved" configurations would allow that.
- Configuration attacks are considered "low hanging fruit" and thus likely are the dominant form of attack today.
- Configurations change not only because a system administrator installs software but also from a user visiting web sites or interacting with web services that cause software downloads.
  - To rule-out such downloads could be a serious limitation on system functionality. Such downloads often bring vulnerabilities, though.

So monocultures help… for one case

- Question becomes: what percent of attacks leverage configuration mistakes?
  - … *nobody knows!*
  - But gray-hat hackers assure us that things like standard passwords are a very common problem

Viruses love monocultures

- Earliest Internet Worm was launched at Cornell!
  - A brief episode of notoriety for us
  - Worm exploited variety of simple mechanisms to break into computer systems, then used them as a springboard to find other vulnerable systems and infect them
  - It had a simple trick to prevent itself from reinfecting an already infected system: checked for a "lock" file
    - But even if present, reinfected with a small probability
    - Idea was to jump back onto systems that might have been fixed by system admin team but who left the lock in place

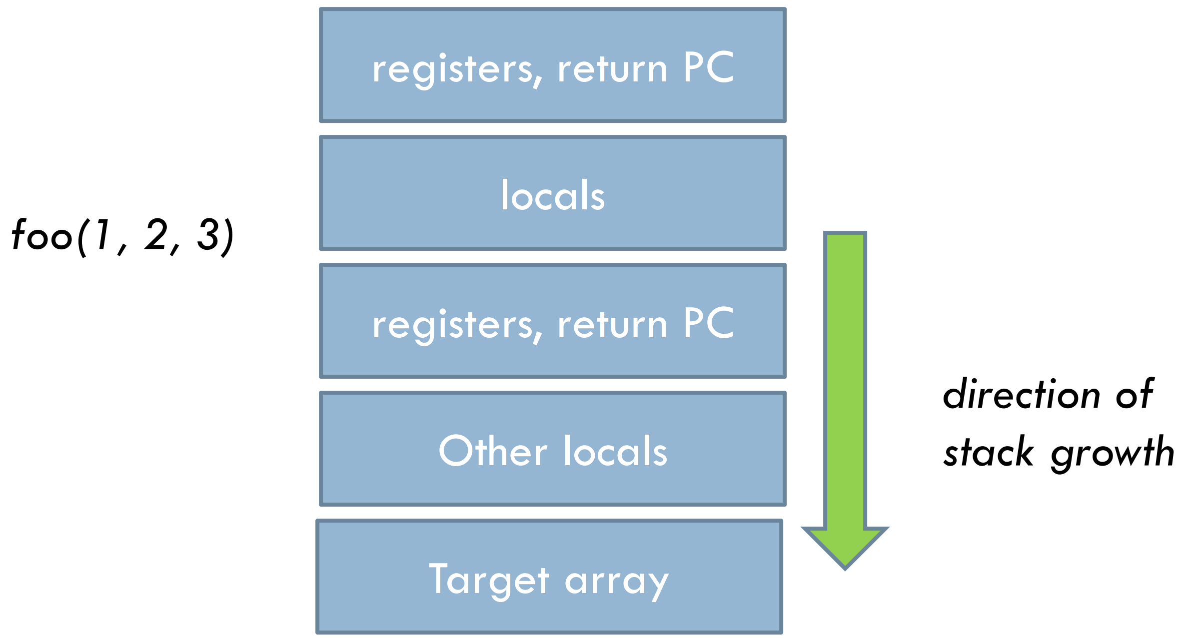
Monocultures are a known risk

- Vast majority of computer viruses and worms operate by exploiting software bugs
  - For example, failure to check boundaries on arrays
  - Very common in code written in C++ or C because those languages check automated boundary checks
  - Nothing stops an input from overrunning the end of the array
- What lives beyond the end of an array?

Beyond the end...

- Two cases to consider
  - Array is on the stack (local to some active method)
  - Array is in the program's data or BSS area, or was allocated from the heap

Stacks grow "downwards..."



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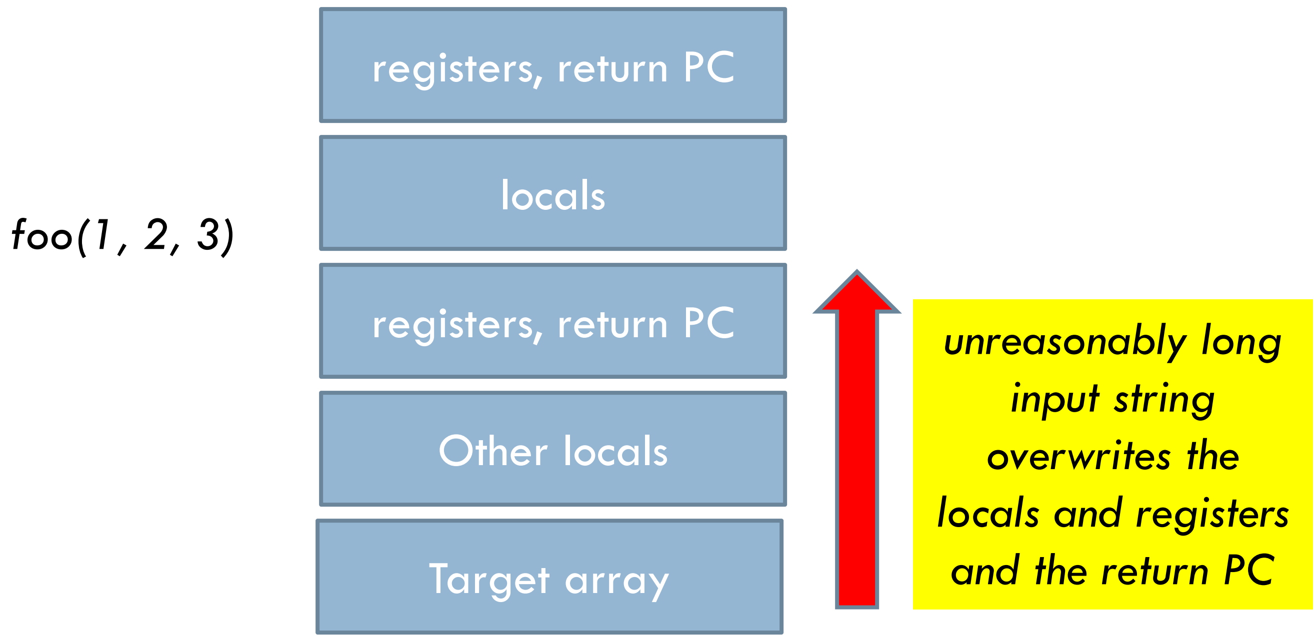

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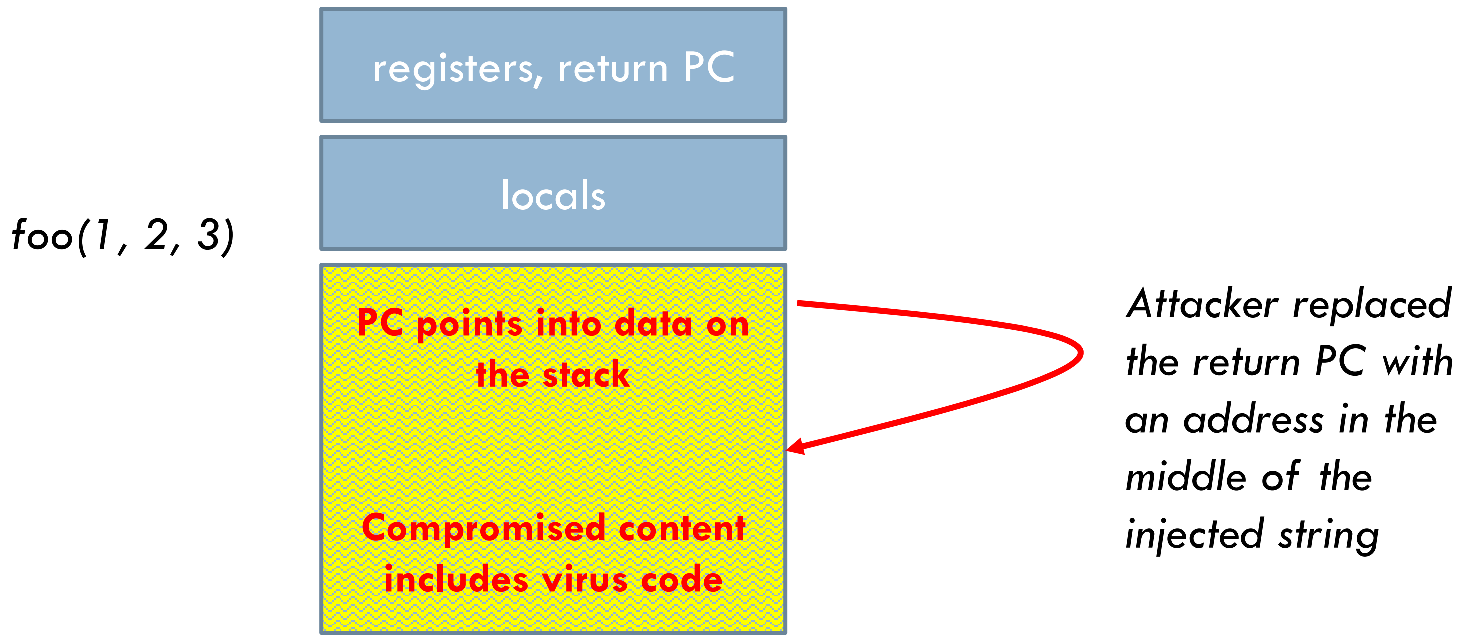


Why does this attack work?

- Attacker needs to be able to predict
  - Where the target string lives in memory
  - How the stack is arranged
  - What the code that reads the string will do

- Trick is to get the code to jump into the data read from the attacker

Bootstrapping concept

- The hacker doesn't have much "room" for instructions

- So typically this logic is very limited: often just code to read a longer string from the network and then execute that longer code
  - In effect, the initial attack is a bootstrap program
  - It loads and launches a more serious program

Example

- String loads code that simply allocates a much bigger object, reads from the same input source into it, and jumps to the start

- Allows the attacker to send a multi-GB program that would be way too large to "fit" within the stack
  - Trick is to take over but not trigger exceptions
  - If the attack causes the program to throw an exception, someone might notice

What about data/heap?

- Here attacker might be in a position to overwrite other adjacent variables on which the program is dependent
  - This does assume some "predictability" in memory layout!
  - We could perhaps replace a filename it reads or one it writes with filenames the attacker would prefer that it use instead, or with network URLs
  - Of course the program will now be a very sick puppy but it might last just long enough to do the I/O for the attacker
  - That I/O becomes a "point of leverage" that the attacker exploits like the first domino in a long line...

Example "attack opportunity"

- Any program that works with strings in C or C++ is at risk even if we length-check inputs

```
void unsafe(char *a, char *b)
{
        char tmp[32];
        strcpy(tmp, a);
        strcat(tmp, b);
        return(strcmp(tmp, "foobar"));
}
```

- Problem here isn't with the input length per-se but with the assumption in "unsafe" that the combined string fits in tmp

Why not just fix the compiler?

- People *have* modified C to check array bounds
  - This only helps in limited ways
- C and C++ and Fortran are *unsafe by design* because of pointer aliasing
  - They let us treat an object of one type as if it was of some other type
  - And they impose no real boundary checking at all
- Fixing the language would break many programs that are in wide use: we would need to fix them too

Broader problem

- We simply don't have a good way to create things that are correct, by construction, ground up
  - Lacking those, trying to find problems in existing code is like trying to plug a leak in a dam

- At best we can prove properties of one thing or another but the assemblage invariably has holes!
  - Or they sneak in over time

Cloud "permissiveness"

- Anyhow, it makes no sense to imagine that we would tell people how to build cloud applications

- With EC2 we just hand Amazon an executable
  - How will it know if the binaries were compiled using the right compiler?
  - What if the version of the compiler matters?
  - Generally not viewed as a realistic option

- In fact when C and C++ run on .NET many of these overflow issues are caught, but "managed" C or C++ will reject all sorts of classic programs as buggy

How to attack a cloud

- A good firewall can block many kinds of attacks
- But something will get through eventually, we can't avoid every possible risk and close every possible virus exploit
- And once the virus breaks in, it compromises every single accessible instance of the same code

What can we do about these issues?

- Today: Focus on these kinds of viral attacks

- Thursday: Look at the bigger picture

First, let's stop the stack attack…

- How can we do that?
  - The attacker is taking advantage of knowledge of the program behavior and flaws
  - An "unpredictable" program would have crashed but not been so easy to compromise
  - Can we take a program written in C or C++ and make it behave less predictably without causing it to crash?

Stack randomization

- Idea is simple:
  - Modify the runtime to randomly allocate chunks of memory (unpredictable size) between objects on stack
  - We can also add a chunk of unpredictable size to the bottom of the stack itself
- Attacker countermeasures?
  - May be possible to use a "block" of jump instructions, no-ops to create code that can run in a "position independent manner"
  - Or might guess the offset and try, try again… If the datacenter doesn't notice the repeated crashes a few hundred tries might suffice to break in

.NET has *automated* diversity

- If enabled, a wide variety of randomization mechanisms will be employed
- Just a bit in the runtime environment you can set
- But important to retest programs with stack randomization enabled
  - Some programs *depend* on bugs, other issues!

But this can't stop all attacks

- For example, database "code injection" attacks have a similar approach and yet don't rely on array overflow:
  - Intended code
    - SELECT * FROM users WHERE name = '" + userName + "';"
    - Limits query to data for this user
  - Attacker sends a "faulty" name argument:
    - ' or '1'='1
    - SELECT * FROM users WHERE name = ` ' or '1'=1;
- There are many examples of this kind because many programs exchange messages that involve application-specific programming languages

Blocking SQL query injection?

- This is easy:
  - Read the input
  - Then "clean it up"
  - Then pass it in to the application

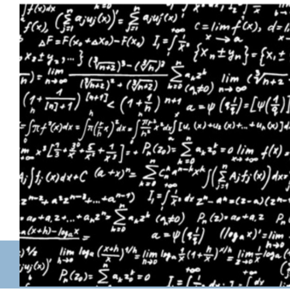
- As long as the developer uses the right tools these issues don't arise
  - But not every developer cooperates

Other ideas: Castro and Costa

- One project at Microsoft monitors program crashes
  - Each time a crash happens they look to see what input caused the program to fail
  - In one project they create virus "signatures"
  - In another they automatically combine these to create a pattern, more and more selective, for blocking the input strings that cause the problem
  - Use gossip, rapidly and robustly disseminate the fix together with a "proof" of the bug that triggers it

Manuel Costa, Jon Crowcroft, Miguel Castro, Antony Rowstron, Lidong Zhou, Lintao Zhang, and Paul Barham, Vigilante: End-to-End Containment of Internet Worms, in ACM Symposium on Operating Systems Principles (SOSP), Brighton, UK, Oct 2005

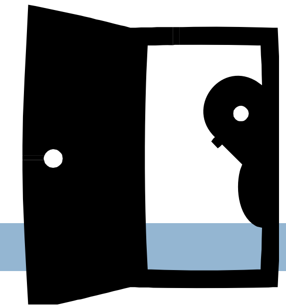
What kind of "proof"?



- Before installing a patch, verify that problem is real
  - Proof: Example of an input that will cause a crash or some other form of compromise
  - Verification: Try it inside a virtual machine

- One issue: if the filter is too broad, it might block legitimate inputs that wouldn't cause a crash
- We want to block the attack but not legitimate users

Back door attacks



- Some attacks don't actually compromise a program
  - For example, the early Internet worm operated by exploiting a feature in the original SNDMAIL program
  - Code was written by Eric Allman and was unstable for the first few years
    - So he needed ways to see what the problem was
    - Included a debug feature allowing him to use SNDMAIL as a kind of remote FTP program to access files on remote system… and SNDMAIL runs with elevated priority…
    - Internet worm used this "feature" as one of its attack vectors

Stack diversity doesn't stop these…

- Backdoor attacks use legitimate features of a program, or perhaps debug features, to ask program to do things it was programmed to do!
  - The program isn't really malfunctioning or compromised
  - But it still does things for us that allow breakin
  - For example, can use SNDMAIL to copy a modified program on top of /etc/init in Linux
  - This modified program might work normally, but always allow logins from Evil.Hacker with password "Gotcha"
  - Better compiler won't help…

Neither would better checking tools

- A back door is a problem with the specification
  - The program shouldn't have functionality that replaces arbitrary files with code downloaded from the network, or copied from other places, or even with code "created" within the program itself
  - Yet it is very hard to pin down the rules we need to check to achieve confidence!

The ultimate back door

- Ken Thompson discussed hidden back doors in a famous Turing Award lecture
  - He considered the Unix login program
  - Showed how a macro substitution could insert a back door
  - Then pointed out that the macro preprocessor could have a back door that does the macro substitution
  - Then he applied this to the macro preprocessor itself
  - Ended up with a vanilla-looking Unix system that would always allow him to log in but where those lines of code could only be discovered by examining the byte code

The ultimate back door

- In general, covert "virtualized" platforms lurk in many settings
  - Virus could virtualize your machine
  - Attacker with serious resources could sneak a monitoring component into your printer or the disk drive itself
  - Even the network could potentially "host" a covert computing device and its own stealth network!
- Very hard to really secure modern computing systems. Cloud actually helps because many operators have resources to build their own specialized hardware

What about virtualization as a tool?

- By running the user's code in a virtual machine the cloud gives us a way to firewall the user from other users
  - We share a machine but I can't see your work and you can't see mine
  - Virtualization code needs to block things like putting the network into promiscuous mode ("monitoring" mode)
  - Forces us to trust the VM hypervisor and the hardware that supports virtualization, but gives "containment"
- Now a virus can only harm the user that "let it in"

Other forms of diversity

- Run different products that offer equivalent functionality, like two versions of an email server
  - Strange finding: researchers have shown that for many applications, even versions created separately share bugs!

- Consider morphing the system calls: code would need to be compiled on a per-instance basis but would protect against attacks that require attacker to know local system call numbering

- Vary thread scheduling order dynamically

Combining multiple methods

- This is sometimes called “defense in depth”

- The first line of defense is the dynamically managed firewall: ideally, attack won’t get in
  - But if it does, randomization has some chance of defeating the attack one step later
  - Each new obstacle is a hurdle for the attacker

- Will this stop attacks? Only simple ones… but most attacks use simple methods!

Defense in depth

… but even so a talented attacker can usually win