Security Analysis

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Outline

- Introduction and applications
- Buffer overrun vulnerability

Introduction

- Security in a broad sense.
  - Effects: crash, non-termination, wrong output, unintended actions
  - Causes: dangling pointers, buffer overruns, null pointer dereference, wrong opcode, arbitrary data-change
- C programs are more susceptible to buffer overflow attacks.
- C allows direct pointer manipulation – since space and performance are primary concerns – not security.
- Standard library contains functions that are unsafe if not used carefully (e.g., *gets, strcpy, strcat*). Does *str**n**cpy* solve the problem?

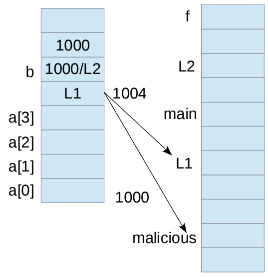
Stack Smashing

- How can a malicious code be executed by exploiting buffer overrun vulnerability?

```
void f(char *b) {
      gets(b);
L2:
}
void main() {
      char a[4];
      f(a);
L1:  ...
}
```

```
f:
      pop b
      push L2
      push b
      jump gets
      ...
      pop PC

main:
      mov a, SP
      add SP, 4
      push L1
      push a
      jump f
```



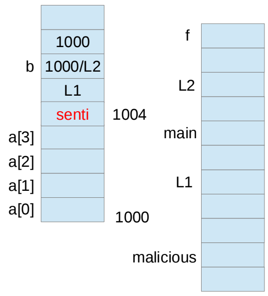
To Avoid Stack Smashing

- Insert a sentinel near the return address.
- Check if it is intact before jumping.

```
void f(char *b) {
      gets(b);
L2:
}
void main() {
      char a[4];
      f(a);
L1:  ...
}
```

```
f:
      pop b
      push senti
      push L2
      push b
      jump gets
      ...
      intact senti?
      pop PC

main:
      mov a, SP
      add SP, 4
      push senti
      push L1
      push a
      intact senti?
      jump f
```



To Avoid Stack Smashing

- Insert sentinel / canary
- Check addresses / bounds explicitly (Java)
- Wrap system calls with security checks

Dynamic techniques
- Runtime overhead
- Program is terminated

- When the code segment is writable, it is more vulnerable to attacks (*self-modifying code, W^X*).
- What does the following program do?

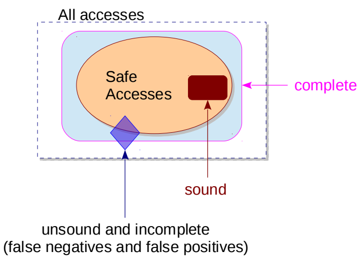
```
char*f="char*f=%c%s%c;main(){printf(f,34,f,34,10);}%c";main(){printf(f,34,f,34,10);}
```

Notes on Stack Smashing

- Using canary for stack smashing detection?
  - Canary is a bird used in coal-mines to detect toxic gases (humans follow the caged birds)
  - Researchers have validated its performance impact to be minimal
  - Randomizing canary improves odds
  - Does not *guarantee* protection
- How about heap smashing?
  - Heap usually doesn't contain return addresses
  - But then, we have function pointers

Static Buffer Overrun Detection

- A good example of static analysis that can be incomplete as well as unsound.



Using Pre and Post-conditions

- Annotations define properties
  - *minDef, maxDef, minUse, maxUse*

    e.g., `minDef(buff) = 0, maxUse(buff) = N / 2`
  - *notNull, null, restrict*

    e.g., `notNull(ptr), restrict(ptr)`
  - **Homework:** Write an example program using `restrict` which enables an optimized code.
- Initially we would assume that these annotations are user-provided. Later, we will try to auto-infer them.

Specifying Pre and Post-conditions

- char *strcpy(char *s1, char *s2)

  /* @requires maxDef(s1) >= maxDef(s2) */

  /* @ensures maxUse(s1) == maxUse(s2)

  and result == s1 */;
- void *malloc(size_t size)

  /* @ensures maxDef(result) == size

  or result == null */;

Inferring Constraints

- From the for-loops init, bound and change
  - Difficult for general loops such as while
- From the array declarations and malloc statements
- From conditional checks in the code
- Small number of heuristics often cover large part of the program.
- Once the constraints are identified, these are checked against the user annotations.

Inferring Constraints

- In absence of annotations, simply generating all possible constraints is expensive.
- In the past, researchers have tried flow-insensitive constraints.
- Auto-inference is feasible when loop-bounds do not depend on values.
  - while (a[i] != '\0') **versus** while (i < n)

Precision vs. Efficiency

```
void main() {
      int *a;
      a = malloc(N);
      ii = N / 2 + f(N);
      a[ii] = 0;
}
```

```
...
int f(int N) {
      return N % 5;
}
```

- Precision requires interprocedural analysis in the above example (recall Analysis Dimensions).
- Domain knowledge about N may help in filtering out false positives.

Stack Smashing in gcc

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

int main(void) {
    char buff[15];
    int pass = 0;

    printf("\n Enter the password : \n");
    gets(buff);

    if(strcmp(buff, "thegeekstuff"))
        printf ("\n Wrong Password \n");
    else
        printf ("\n Correct Password \n"),    pass = 1;

    if(pass)
      /* Now Give root or admin rights to user*/
        printf ("\n Root privileges given to the user \n");

    return 0;
}
```

Older gcc

```
Enter the password :
hhhhhhhhhhhhhhhhhhhh

Wrong Password

Root privileges given to the user
```

New gcc

```
Enter the password :
hhhhhhhhhhhhhhhhhhhh

Wrong Password
*** stack smashing detected ***: ./a.out terminated
```

New gcc with *-fno-stack-protector*

```
Enter the password :
hhhhhhhhhhhhhhhhhhhh

Wrong Password

Root privileges given to the user
```

Source: Ramesh Natarajan, thegeekstuff.com

Vulnerability Analysis as a DFA

- Data-flow facts
- Statements of interest
- Analysis direction
- Meet operator

Classwork

Vulnerability Analysis in Polyhedral Model

- How do you model inequalities?
- What are the constants?
- What do you get after solving the system?

Tools

3. BOON
   - Array out of bound check for C
   - Flow-insensitive, intra-procedural, pointer-insensitive
2. CQual
   - Annotation-based
   - Uses type qualifiers to propagate taint annotation
   - Detects format string vulnerability by type checking

Tools

1. xg++
   - Template-driven compiler extension
   - Finds kernel vulnerabilities
   - Tracks kernel data originated in untrusted source, memory leaks, deadlock situations
0. Eau Claire
   - Theorem-prover based (specification-checker)
   - Finds buffer overruns, file access races, format string bugs

Self-Modifying Code

```
:StartAfresh
ShowMenu.exe
```

Original batch file

```
:StartAfresh
ShowMenu.exe
CALL C:\Commands\somename.bat
GOTO StartAfresh
```

Modified batch file

In earlier single-window DOS systems, only one window could be active, and easy inter-process communication was not well-developed.