CIS 4360
Secure Computer Systems

Buffer Overflows

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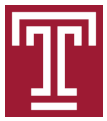
Some slides are courtesy of Dr. David A. Wheeler

Hard link vs. soft link

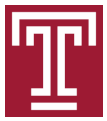
- How are they implemented?
  - When you create a hard link, you add a directory entry that points to the inode of the target file
  - When you create a soft link, you create a file whose metadata (stored in the created file's inode block) records that it is a soft link and the target file's name
- The hard link will never be dangling (there is a reference count in the inode of the target file), while the soft link may get dangling
- The hard link can only point to a file in the same partition, while a soft link can point to any file or dir



Previous Class

How doe the sticky bit improve the security of using the directory /tmp?

Once a user creates a file in /tmp, only the directory owner (root in this case) or the file owner can delete or rename the file

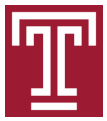


Previous Class

Describe, even with the sticky bit, why /tmp is till insecure to use? What is the lesson?

(1) If the attacker knows the name of the file to be created by a victim, the attacker can create a file with that name to hurt the confidentiality and integrity in case the exclusive flag (O_EXCL) is not used in "open" (e.g., the "stat-open" vul.)
(2) Even if the exclusive flag is used in "open" by the victim, the attacker can launch DoS attacks by creating a file with the same name ahead of the victim

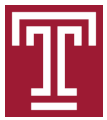
Lesson: try your best not to use publicly writable directory



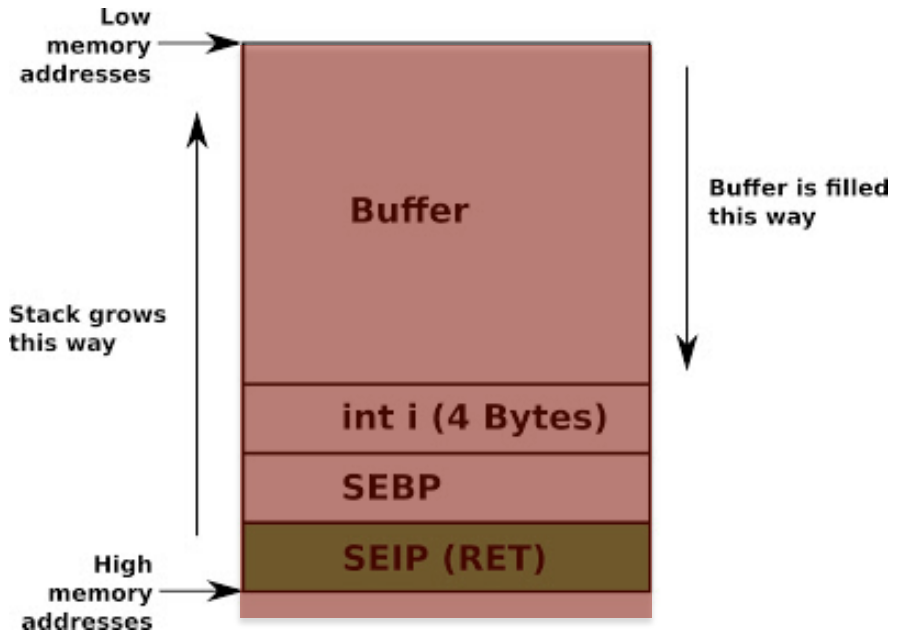
Buffer Overflow

- Also called "Buffer Overrun"
- It occurs when the access to a buffer is out of the bounds of the buffer, e.g.

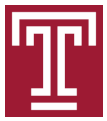
```
char dst[5];
strcpy(dst, "some user provided input");
```



Common and dangerous

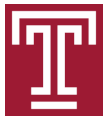


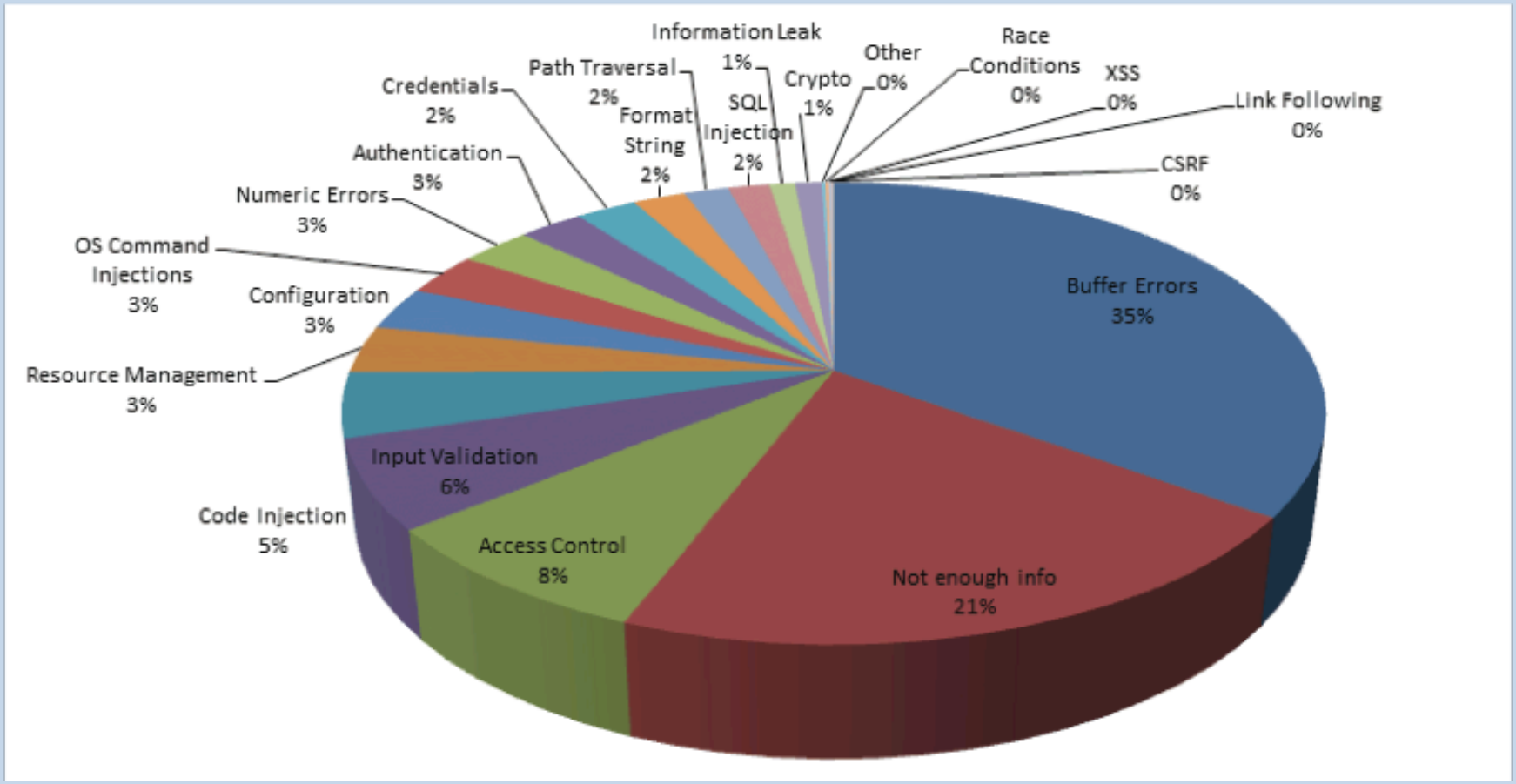
E.g., strcpy(buffer, long-src-str);



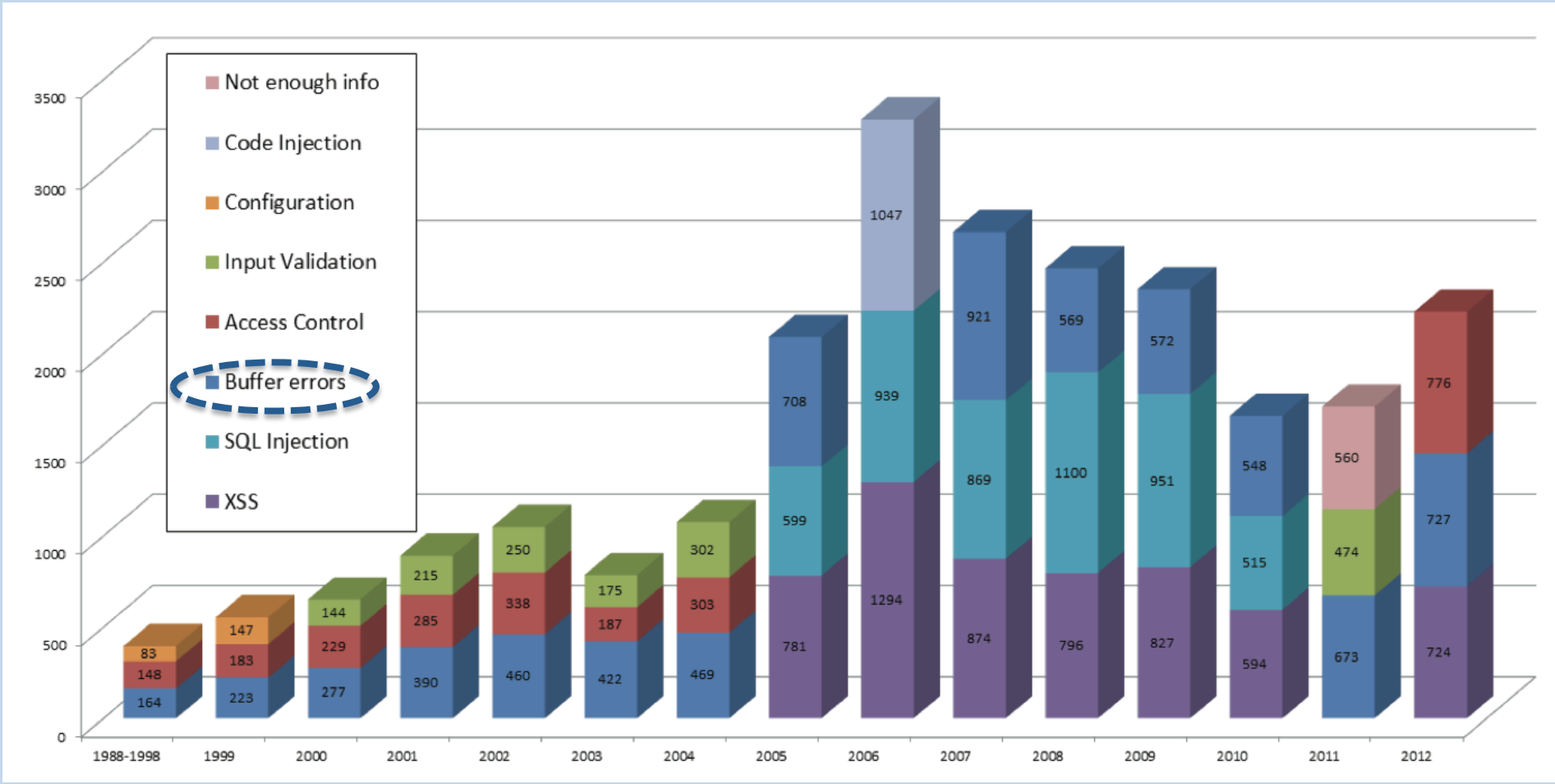
Types of buffer overflows

- Direction
  - Access beyond upper bound: overflow
  - Access beyond lower bound: underflow
  - People usually call both as Buffer Overflows
- The out-of-bound access can be read or write
  - Overread (leak info)
  - Overwrite (manipulate memory content)
- The access can occur on stack or heap
  - Stack-based / heap-based buffer overflows



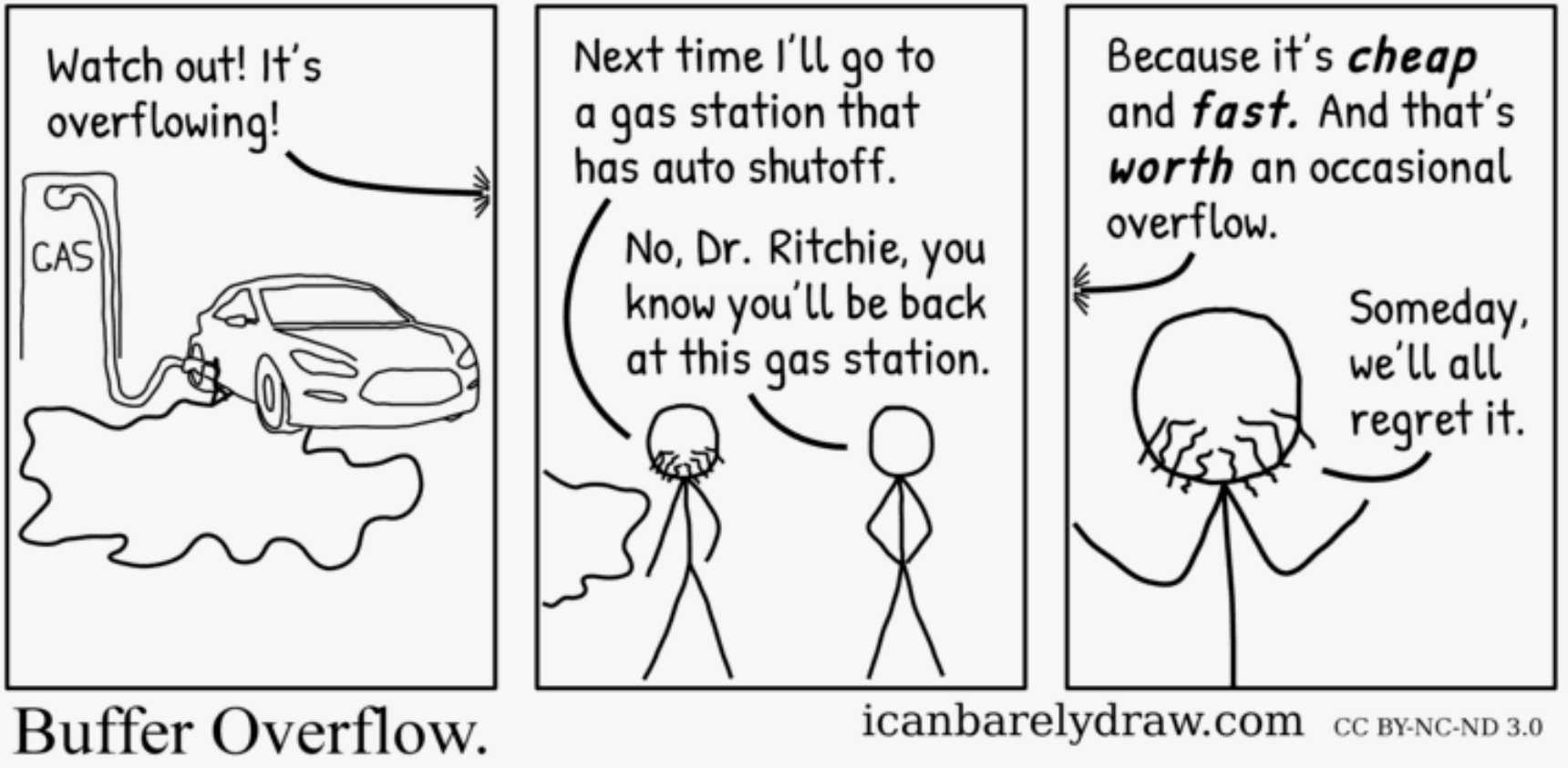


“If buffer overflow vulnerabilities could be effectively eliminated, a very large portion of the most serious security threats would also be eliminated.” C. Cowan



"If buffer overflow vulnerabilities could be effectively eliminated, a very large portion of the most serious security threats would also be eliminated." C. Cowan

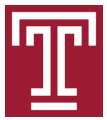
"It is now safe to declare the buffer overflow the vulnerability of the quarter-century." Y. Younan



Almost all the operating system kernels, device drivers, compilers, JVM, and Python interpreters are coded in C and C++

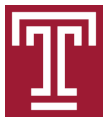
Famous attacks due to buffer overflows

- 1988: Morris worm – took down Internet
  - Includes buffer overflow via gets() in fingerd
- 1999: RSA crypto reference implementation
  - Subverted PGP, OpenSSH, Apache's ModSSL, etc.
- 2001: Code Red worm – buffer overflow in Microsoft's Internet Information Services (IIS) 5.0
- 2003: SQL Slammer worm compromised machines running Microsoft SQL Server 2000
- ~2008: Twilight hack – unlocks Wii consoles
  - Creates an absurdly-long horse name for "The Legend of Zelda: Twilight Princess" that includes a program
- 2014: Heartbleed - buffer overread vul. in OpenSSL lib
  - Half a million web servers are vulnerable to Heartbleed attacks



Background – representation of C string

- In C/C++ programming
  - strlen("Hello") returns 5
  - The space needed by "Hello" is 6
  - Each string needs a \0 to flag the ending
- memcpy(str_dst, str_src, strlen(str_src));
  - Bug 1: buffer overflow when str_dst is too small
  - Bug 2: the ending \0 is not copied



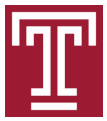
Background - Calling a procedure

- Given this C program:

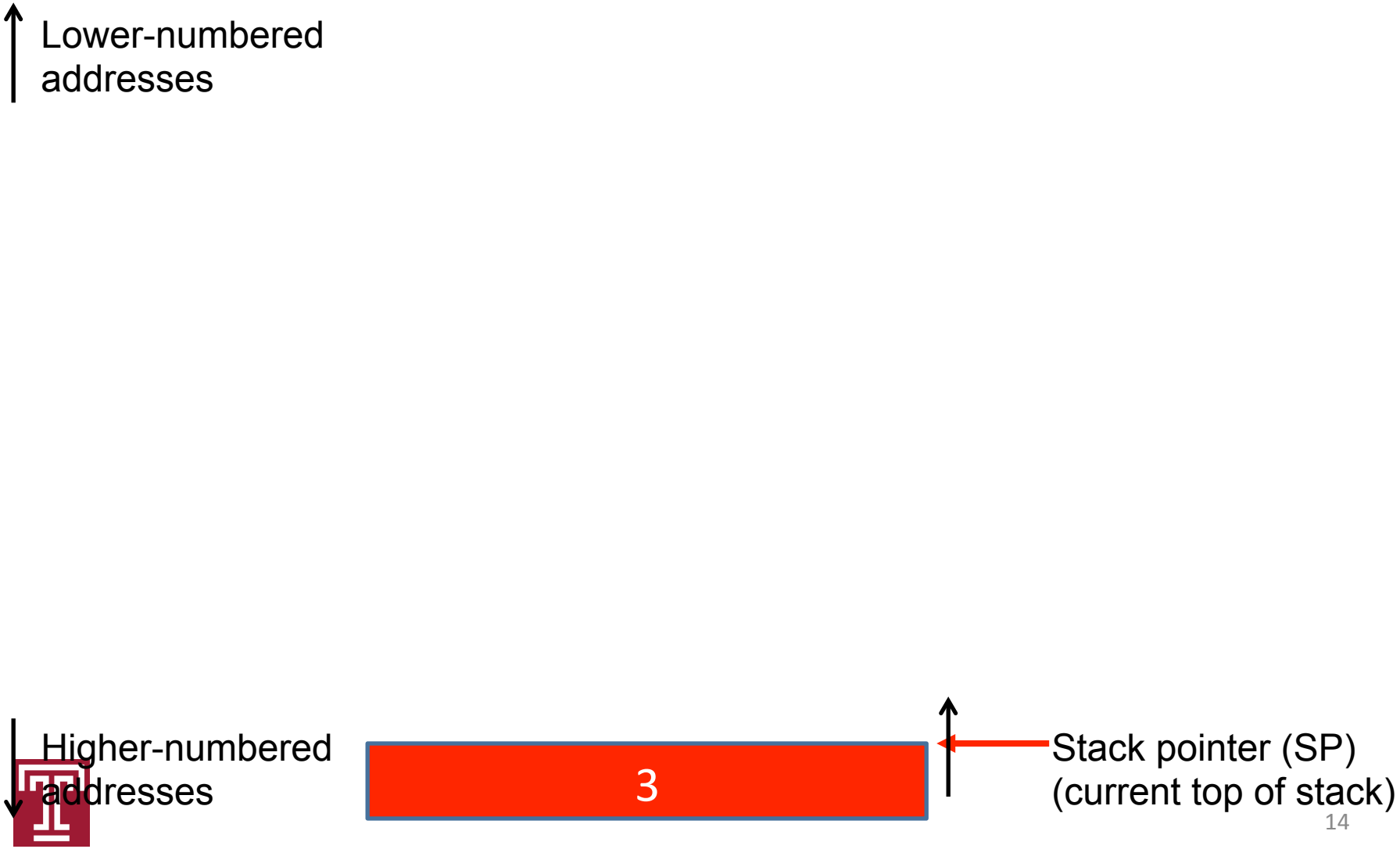
```
void main() {
  f(1,2,3);
  exit(0);
}
```

- The invocation of f() generates code (parameters are pushed from right to left):

```
pushl $3 ; // constant 3
pushl $2 ;
pushl $1
call f // push the IP on stack and jump to f()
```



Background: Stack



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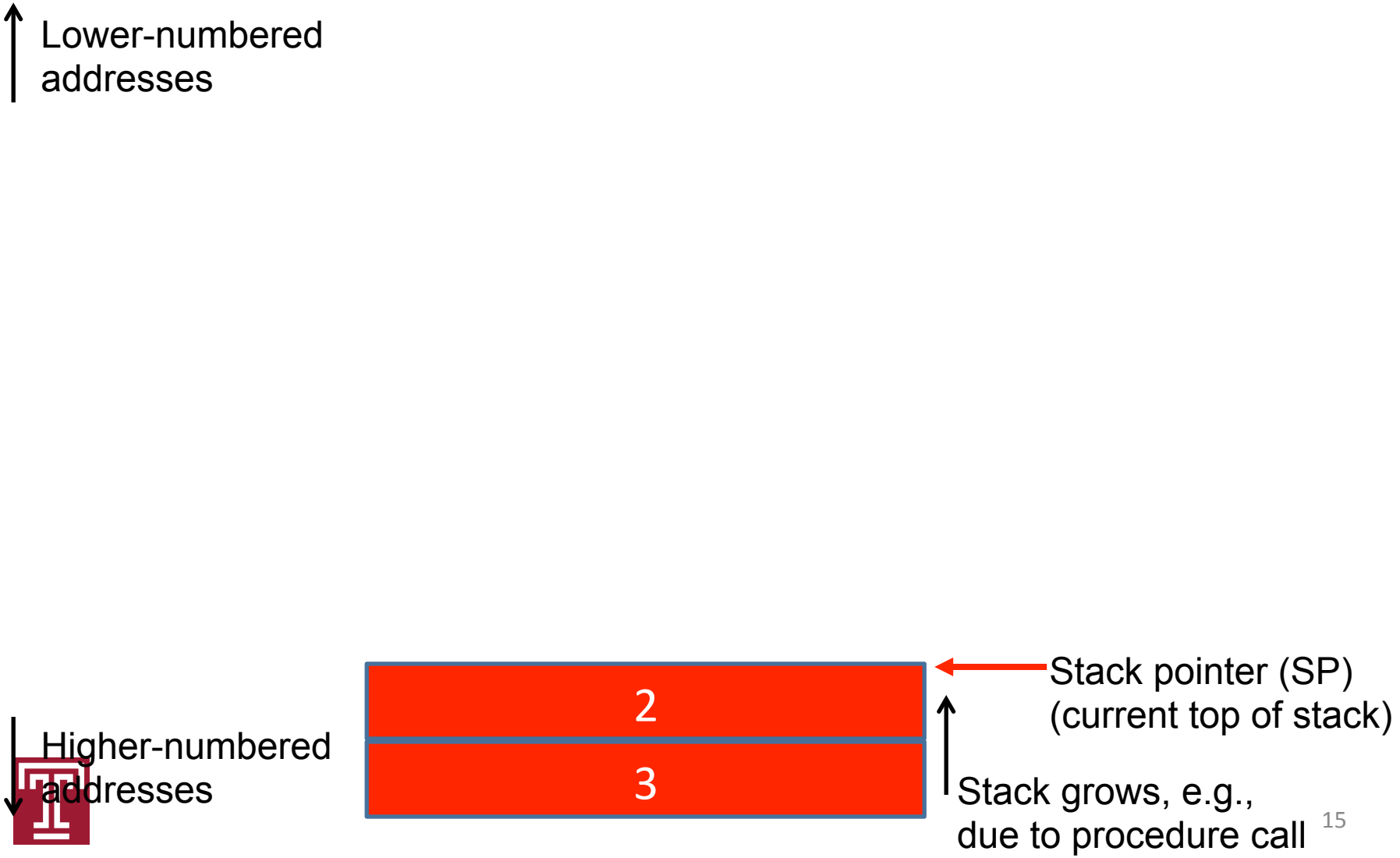

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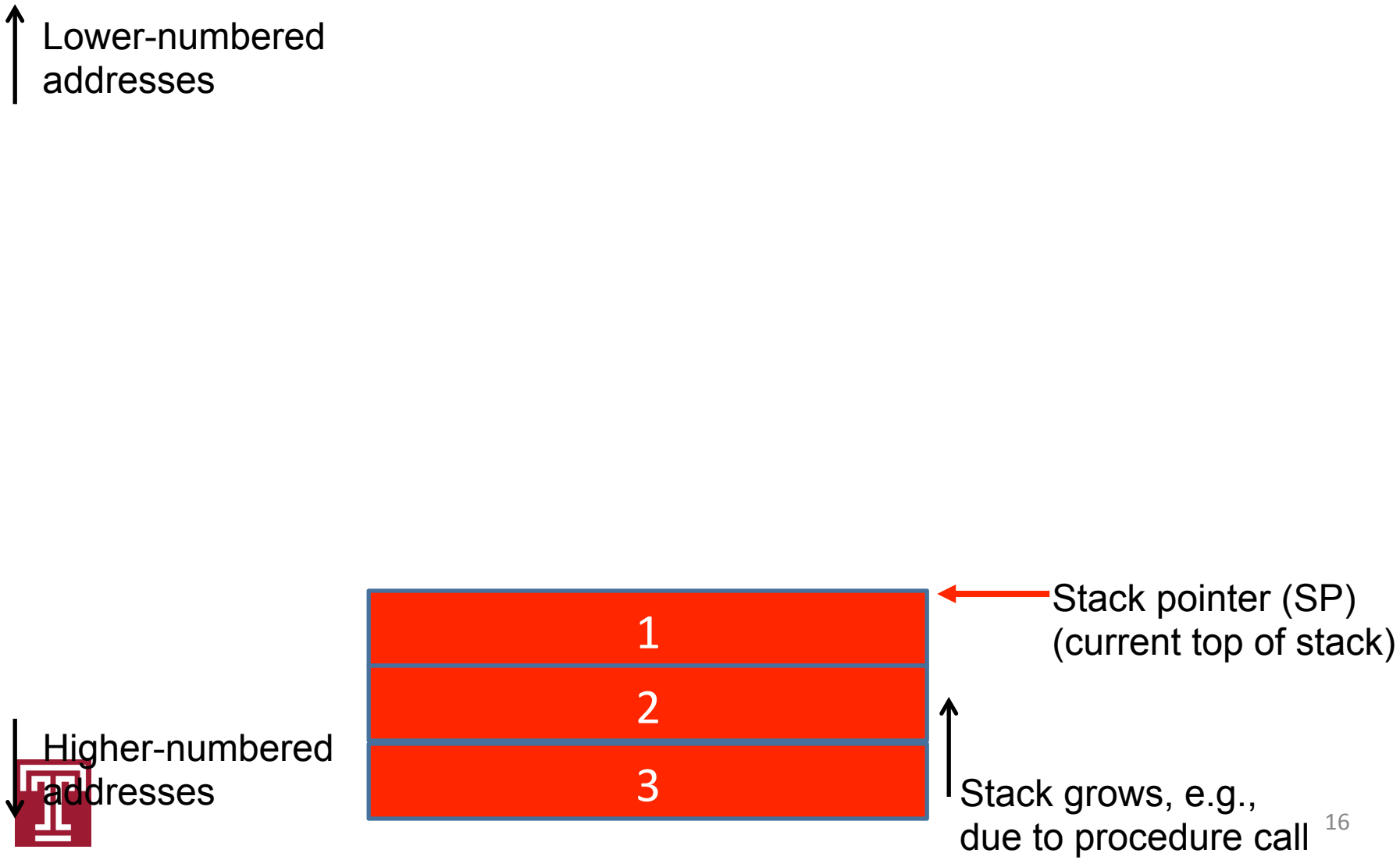

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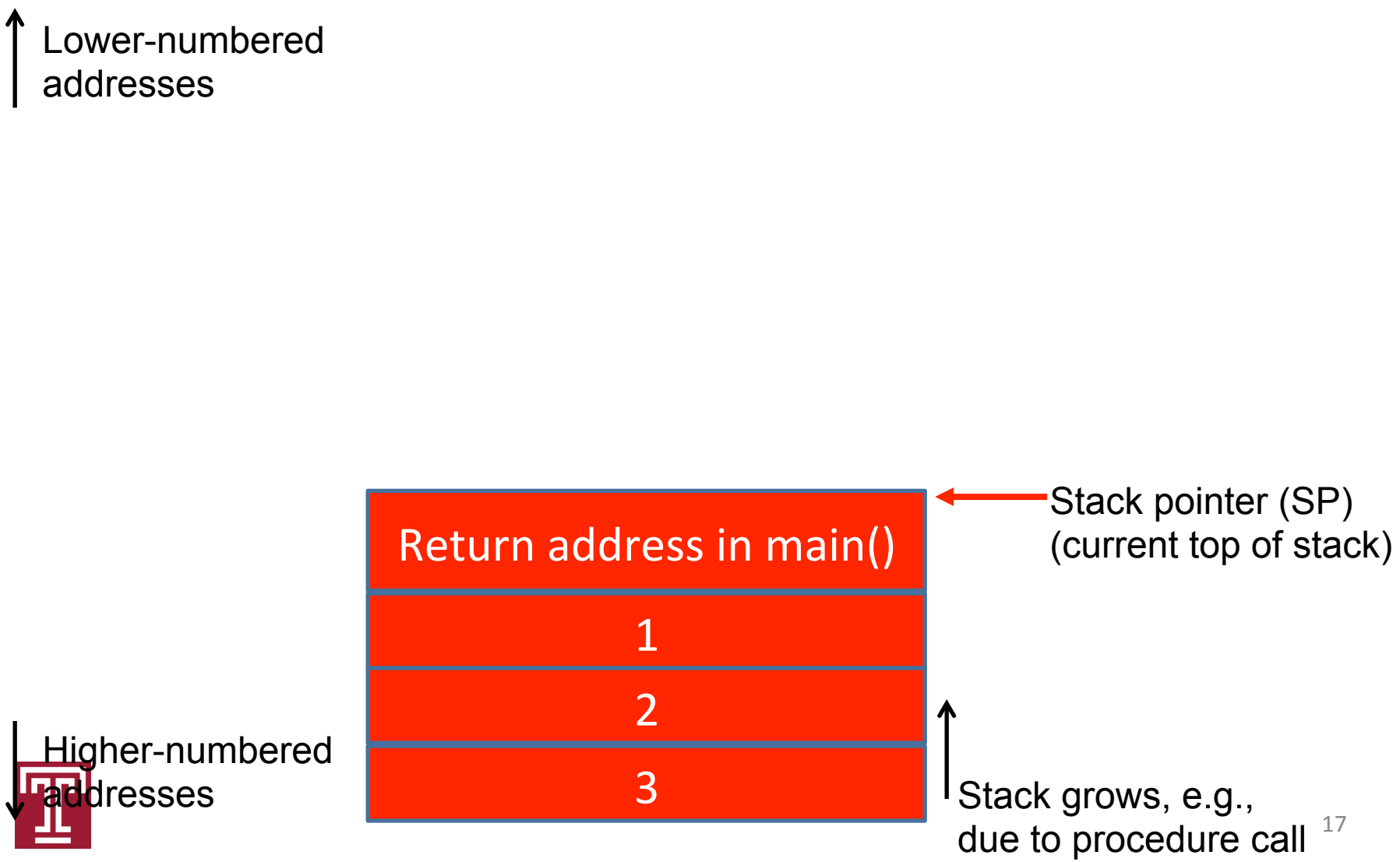


Background: Function prologue

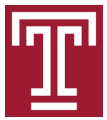
- Imagine f() has local variables, e.g. in C:

```
void f(int a, int b, int c) {
  char buffer1[5];
  char buffer2[10];
  strcpy(buffer2, "This is a very long string!!!!!!!");
}
```

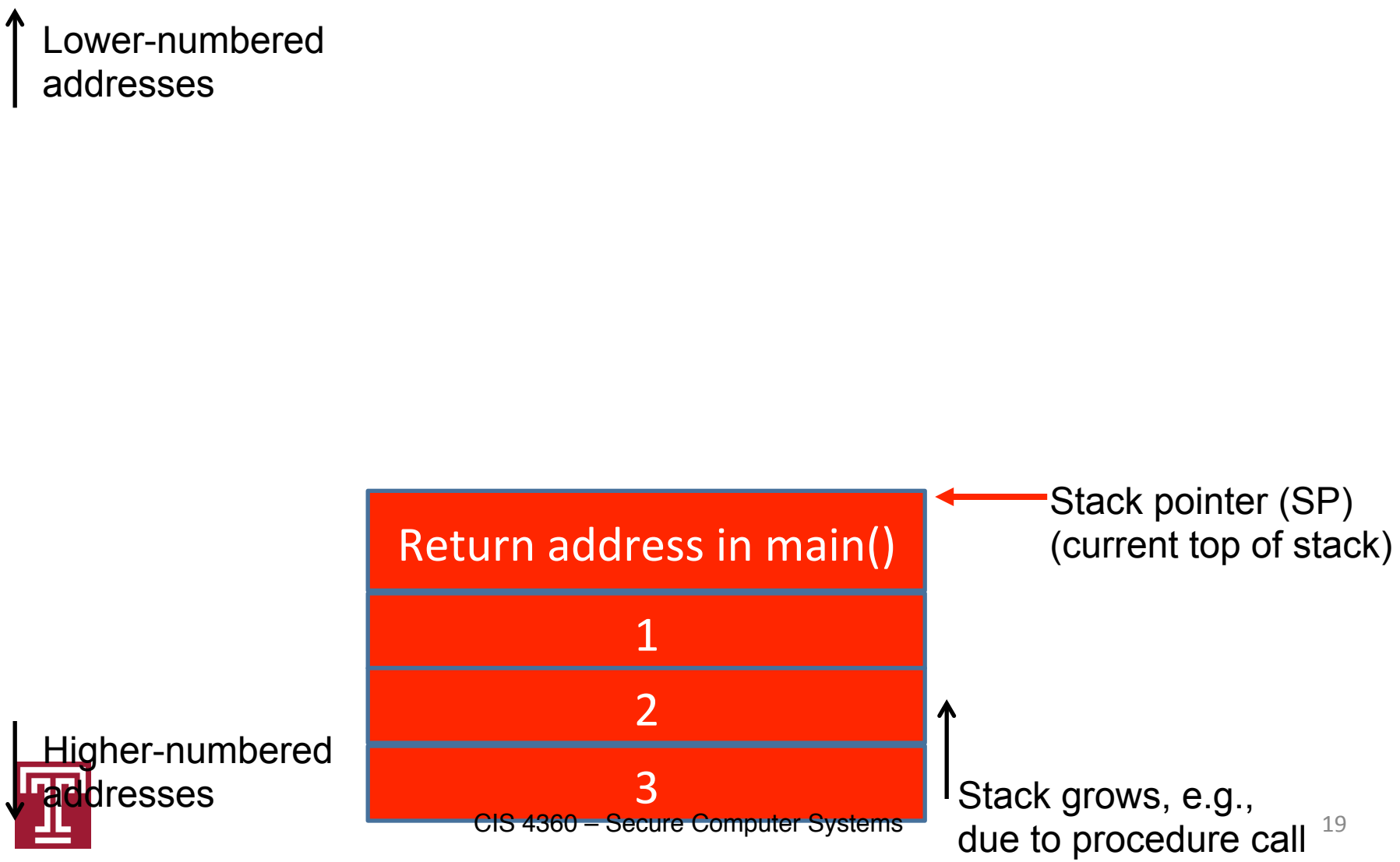
- Typical x86-32 assembly on entry of f() ("prologue"):

```
pushl %ebp  ; Push old frame pointer (FP)
movl %esp,%ebp ; New FP is old SP
subl $20,%esp ; New SP is after local vars
  ; "$20" is calculated to be >= local var space
```

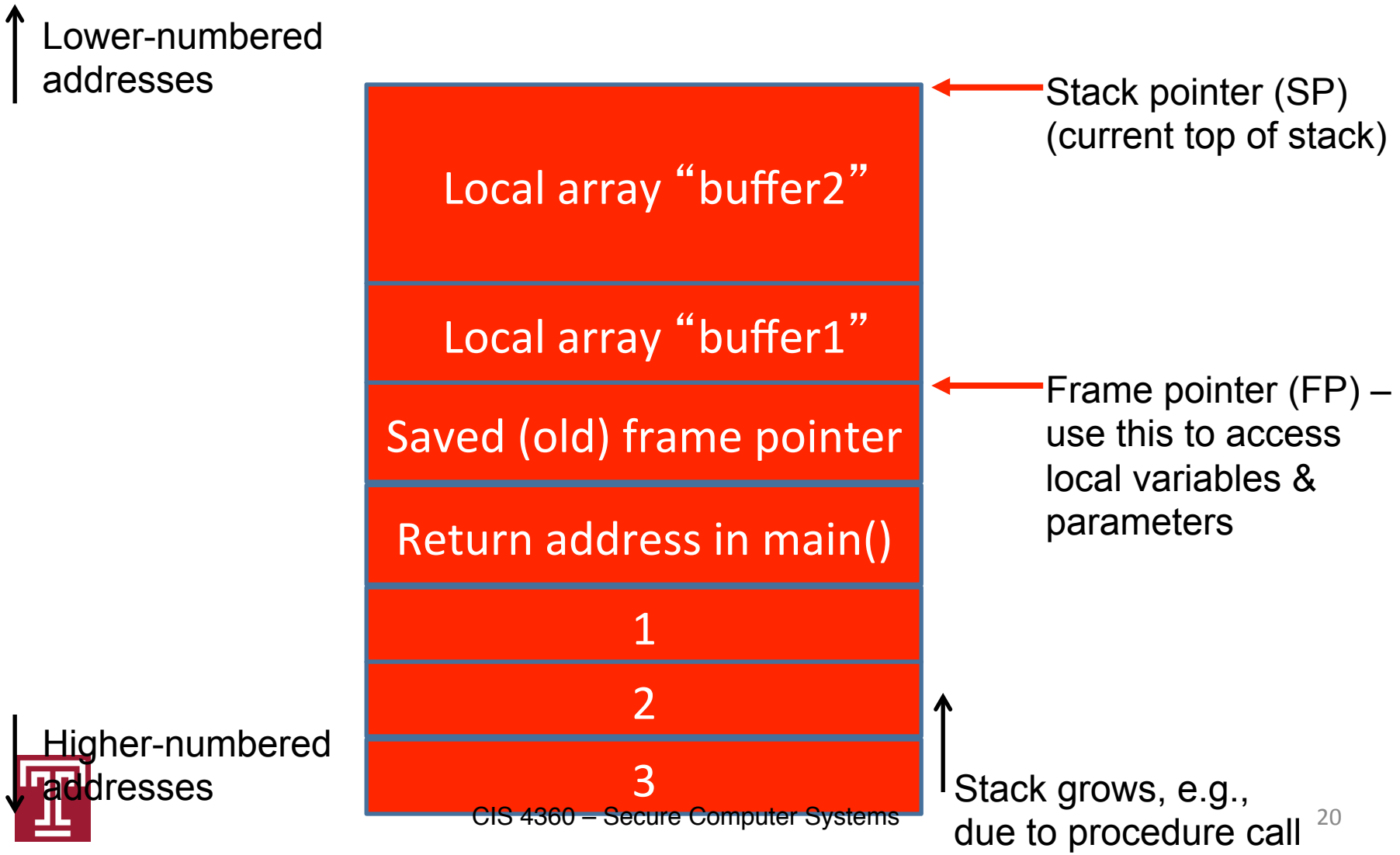
In the assembly above, ";" introduces a comment to end of line



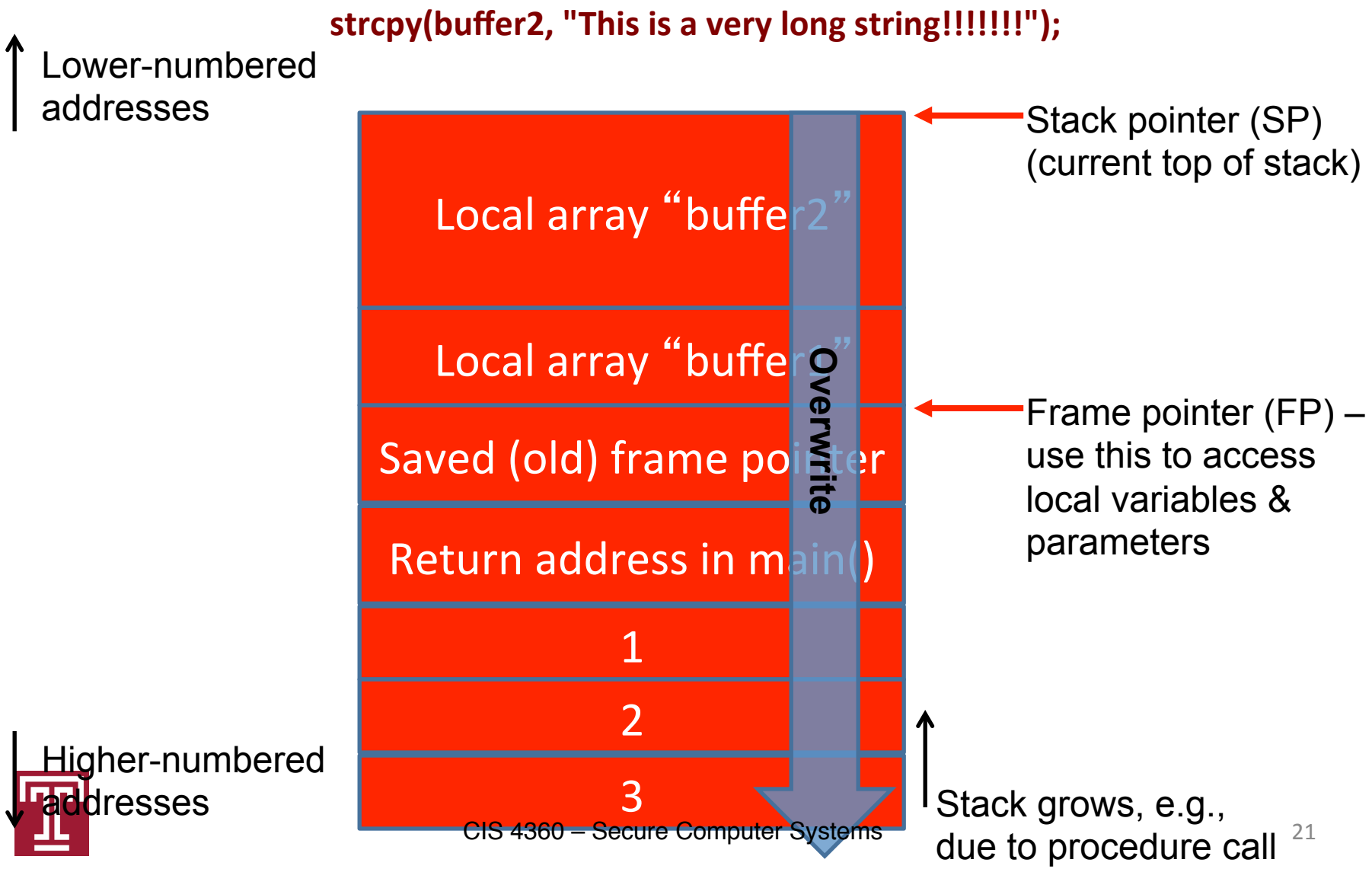
Immediately after call instruction



After prologue

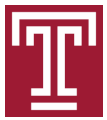


Overflowing buffer2



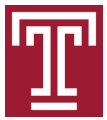
What happens if we write past the end of buffer2?

- Overwrites whatever is past buffer2!
  - As you go further, overwrite *higher* addresses
- Impact depends on system details
- In our example, can overwrite:
  - Local values (buffer1)
  - Saved frame pointer
  - Return value (changing what we return to)
  - Parameters to function
  - Previous frames

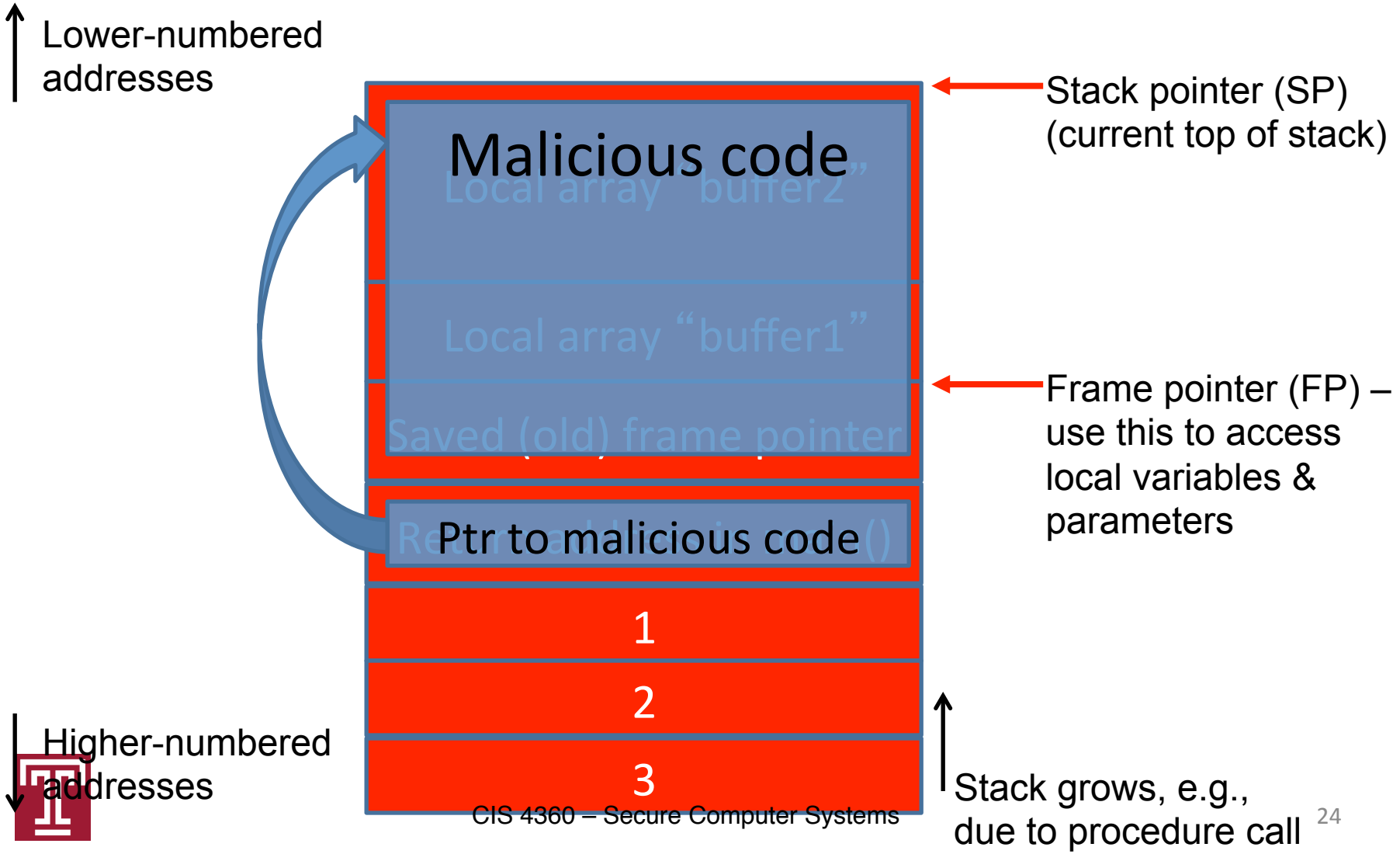


Inserting code in the buffer overflow attack (e.g., shell code)

- Attacker can also include machine code that they want us to run
- If setting the "return" value to point to this malicious code, the victim will run that code on return
- Significant portion of "Smashing the Stack" paper describes how to insert such code



Stack:
One possible result after attack



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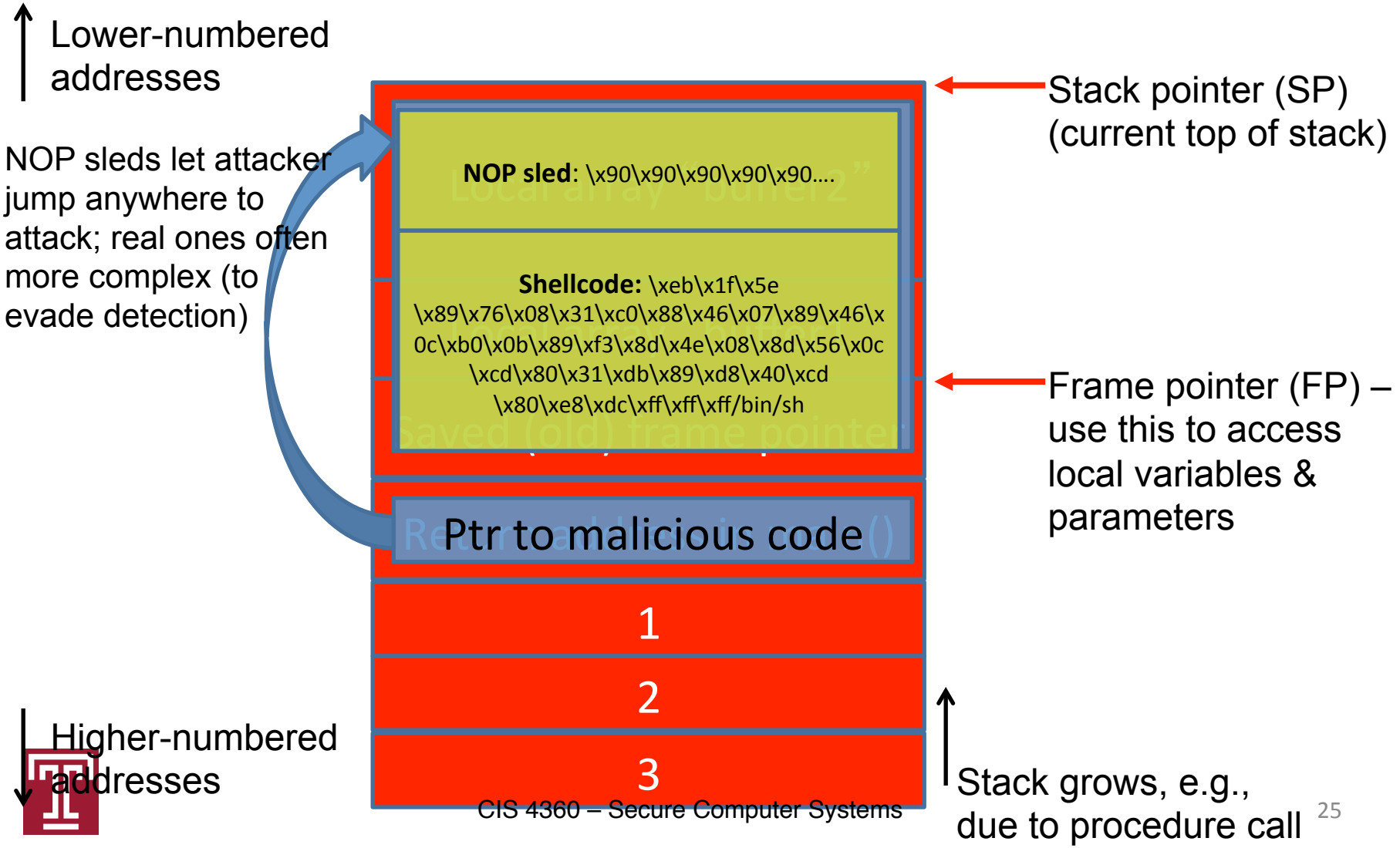
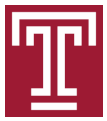


Other types of attacks possible with a stack buffer overflow

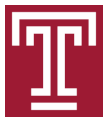
- Make "return" point to *existing* code that the attacker wants us to run *now*
  - Return to libc
  - Return-oriented programming
- Change value of adjacent local variables, e.g., a function pointer or a critical bool variable
- Change value of parameters

... and so on



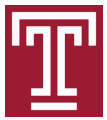
Smashing elsewhere

- "Heap" contains dynamically-allocated data
  - "new" (Java/C++), malloc (C), etc.
- "Data" contains global data
- If attacker can overwrite beyond buffer, he can control other values (e.g., stored afterwards)
  - Values of other structures
  - Heap: Heap maintenance data (e.g., what's free/used)



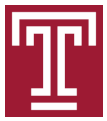
Obvious solution in C

- "Obvious" solution when using C is to always check bounds
  - E.g., if (strlen(src) + 1 > dst_buffer_size) return error;
- However…



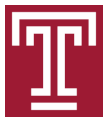
Many C functions don't check bounds

- gets(3) – reads input without checking. Don't use it!
- strcpy(3) – strcpy(dest, src) copies from src to dest
  - If src longer than dest buffer, keeps writing!
- strcat(3) – strcat(dest, src) appends src to dest
  - If src + data in dest longer than dest buffer, keeps writing!
- scanf() family of input functions – e.g., scanf("%s", buf);
  - scanf(3), fscanf(3), sscanf(3), vscanf(3), vsscanf(3), vfscanf(3)
  - Many options don't control max length (e.g., bare "%s")
- It's not just functions; ordinary loops can overflow



Do not use strncpy()

- First thing first, do not use strncpy(dst, src, n)
  - Very weird behaviors
  - copy at most n characters from src to dst (the ending null is not guaranteed)
  - extra space will be padded with 0's (so inefficient)

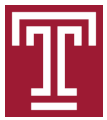


Solution 1: strlcpy/strlcat -- OpenBSD only

- Example code:

```
char    *dir, *file, pname[MAXPATHLEN];
if (strlcpy(pname, dir, sizeof(pname)) >= sizeof(pname))
        goto    toolong;
if (strlcat(pname, file, sizeof(pname)) >= sizeof(pname))
        goto    toolong;
```

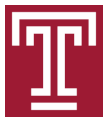
- A variant of strcpy/strcat that truncates the result to fit in the destination buffer
  - Always \0-terminates if dest has any space
  - strlcpy doesn't \0-fill the extra dst space
  - Easy to detect if terminates "in the middle" => Returns "bytes would have written"
  - if (strlcpy(dest, src, destsize) >= destsize) … // truncation detected!



Solution 2: Best solution – snprintf

- int snprintf(char * s, size_t *n*, const char * format, ...);
  - Writes output to buffer "s" up to *n* bytes
  - Always writes \0 at end if n>=1 (hooray!)
  - Returns "length that would have been written (excluding the ending null) if n is large enough" or negative if error, so result-checking can be slightly annoying
- Sample:

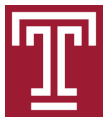
```
len = snprintf(buf, n, "%s", src);
if (len < 0 || len >= n) … // handle error/truncation
```



Question

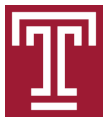
Write the equivalent code of “n = strlcpy(dst, src, len);”

```
n = snprintf(dst, len, "%s",      src);
```



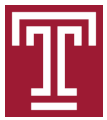
Solution 3: C++ std::string class (resize)

- If using C++, avoid using char* strings
- Instead, use std::string class
  - Automatically resizes
  - Avoids buffer overflow
  - E.g., str1 = str2; str1.append(str2);



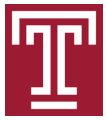
The System Has Done the Following…

- Canary
  - Insert a secret value (cookie) between the return address and the buffer on the stack at call entry, and check the canary integrity at the call exit
  - If the canary is corrupted, a buffer overflow is detected
  - Very effective against stack based overflows
- DEP: Data Execution Prevention
  - Data on stack and heap cannot be executed
  - Prevent injected code from being executed
- ASLR (Address Space Layout Randomization)
  - Scramble the locations of libraries and executables
  - So attackers do not know how to reuse their code



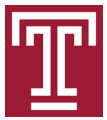
The Compiler Can Do the Following…

- Enabled by default in may systems, such as Ubuntu
- -fstack-protector --param=ssp-buffer-size=4
  - Any function that has a buffer whose size >=4 will be protected with canary checking
- -D_FORTIFY_SOURCE=2
  - Add overflow compile-time/runtime checking for strcpy/ memcpy
  - Needs –O1 to take effect; -O2 is preferred
- To disable the protection above (very bad; but sometimes you want to be crazy)
  - -fno-stack-protector -D_FORTIFY_SOURCE=0



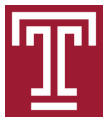
Debugging Tools

- Valgrind –memcheck: how to use it?
  - $valgrind ./your-exe
- Google's "Address sanitizer"
  - faster but not so powerful as Valgrind



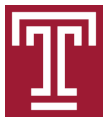
Recap

- Buffer overflows can be devastating
  - C/C++/Objective-C vulnerable to them
  - Most other languages not natively vulnerable
  - But many components/languages in C/C++
- The system has done a lot for us (but it is insufficient)
  - Canary
  - DEP
  - ASLR
- What you should do
  - Always enforce bounds checking in your code
  - Use snprintf/strlcpy/strlcat in your code
  - Do not use strncpy



Writing Assignments

- What concrete attacks can be launched by exploiting a buffer overflow attack? List at least four.
- Compare strcpy, strncpy, strlcpy, and snprintf
- Describe Canary, DEP, and ASLR



References

- Buffer Overflows and friends (one of the series lectures of “Secure programming HOWTO”)
  - http://www.dwheeler.com/secure-class/
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- Secure Coding in C and C++: Strings and Buffer Overflows
  - http://www.informit.com/articles/article.aspx?p=2036582&seqNum=6
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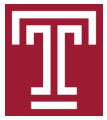

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