Security Analysis

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CS6843 Program 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?

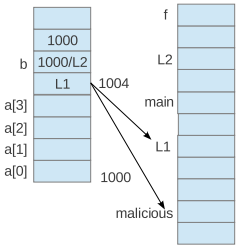
Stack Smashing

- 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
```



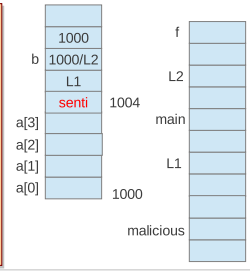
To Avoid Stack Smashing

- 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

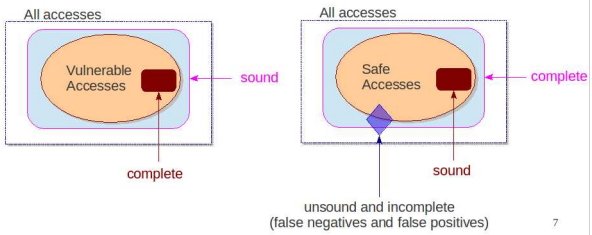
- Insert sentinel
- Check addresses / bounds explicitly (Java)
- Wrap system calls with security checks

Dynamic techniques
- Runtime overhead
- Program is terminated

- When the code segment is writable, it is more vulnerable to attacks (*self-modifying code, W^X*).

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)
- 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) >= maxUse(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

Correct Password

Root privileges given to the user
```

New gcc

```
Enter the password :
hhhhhhhhhhhhhhhhhhhh

Wrong Password
*** stack smashing detected ***: ./a.out terminated
======= Backtrace: =========
/lib/i386-linux-gnu/libc.so.6(__fortify_fail+0x45)[0xb766aeb5]
/lib/i386-linux-gnu/libc.so.6(+0x104e6a)[0xb766ae6a]
./a.out[0x8048510]
/lib/i386-linux-gnu/libc.so.6(__libc_start_main+0xf3)
[0xb757f4d3]
./a.out[0x80483d1]
======= Memory map: ========
...
```

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?

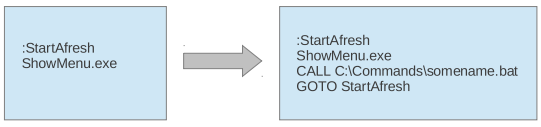
Tools

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



Original batch file

Modified batch file

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

Source: wikipedia

TCF

- Program Analysis CS6843
- Rupesh Nasre 008606
- G1..G5
- (i) 102 and 111
- (ii) 201 and 206
- (iii) 303 and 311
- (iv) 407 and 411
- (v) 506 and 508
- (vi) 601
- (vii) 708 and 720
- (viii) 805 and 810