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?

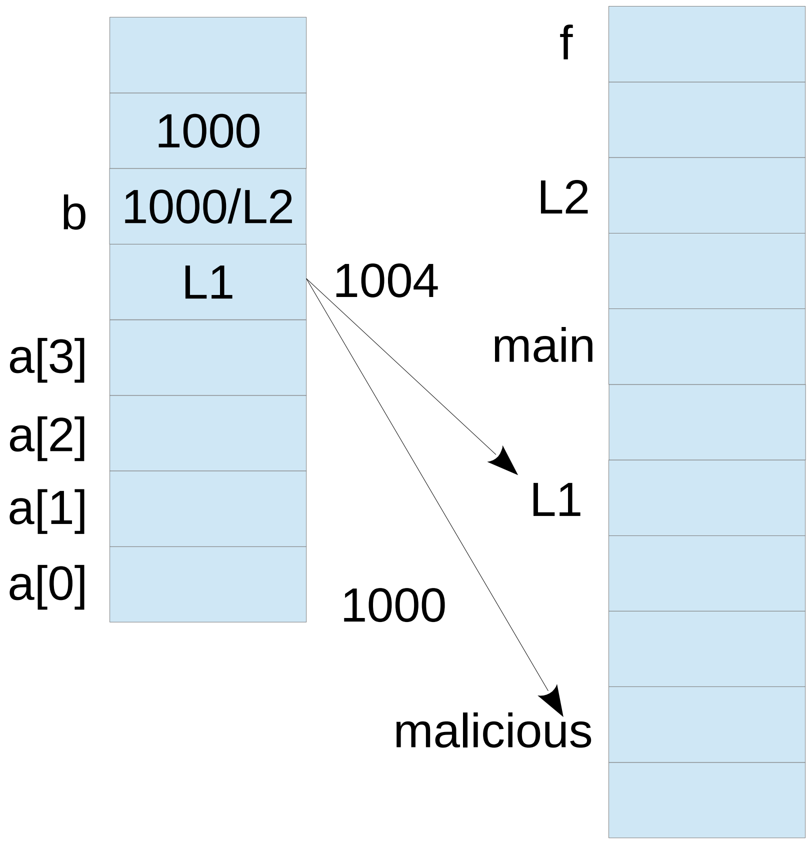
Stack Smashing

- 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
```



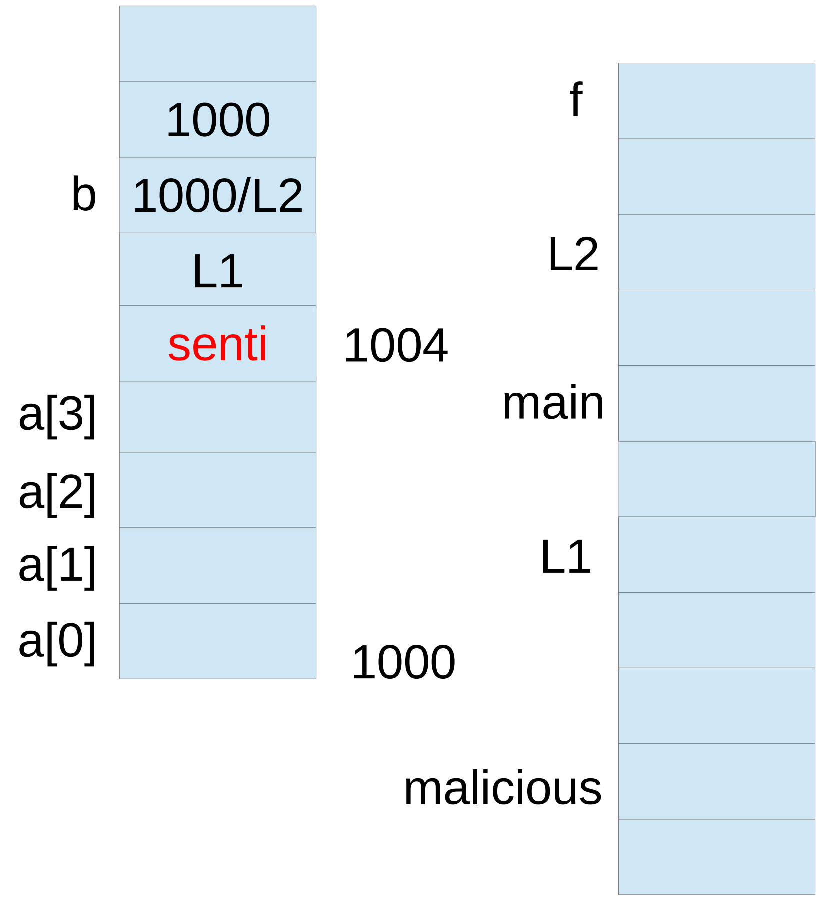
To Avoid Stack Smashing

- 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

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;
}
```

Source: Ramesh Natarajan, thegeekstuff.com

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*

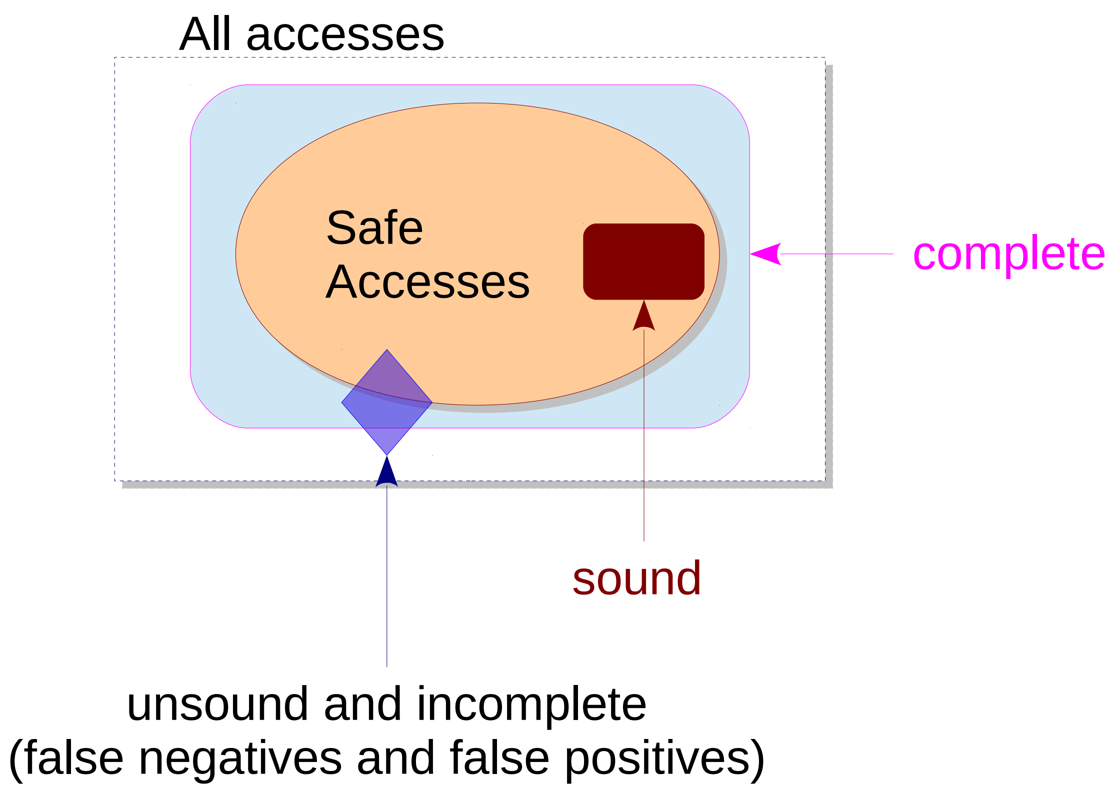
```
Enter the password :
hhhhhhhhhhhhhhhhhhhh

Wrong Password

Root privileges given to the user
```

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 array 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.

Security Analysis

- Null pointer dereference
- Dangling pointers
- Buffer overflow
- Stream safety (fread without fopen)
- ...

Vulnerability Analysis as a DFA

- Data-flow facts
- Statements of interest
- Analysis direction
- Meet operator and transfer functions

Classwork

Vulnerability Analysis in Polyhedral Model

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

Classwork

For the following code, write down the inequations in Ax <= B matrix form for checking array out-of-bounds vulnerability.

```
char *a = malloc(M);
for (i = x; i < 20; ++i)
    a[2*i - 3] += a[i + 1];
```

In This Course

7. Dynamic Analysis (DYN)
6. Shape Analysis (SHA)
5. Program Slicing (SLI)
4. Parallelization (PAR)
3. Security Analysis (SEC)
2. Pointer Analysis (PTR)
1. Data Flow Analysis (DFA)

Learning Outcomes

- To apply data-flow analysis and its variants on input programs and collect relevant information
  - DFA, SHA, SLI, PAR, SEC, DYN, PTA
- To design and implement analyses for new problems
  - Your assignments
  - Classworks

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.