Generic Technical Defences

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Introduction

- Techniques for mitigating threats
  - Even unknown ones
- Host Based
- Generic

Overview

- Relating host security to the human body
- Immune System – Generic Protections
- Biodiversity – Being Different

Relating a Host to a Human Body

- A single vulnerability is like one specific illness
  - A patch is like a medical cure for that one illness
- There are many unknown illnesses and previously unseen variants of known illnesses
  - The immune system tries to adapt
- Even an illness the immune system cannot stop requires conditions to be right
  - Natural diversity can stop them in their tracks

Enterprise Security

- Most enterprises manage security with:
  - Firewalls
  - Network IDS systems
  - Patching

Firewalls/IDS

- Firewalls and Network IDS systems are at the perimeter
- Not helpful for new attacks over vectors considered safe
- In our body analogy we could say that they act like covering your mouth when somebody else sneezes

Patching

- Patching is rapidly becoming an impossible task
  - Particularly since they need to be well tested to insure they don't break other things
- Once a "virus" makes it past the IDS and into an unpatched vulnerable application it's open season
  - A host has a soft underbelly

Attacks as “Viruses”

- An attack making it past the firewall and IDS is like Flu particles making it into a bodies system
- The body will develop an infection unless immune system stops it or the host is otherwise unsuitable

Technical Protections

- Software to harden the OS/Application
- Effectively add an "immune" system to a host
- Don’t need to be deployed alone
  - Deployed in concert they can have an effect greater than the sum of the parts

Immune System Failures

- Even a strong immune system will not resist every attack
  - Particularly not attacks of a kind never seen before
- Technical protections are the same
  - They serve to make it much more difficult for attacks
  - Particularly for known attack vectors

Soft Targets

- Illness has a tendency to afflict the frail, and to do so with greater severity, than it does the healthy
- Computer security is much the same
  - The majority of computer crime, like crime in real life, is crime of opportunity
- A host that has a strong immune system becomes a far less interesting target

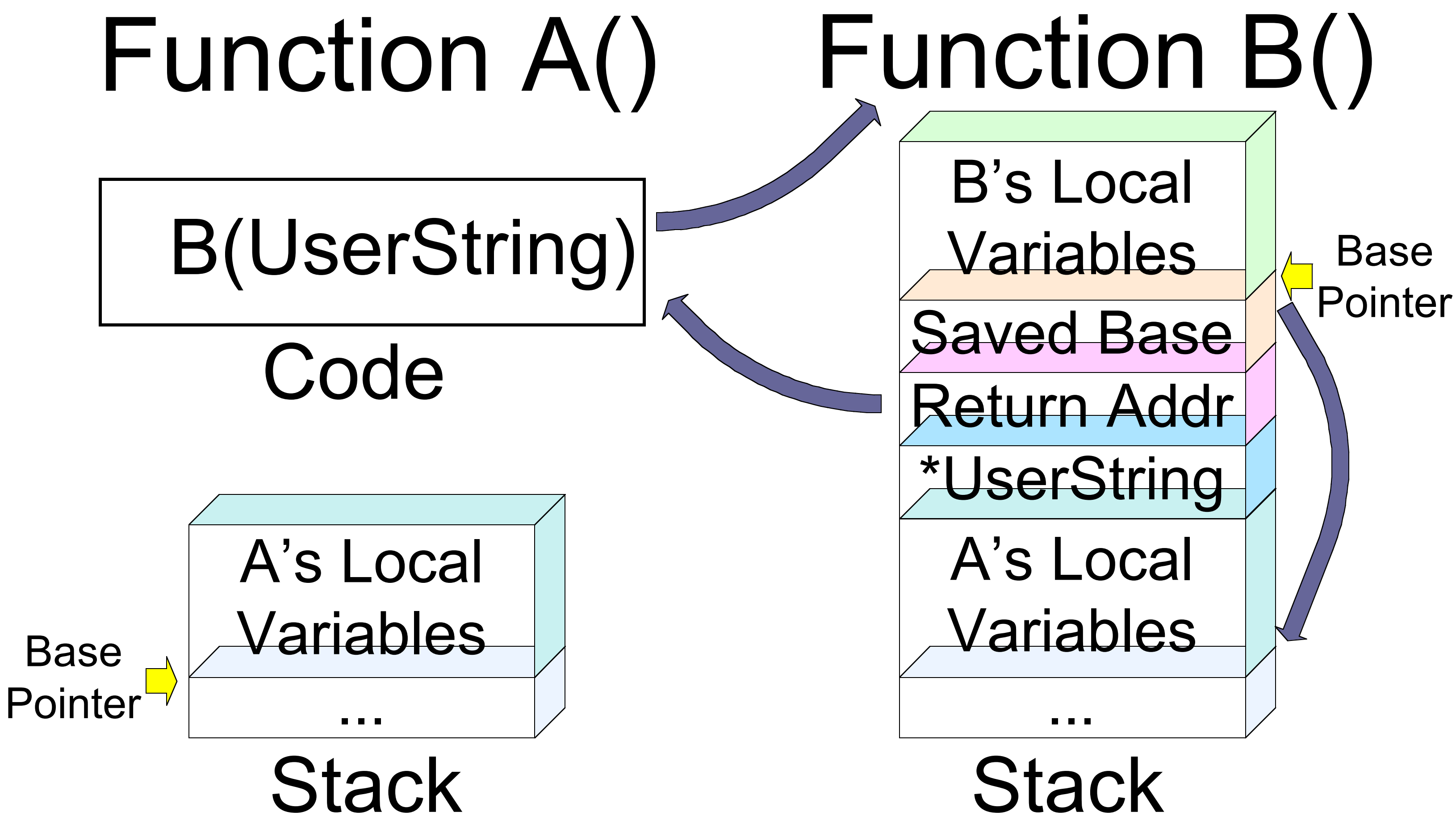
Making Attacks Ineffective

- Most technical protections aim to stop one or more key aspects of known attack classes
- We'll first quickly cover some attack classes
  - How they work, key attributes for attack success
- We'll then discuss a number of generic protections:
  - How they work, how they can be bypassed
  - All can be applied to system without source code

Stack Overflow

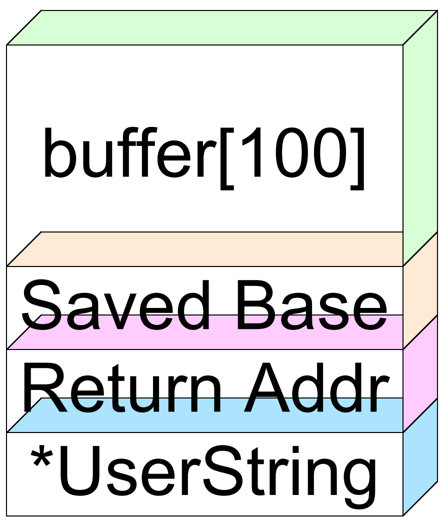
- Smashing the Stack for Fun and Profit
- Important data on the stack is overwritten
  - Resulting state can be controlled in some way by the attacker
- Traditional example is a string copy of a string from a user into a stack buffer
- Not particularly common any more

Traditional Stack Smash



Traditional Stack Smash

Function B()



Stack

```
char buffer[100];
strcpy(buffer, UserString);
```

Code

Traditional Stack Smash

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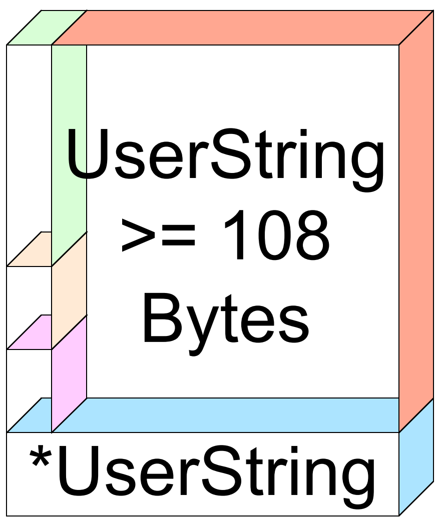

Stack

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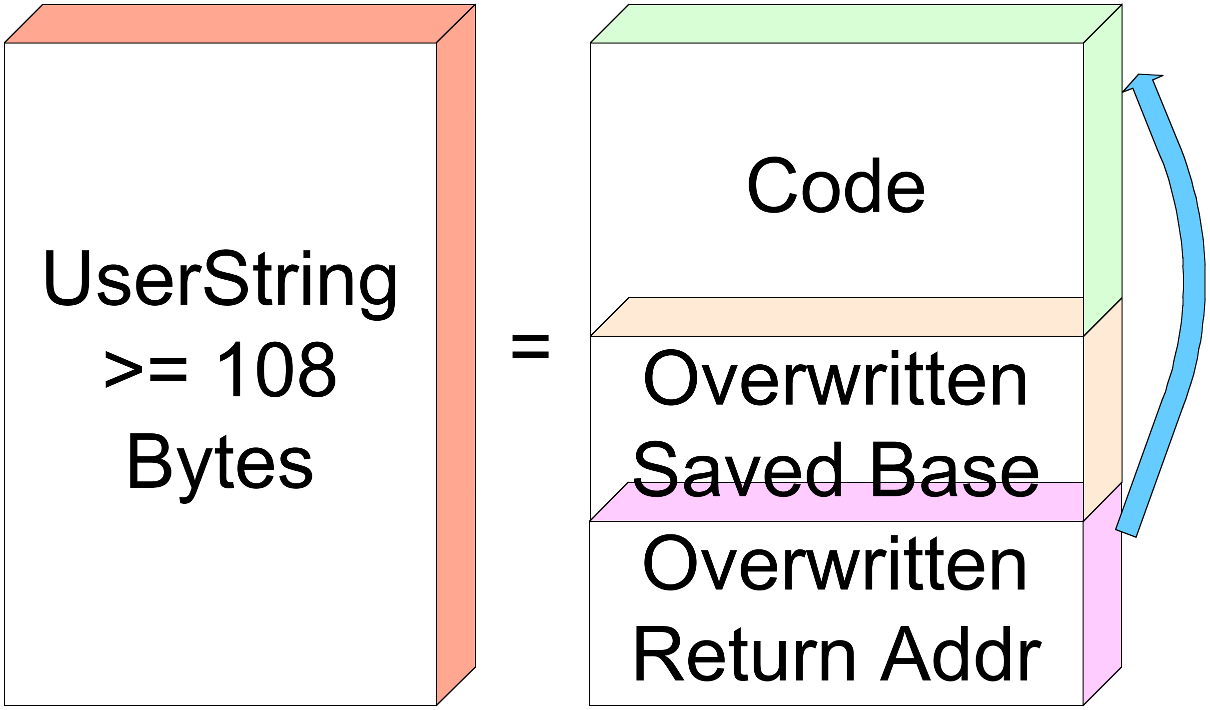
Code

Traditional Stack Smash

- At this point the attacker can redirect execution as they wish
  - Address usually cannot contain nulls
  - Other restrictions may be enforced (e.g input filters)
- Usually want to execute arbitrary code
- Redirect execution to an input buffer
  - Fill that input buffer with executable machine code

Traditional Stack Smash

Function B()



Traditional Stack Smash

- The attacker's code does ***not*** have to be stored in the overflowed stack buffer
  - It just needs to be at a reasonably predictable address
  - Must be in an executable memory page
  - Stack and Static buffers are the most convenient for this
    - Static buffers are at an *absolute* address
  - Some heap buffers are also highly predictable

Format String Attack

- Simple programming error
- Becoming less and less common
- Functions with variable number of arguments cannot know how many they were passed
  - Have to be given guidance
  - If the guidance is wrong (i.e indicates more arguments than there are) function will just keep walking down the stack operating on unrelated data

Format String Attack

- Formatted output functions (fprintf, printf, sprintf etc) use a “format” string argument
  - Format string is directly copied to the output except for “%<format><type>” tokens which are substituted with a string created from the next argument
  - One format type ***writes*** to an address specified in an argument (%n), it writes the number of bytes that would have been copied to the output so far

Format String Attack

- If a programmer wants to output or otherwise copy a user string they may accidentally specify it as the format argument
  - This will work perfectly as long as there are no % modifiers in it
  - printf(UserString); vs printf("%s", UserString);

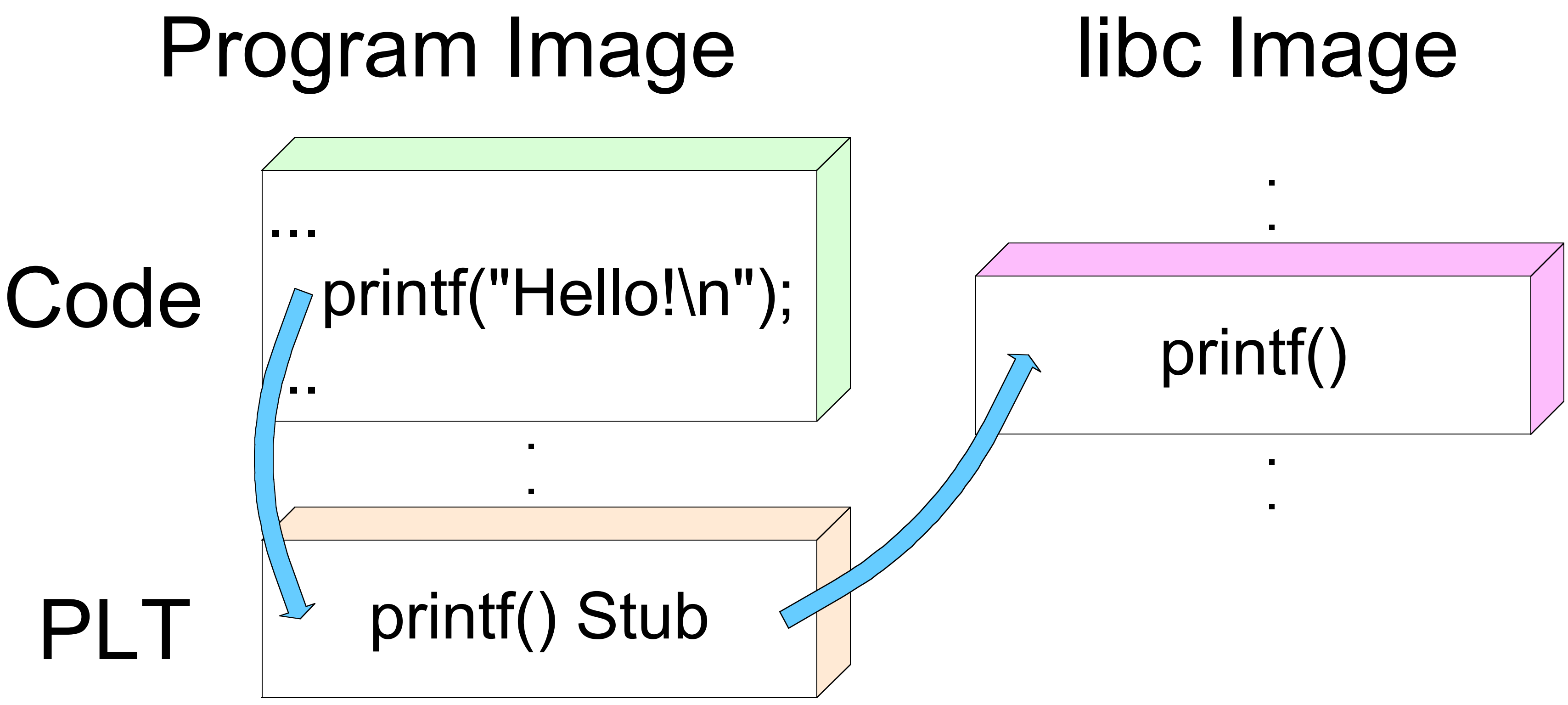
Format String Attack

- If the attacker can control the format string they can use %n to write arbitrary data to arbitrary addresses
  - Can’t normally have nulls in data/addresses
  - Need to have known control over some stack values in order to be able to specify the target address

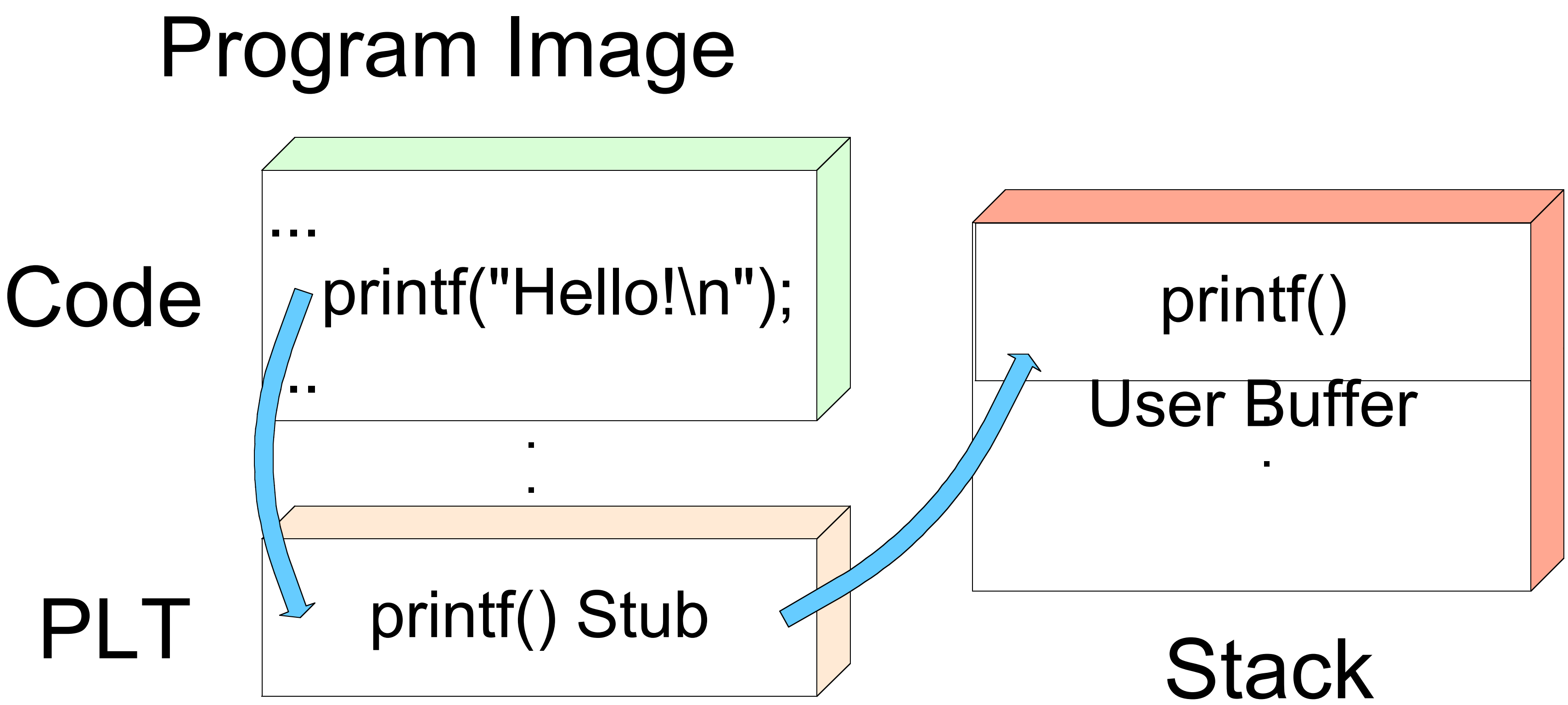
Format String Attack

- Redirect execution to hostile code by overwriting:
  - Return address on stack (jump into one of their buffers)
  - A GOT/PLT entry (used to call external functions, *known location*)
  - Function pointer somewhere in program
  - atexit pointers
  - … the list is endless

PLT/GOT Overwrite



PLT/GOT Overwrite



Heap Overwrites

- The system allocates memory to processes in large blocks (page sized)
- But applications typically want to allocate small blocks of memory for miscellaneous storage
- A heap implementation manages dividing the large blocks of memory for use
  - Which parts are in use and which aren’t

Heap Overwrites

- The information about the blocks must be stored somewhere
  - Makes most sense to store it in the bytes immediately around the block itself
- The MetaData is usually used not just to describe the block nearby but also to link the blocks together

Heap Overwrites

- If the meta data can be overwritten the logic that links the blocks together can often be manipulated to overwrite arbitrary memory locations
  - Fooling the heap implementation into thinking the target area is a block
- Similar situation as for format strings results

Integer Evaluation Problems

- Getting a lot of attention lately
- Based around C/C++ integer calculation characteristics
  - *int* 2147483647 + 1 = -2147483648
  - *unsigned int* 4294967295 + 1 = 0
  - *int* 65536 = *short* 0
  - *int* 1073741825 * sizeof(*int*) = 4

Integer Evaluation Problems

- Two common scenarios:
- Fool program into allocating a much smaller block of memory than needed, resulting in a heap overwrite
  - Usually involves providing a large number which later calculations cause to loop back to a small number
  - Opens door for heap overwrites

Integer Evaluation Problems

- Fool program into writing to memory outside the bounds of a block
  - Usually when the integer is used as an array index, providing a negative number that passes x < array length tests
  - Often results in ability to write data to a selection of memory address

Most Common Factors

- A user buffer at a reasonably predictable location
  - In memory with execute permission
- Use of vulnerable standard functions
  - strcpy(), strncpy() etc
- The ability to access standard system services in hostile code
  - fork(), exec(), open() etc

Libsafe

http://www.research.avayalabs.com/project/libsafe/

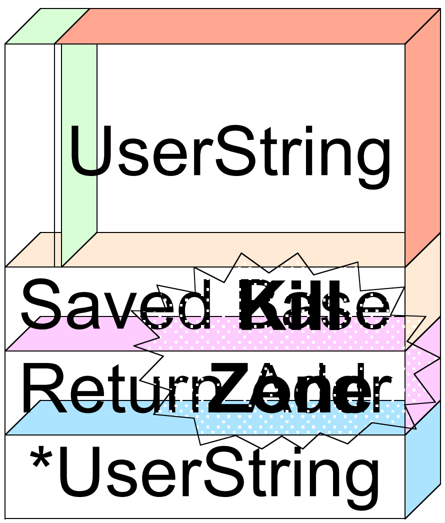
- Shared library that intercepts calls to vulnerable functions
  - strcpy(), strncpy(), stpcpy(), wcscpy(), wcpcpy(), strcat(), strncat(), wcscat(), vfprintf(), sprintf(), snprintf(), vsprintf(), vsnprintf(), gets(), getwd(), realpath(), fscanf(), vfscanf(), sscanf()
- Loaded via LD_PRELOAD environment variable or /etc/ld.so.preload file
  - Loaded before libc, application transparently uses the replacements

Libsafe

- Replacement functions check if any of the destination locations are on the stack
  - If they are verifies they’re ***within*** a frame (i.e saved frame pointers excluded)
  - If the destination would overwrite a frame a stack trace is generated, a log is sent to syslog() and the program is terminated with SIGKILL
- Prevents stack frame smashing via the vulnerable functions

Libsafe

Function B()



Stack

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char buffer[100];
strcpy(buffer, UserString);
```

Code

Libsafe - Strengths

- *Very* easy to install and enable
- Minimal impact on applications/system

Libsafe - Weaknesses

- Protects *only* the specified functions against *only* stack frame overwrites
  - The vulnerable functions may still overwrite other important data structures (e.g heap overflows, format string exploits)
  - Does not protect any application functions
- Cannot protect code compiled with -fomit-frame-pointers

Libsafe - Weaknesses

- Format string parsing code is buggy, “%1n” can bypass checks
- While libsafe is limited in scope, its adverse impact is so minimal that deploying it is a nill sum equation

Openwall Kernel Patches

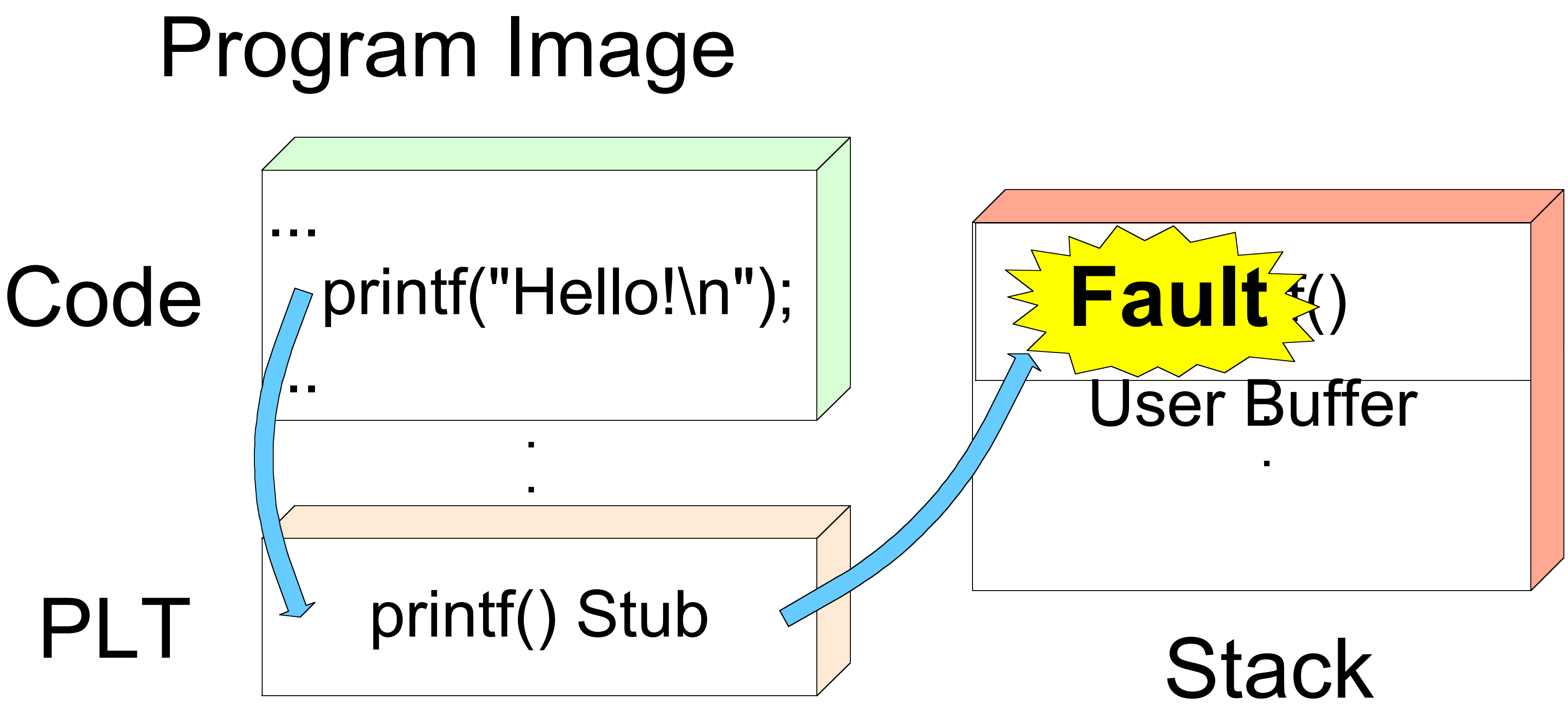
http://www.openwall.com/linux/

- Part of the Openwall Linux distribution
- Set of patches to the kernel designed to restrict a variety of attack avenues
- Most important for our discussion (and the most talked about feature) is the non-executable stack

Openwall Kernel Patches

- Non-executable stack
  - Similar to that included in Solaris and HP-UX
    - Solaris (since 2.6) noexec_user_stack kernel parameter
    - HPUX (since 11i) executable_stack kernel parameter
  - The CPU will refuse to execute code located in the stack region
    - Programs that attempt to do so will receive a Segmentation Violation
    - Logged to syslog

Openwall Kernel Patches



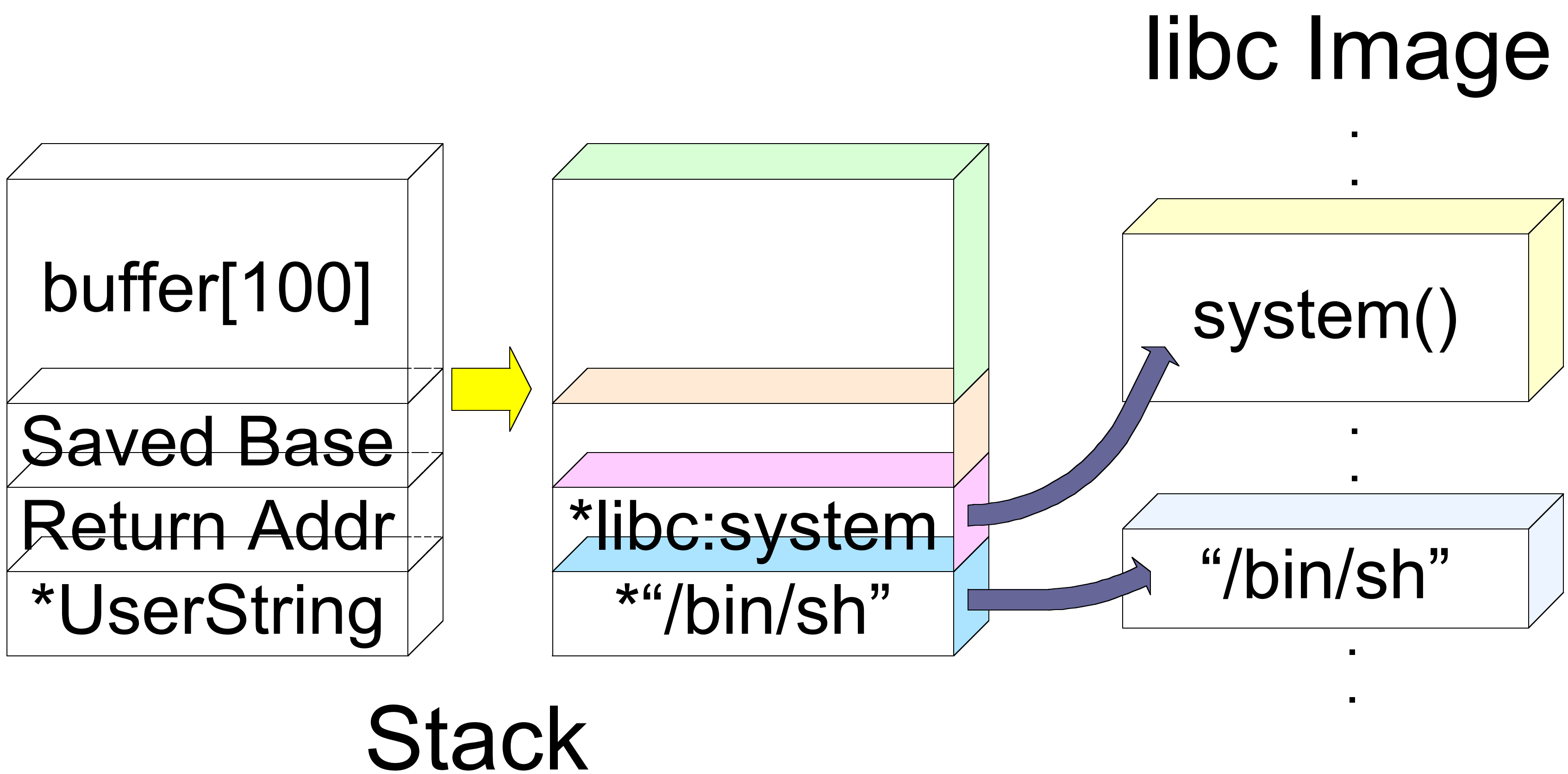
Openwall Kernel Patches

- Some programs normally attempt to execute code on the stack
  - Debuggers (inject code into the debugged process)
  - GCC Trampolines (nested functions)
  - Kernel sigreturn() code
- Trampolines/Signal code can be handled automatically
  - Detect call into stack rather than ret onto stack
- Stack protection can be switched off for programs to be debugged

Return Into libc

- The process space of an executable already contains all the useful routines an attacker would like to execute
- Why bother trying to insert new code?
- Given a known version of the OS and a known version of libc the location of routines in libc is absolutely predictable

Return Into libc/code



Openwall Kernel Patches

- To try to combat return into libc style attacks the Openwall patches map shared libraries on addresses containing 0x00
- Since 0x00 is a string terminator standard string overflows can no longer construct the address or arguments

Return into code

- While libc address may be impossible to construct directly there are still many other targets
  - PLT is at known location, may even contain stub for useful functions like system()
  - Program image itself may contain useful code, for example su contains code to setuid() and spawn shell

Openwall Kernel Patches - Strengths

- Reduces ability of attacker to execute their own code in program buffers
- Minor CPU impact
- Other features of patches not discussed today also improve system security

Openwall Kernel Patches – Weaknesses

- Code in static buffers or on the heap may still be executed
- Return into code style attacks still possible
- Some programs validly try to execute generated code, they fail

PaX

http://pageexec.virtualave.net/

- Kernel patches that result in non executable:
  - Stack
  - Heap
  - BSS (Static Storage)
- This effectively wipes out all places an attacker could get arbitrary code stored
- Basically only return into code attacks are viable

PaX

- To prevent return into code attacks PaX introduced total Address Space Layout Randomization (ASLR)
- Automatically randomizes base addresses of the stack and heap
- Also randomizes the load address of all libraries
  - Making it impossible to predict the location of libc or other libraries inside the target executable
  - Thus return into libc exploits are avoided

PaX

- The only remaining avenue for attack against PaX is return into code, most likely the PLT
- But PaX can even be told to load the executable itself at a random address
- This previously hasn’t been possible because executable code has expected addresses compiled in

PaX

- To make it work PaX keeps two copies of the executable in memory,
  - One non executable (at the original location)
  - One executable (somewhere else)
- The executable one faults when it tries to jump to a location in the non executable area (with an absolute address)
  - PaX intercepts the crash and redirects to the new executable location

PaX

- PaX can have it’s various features switched off on a program to program basis

PaX - Strengths

- Makes arbitrary execution flow and arbitrary code execution attacks *extremely* difficult

PaX - Weaknesses

- Total address space layout randomization has a significant performance impact
  - Executable remapping is not stable
- Some programs validly try to execute generated code, they fail

Program State

- All of the attacks described provide the attacker the ability to corrupt program state
- Doesn’t *have* to result in code execution
  - Overwrite stored credentials
  - Overwrite authentication state

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Other Generic Protections

- Compilation Time
  - StackGuard & FormatGuard
    http://www.immunix.org
  - ProPolice
    http://www.trl.ibm.com/projects/security/ssp/
- Monitoring
  - SysCallTrack
    http://syscalltrack.sourceforge.net/
- Access Restriction
  - SysTrace
    http://www.citi.umich.edu/u/provos/systrace/

Why aren’t they widely deployed?

- Fear of impact on production systems
- Unsupported software
- Compatibility
- However…in the vast majority of cases these approaches provide a strong “immune” system with little adverse impact

Biodiversity

- In nature a “virus” that has survived the immune system hasn’t won just yet
  - The conditions in the host must still be favourable
  - If the host behaves differently from conditions the “virus” expects, infection may be avoided

Biodiversity

- Unfortunately most operating environment installations are extremely predictable
  - Homogenous pre-compiled binary software
  - Commodity hardware
- If your installation behaves ***differently***, attacks can be confused and stifled
  - Normally only helps against remote attacks

Biodiversity

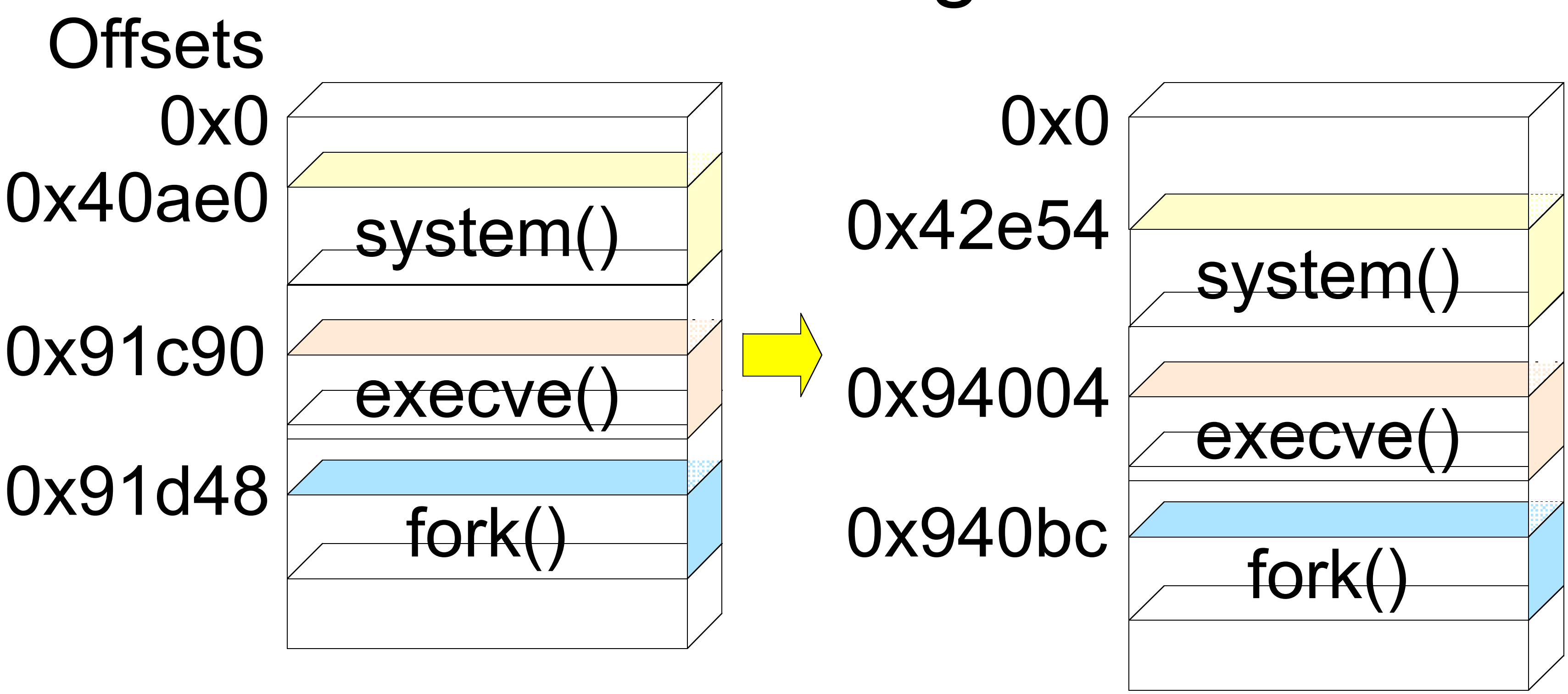
- Simply recompiling all the applications you have access to the source to will help
  - Make addresses less guessable (particularly if you use the latest compiler with special options)
- But it’s also possible to modify the program execution environment in more general ways
  - We’ll discuss a couple, many more are possible
  - Not designed to hold back the tide, just be different

Moving Libraries

- Libraries are not mapped at fixed addresses
  - But they are highly predictable
- Each library is mapped from a known base, one by one moving upwards in the process image
- A remote attacker that knows the operating environment version of the target knows where each library (and each routine) will be

Moving Libraries

libc Image



Moving Library Images

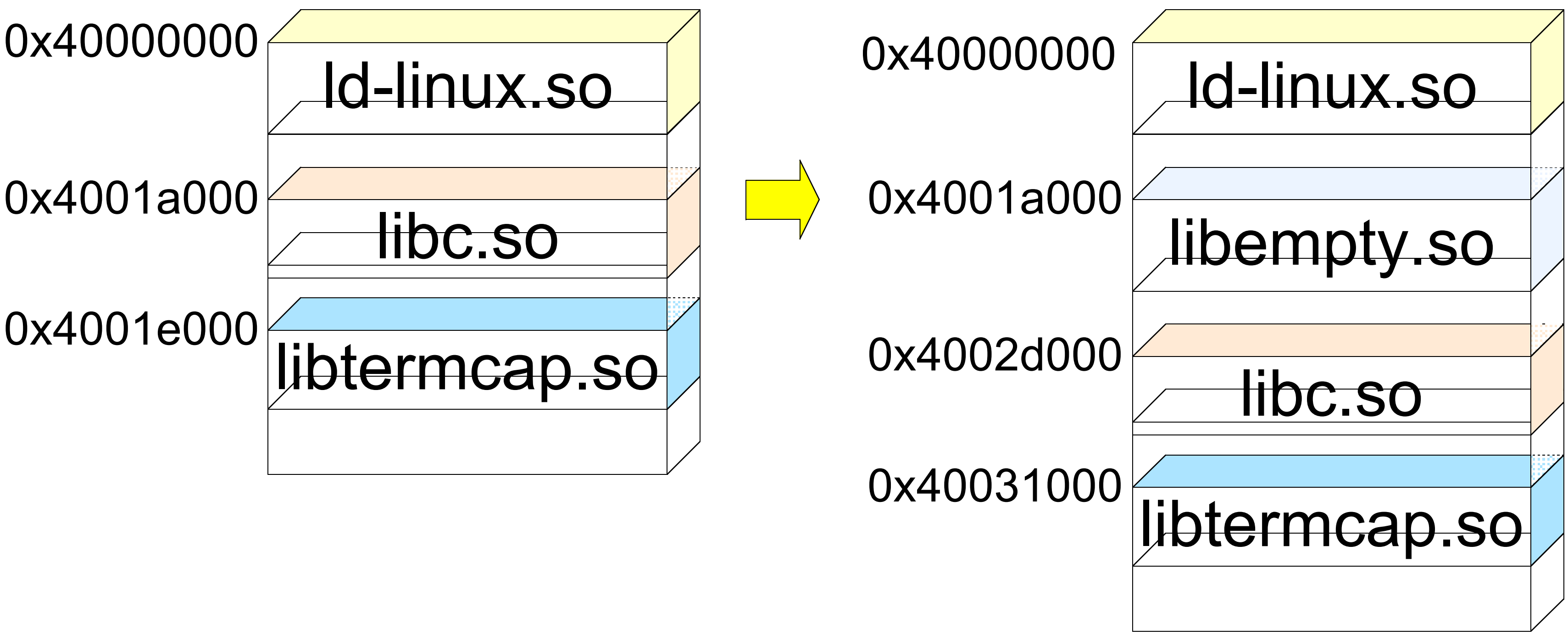
- We can in fact move the image of a library, padding it’s start as much as we like
- So that the routines are no longer at the predictable location.
- An attacker can still determine the address but will have to brute force it
  - Depending how many bytes of padding are added, this could take a while

Moving Library Bases

- We can also move the base of the library by forcing a padding library into every process
- All we need to do is create an empty shared library which will take up some space and force it in via:
  - LD_PRELOAD
  - /etc/ld.so.preload
  - addlibrary

Moving Library Bases

Process Library Space



Moving the Stack Base

- The stack starts at a fixed location and grows down (on most architectures/OSs)
  - 0xc0000000 on Linux
- Stack smashes usually rely on being able to know (or brute force) the address of data on the stack
- We can trivially move the stack with a preloaded library

Moving the Stack Base

- Does not help for most format string attacks
  – They often give away stack information
- Does not help for stack locations of data constructed during program load
  – Program Arguments
  – Environment Variables

Switching Syscalls

- All privileged operations (I.e operations that affect anything external to the process) are performed for the kernel on behalf of the process
- The application requests the operation by performing a system call
- System calls are called by number

Switching Syscalls

- Syscall numbers are usually fixed and known
  - fork = 2
  - execve = 11
- Applications should ***not*** make system calls directly
  - They're system/platform/version specific
  - libc wraps them in functions

Switching Syscalls

- In a fully dynamically linked environment libc should be the only userland code with syscall interfaces
- Code injected by attackers will normally try to call syscalls directly
- If we use a kernel module to switch syscalls around and patch libc the system operates but injected code will fail

Future Generic Protections

- Program Shepherding

  http://www.cag.lcs.mit.edu/commit/papers/02/RIO-security-usenix.pdf

- Program characterization and sandboxing with
  - Subterfuge
  - Janus
  - SysTrace

Thanks for listening!

- Questions?
- SecureReality Web Site:

  http://www.securereality.com.au
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