CS202 (003): Operating Systems
Trusting Trust

Instructor: Jocelyn Chen

Last time

Buffer Overflow Defenses

- Avoid unsafe functions
- Stack canary
- Separate control stack
- Address Space Layout Randomization (ASLR)
- Memory writable or executable, not both (W^X)
- Control flow integrity (CFI)

Avoiding Unsafe Functions

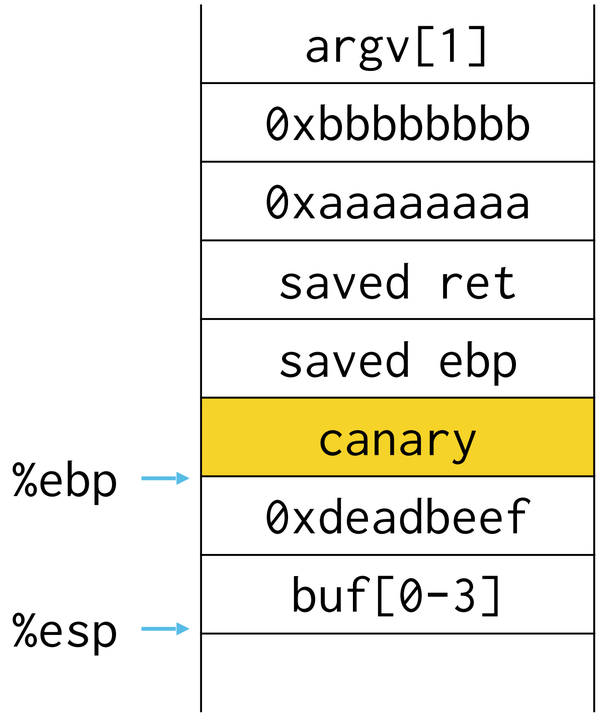
- strcpy, strcat, gets, etc.
- **Plus:** Good idea in general
- **Minus:** Requires manual code rewrite
- **Minus:** Non-library functions may be vulnerable
  - E.g. user creates their own strcpy
- **Minus:** No guarantee you found everything
- **Minus:** alternatives are also error-prone

Stack Canary

- Special value placed before return address
  - Secret random value chosen at program start
  - String terminator ‘\0’
- Gets overwritten during buffer overflow
- Check canary before jumping to return address
- Automatically inserted by compiler
  - GCC: -fstack-protector or -fstack-protector-strong

Back to Example 2

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xdeadbeef;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```

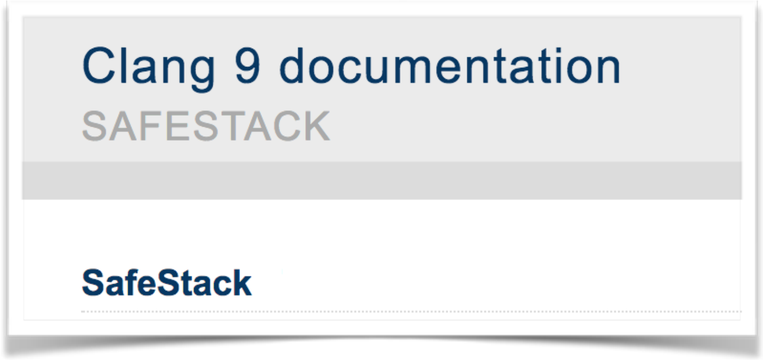


Check canary on ret

Stack Canary

- **Plus:** No code changes required, only recompile
- **Minus:** Performance penalty per return
- **Minus:** Only protects against stack smashing
- **Minus:** Fails if attacker can read memory

Separate Stack



“SafeStack is an instrumentation pass that protects programs against attacks based on stack buffer overflows, without introducing any measurable performance overhead. It works by separating the program stack into two distinct regions: the safe stack and the unsafe stack. The safe stack stores **return addresses**, **register spills**, and **local variables that are always accessed in a safe way**, while the unsafe stack stores everything else. This separation ensures that buffer overflows on the unsafe stack cannot be used to overwrite anything on the safe stack.”

WebAssembly has separate stack (kind of)!

Address Space Layout Randomization

- Change location of stack, heap, code, static vars
- Works because attacker needs address of shellcode
- Layout must be unknown to attacker
  - Randomize on every launch (best)
  - Randomize at compile time
- Implemented on most modern OSes in some form

Address Space Layout Randomization

- **Plus:** No code changes or recompile required
- **Minus:** 32-bit arch get limited protection
- **Minus:** Fails if attacker can read memory
- **Minus:** Load-time overhead
- **Minus:** No exec img sharing between processes

W^X: write XOR execute

- Use MMU to ensure memory cannot be both writeable and executable at same time
- Code segment: executable, not writeable
- Stack, heap, static vars: writeable, not executable
- Supported by most modern processors
- Implemented by modern operating systems

W^X: write XOR execute

- **Plus:** No code changes or recompile required
- **Minus:** Requires hardware support
- **Minus:** Defeated by return-oriented programming

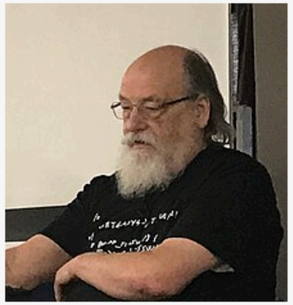
Control Flow Integrity

- Check destination of every indirect jump
  - Function returns
  - Function pointers
  - Virtual methods
- What are the valid destinations?
  - Caller of every function known at compile time
  - Class hierarchy limits possible virtual function instances

CFI

- **Plus:** No code changes or hardware support
- **Plus:** Protects against many vulnerabilities
- **Minus:** Performance overhead
- **Minus:** Requires smarter compiler
- **Minus:** Requires having all code available

Ken Thompson



Thompson, 2019

Born	Kenneth Lane Thompson February 4, 1943 (age 81) New Orleans, Louisiana, U.S.
Alma mater	University of California, Berkeley (B.S., 1965; M.S., 1966)
Known for	Multics Unix B (programming language) C (programming language) Belle (chess machine) UTF-8 Plan 9 from Bell Labs Inferno (operating system) grep Endgame tablebase Go
Awards	IEEE Emanuel R. Piore Award (1982)[1] Turing Award (1983) Member of the National Academy of Sciences (1985)[2] IEEE Richard W. Hamming Medal (1990) Computer Pioneer Award (1994) National Medal of Technology (1998) Tsutomu Kanai Award (1999) Harold Pender Award (2003) Japan Prize (2011)
Scientific career	
Fields	Computer science
Institutions	Bell Labs Entrisphere, Inc Google

Did you do the reading?

To what extent should one trust a statement that a program is free of Trojan horses?
Perhaps it is more important to trust the people who wrote the software.

https://en.wikipedia.org/wiki/Ken_Thompson

Forget about what you read for a sec...

Compiler

```
MONITOR FOR 6802 1.4          9-14-80  TSC ASSEMBLER  PAGE    2


C000                    ORG    ROM+$0000 BEGIN MONITOR
C000 8E 00 70  START    LDS    #STACK

                ****************************************
                * FUNCTION: INITA - Initialize ACIA
                * INPUT: none
                * OUTPUT: none
                * CALLS: none
                * DESTROYS: acc A

0013            RESETA  EQU    %00010011
0011            CTLREG  EQU    %00010001

C003 86 13      INITA   LDA A  #RESETA   RESET ACIA
C005 B7 80 04           STA A  ACIA
C008 86 11              LDA A  #CTLREG   SET 8 BITS AND 2 STOP
C00A B7 80 04           STA A  ACIA

C00D 7E C0 F1           JMP    SIGNON    GO TO START OF MONITOR
```

Compiler is a program.
So what does this program written in?

Forget about what you read for a sec…

Compiler written in

C

```
MONITOR FOR 6802 1.4          9-14-80  TSC ASSEMBLER  PAGE    2


C000                    ORG     ROM+$0000 BEGIN MONITOR
C000 8E 00 70  START    LDS     #STACK

                ****************************************
                * FUNCTION: INITA - Initialize ACIA
                * INPUT: none
                * OUTPUT: none
                * CALLS: none
                * DESTROYS: acc A

0013            RESETA  EQU     %00010011
0011            CTLREG  EQU     %00010001

C003 86 13      INITA   LDA A   #RESETA   RESET ACIA
C005 B7 80 04           STA A   ACIA
C008 86 11              LDA A   #CTLREG   SET 8 BITS AND 2 STOP
C00A B7 80 04           STA A   ACIA

C00D 7E C0 F1           JMP     SIGNON    GO TO START OF MONITOR
```

How does compiler know how to translate different types of language features (conditionals, loops, classes) into another language?

Forget about what you read for a sec…

Compiler written in

C

```
MONITOR FOR 6802 1.4          9-14-80  TSC ASSEMBLER  PAGE    2


C000                    ORG    ROM+$0000 BEGIN MONITOR
C000 8E 00 70  START    LDS    #STACK

                ****************************************
                * FUNCTION: INITA - Initialize ACIA
                * INPUT: none
                * OUTPUT: none
                * CALLS: none
                * DESTROYS: acc A

0013            RESETA  EQU    %00010011
0011            CTLREG  EQU    %00010001

C003 86 13      INITA   LDA A  #RESETA   RESET ACIA
C005 B7 80 04           STA A  ACIA
C008 86 11              LDA A  #CTLREG   SET 8 BITS AND 2 STOP
C00A B7 80 04           STA A  ACIA

C00D 7E C0 F1           JMP    SIGNON    GO TO START OF MONITOR
```

How can we add new language features to Java?

Forget about what you read for a sec…

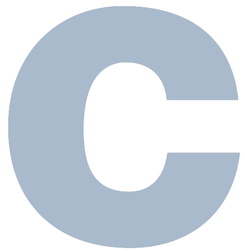
A **new** compiler written in

C

```
MONITOR FOR 6802 1.4          9-14-80  TSC ASSEMBLER  PAGE    2


C000                    ORG     ROM+$0000 BEGIN MONITOR
C000 8E 00 70  START    LDS     #STACK

                ****************************************
                * FUNCTION: INITA - Initialize ACIA
                * INPUT: none
                * OUTPUT: none
                * CALLS: none
                * DESTROYS: acc A

0013            RESETA  EQU     %00010011
0011            CTLREG  EQU     %00010001

C003 86 13      INITA   LDA A   #RESETA   RESET ACIA
C005 B7 80 04           STA A   ACIA
C008 86 11              LDA A   #CTLREG   SET 8 BITS AND 2 STOP
C00A B7 80 04           STA A   ACIA

C00D 7E C0 F1           JMP     SIGNON    GO TO START OF MONITOR
```

How can we add new language features to Java?

Forget about what you read for a sec…



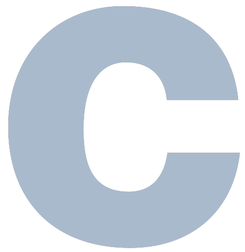
Compiler written in

c

```
MONITOR FOR 6802 1.4          9-14-80  TSC ASSEMBLER  PAGE    2


C000                    ORG     ROM+$0000 BEGIN MONITOR
C000 8E 00 70  START    LDS     #STACK

                        ****************************************
                        * FUNCTION: INITA - Initialize ACIA
                        * INPUT: none
                        * OUTPUT: none
                        * CALLS: none
                        * DESTROYS: acc A

0013            RESETA  EQU     %00010011
0011            CTLREG  EQU     %00010001

C003 86 13      INITA   LDA A   #RESETA   RESET ACIA
C005 B7 80 04           STA A   ACIA
C008 86 11              LDA A   #CTLREG   SET 8 BITS AND 2 STOP
C00A B7 80 04           STA A   ACIA

C00D 7E C0 F1           JMP     SIGNON    GO TO START OF MONITOR
```

How can we add new language features to C?

Forget about what you read for a sec…



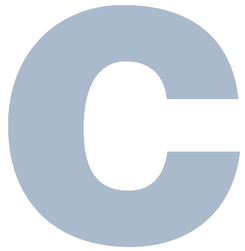
Old compiler written in

c

```
MONITOR FOR 6802 1.4          9-14-80  TSC ASSEMBLER  PAGE    2


C000                    ORG     ROM+$0000 BEGIN MONITOR
C000 8E 00 70  START    LDS     #STACK

                ****************************************
                * FUNCTION: INITA - Initialize ACIA
                * INPUT: none
                * OUTPUT: none
                * CALLS: none
                * DESTROYS: acc A

0013            RESETA  EQU     %00010011
0011            CTLREG  EQU     %00010001

C003 86 13      INITA   LDA A   #RESETA   RESET ACIA
C005 B7 80 04           STA A   ACIA
C008 86 11              LDA A   #CTLREG   SET 8 BITS AND 2 STOP
C00A B7 80 04           STA A   ACIA

C00D 7E C0 F1           JMP     SIGNON    GO TO START OF MONITOR
```

How can we add new language features to C?

Forget about what you read for a sec…



New compiler written in

c

compiled using the old compiler

```
MONITOR FOR 6802 1.4          9-14-80  TSC ASSEMBLER  PAGE    2


C000                    ORG    ROM+$0000 BEGIN MONITOR
C000 8E 00 70  START    LDS    #STACK

                ****************************************
                * FUNCTION: INITA - Initialize ACIA
                * INPUT: none
                * OUTPUT: none
                * CALLS: none
                * DESTROYS: acc A

0013            RESETA  EQU    %00010011
0011            CTLREG  EQU    %00010001

C003 86 13      INITA   LDA A  #RESETA   RESET ACIA
C005 B7 80 04           STA A  ACIA
C008 86 11              LDA A  #CTLREG   SET 8 BITS AND 2 STOP
C00A B7 80 04           STA A  ACIA

C00D 7E C0 F1           JMP    SIGNON    GO TO START OF MONITOR
```

How can we add new language features to C?

“Bootstrapping”: the technique for producing a self-compiling compiler

Some more context

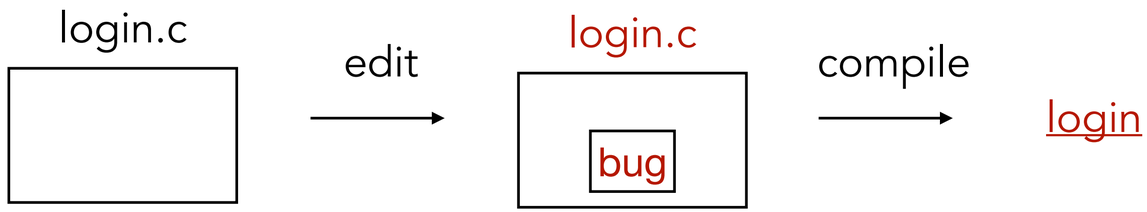
Earlier version of Unix were distributed with a full set of binaries and source for those binaries.

It is common for people to make change in one source file and recompile all their programs

How did Thompson add a bug to the login program without leaving a trace?

Goal

Have no source files hint at the bug, and meanwhile, the bug will persist across all recompilations



Anyone looking at login.c will realize something is wrong!

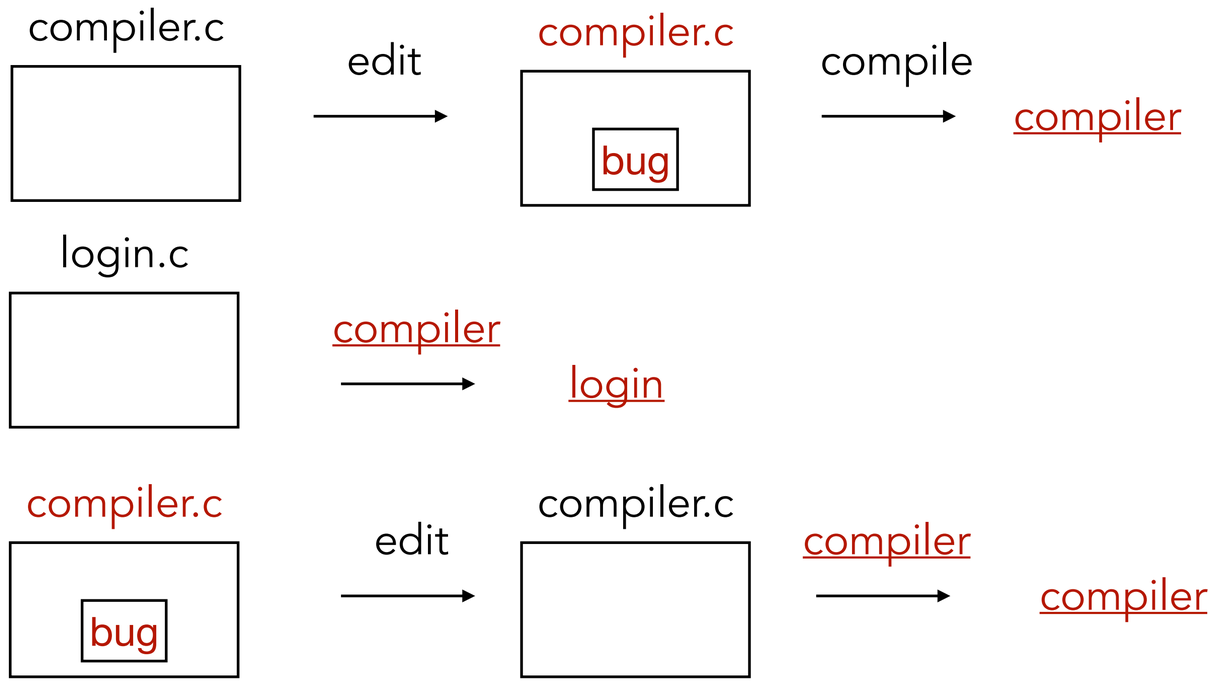
Goal

Have no source files hint at the bug, and meanwhile, the bug will persist across all recompilations

If you recompile locally, login will be bug-free again

Goal

Have no source files hint at the bug, and meanwhile, the bug will persist across all recompilations



Done!

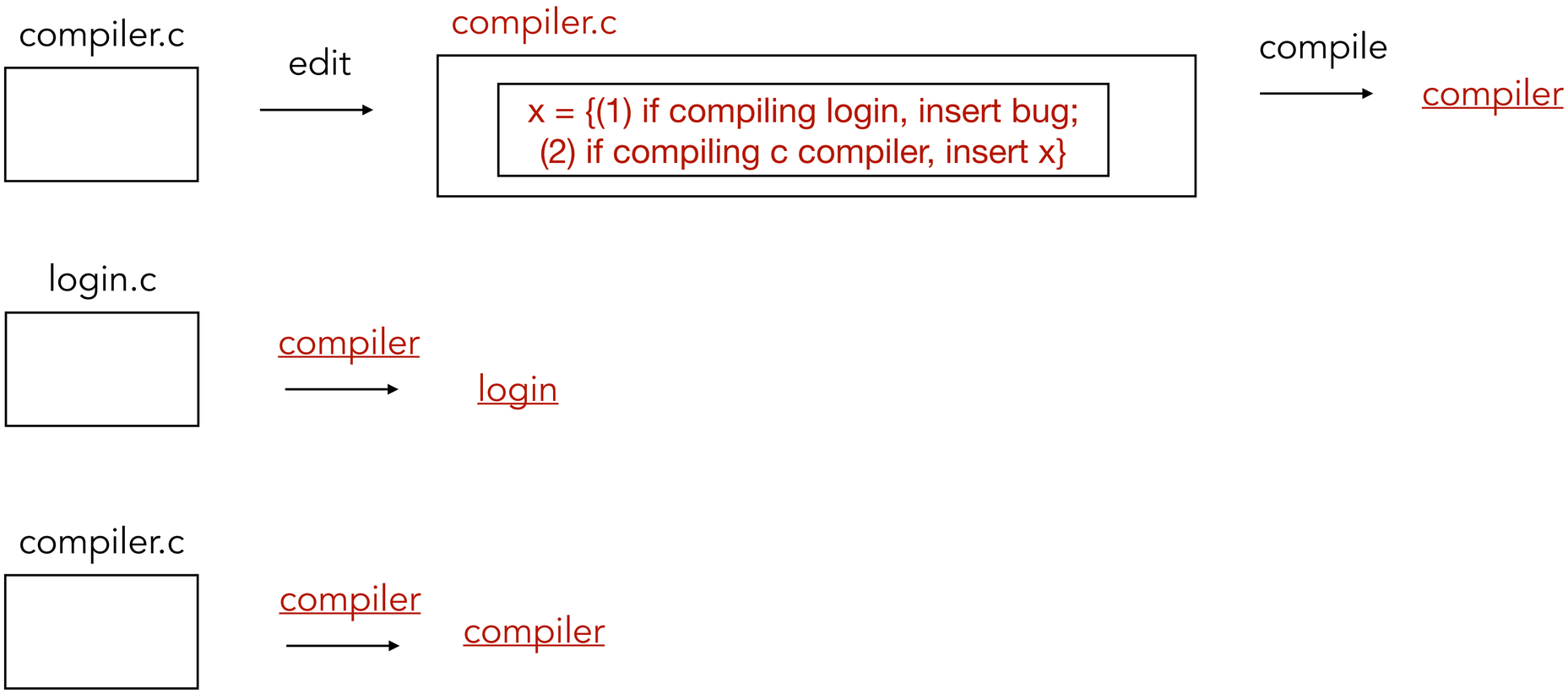
How can Ken figure out this attack?

Self-reproducing program: a computer program that takes no input and produces a copy of its own source code as its only output. (Quine)

"yields falsehood when preceded by its quotation" yields falsehood when preceded by its quotation.

https://en.wikipedia.org/wiki/Quine%27s_paradox
https://rosettacode.org/wiki/Quine

Actual attack



Done!

Implications

You can’t trust code that you did not totally create yourself!