Computer Security

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1 Introduction to Computer Security

1.1 Security requirements

CIA Paradighm

Confidentiality Information can be accessed only by authorized entities

Integrity information can be modified only by authorized entities, and only how they're entitled to do

Availability information must be available to entitled entities, within specified time constraints

The engineering problem is that **A** conflicts with **C** and **I**

2 Computer Security Concepts

2.1 General concepts

Vulnerability Something that allows to violate some CIA constraints

- The physical behaviour of pins in a lock
- A software vulnerable to SQL injecton

Exploit A specific way to use one or more vulnerability to violate the constraints

- lockpicking
- the strings to use for SQL injection

Assets what is valuable/needs to be protected

- hardware
- software
- data
- reputation

Thread potential violation of the CIA

- DoS
- data break

Attack an intentional use of one or more exploits aiming to compromise the CIA

- Picking a lock to enter a building
- Sending a string creafted for SQL injection

Thread agent whoever/whatever may cause an attack to occour

- a thief
- an hacker
- malicious software

Hackers, attackers, and so on

Hacker Someone proficient in computers and networks

Black hat Malicious hacker

White hat Security professional

Risk statistical and economical evaluation of the exposure to damage because of vulneravilities and threads
$Risk = \underbrace{Assets \times Vulnerabilities}_{\text{controllable}} \times \underbrace{Threads}_{\text{independent}}$

Security balance of (vulnerability reduction+damage containment) vs cost

2.2 Security vs Cost

Direct cost

- Management
- Operational
- Equipment

Indirect cost

- Less usability
- Less performance
- Less privacy

Trust We must **assume** something as secure

- the installed software?
- our code?
- the compiler?
- the OS?
- the hardware?

3 Introduction to crypthography

Kerchoffs' Principle The security of a (good) cryptosystem relies only on the security of the key, never on the secrecy of the algorithm

3.1 Perfect Chipher

- $P(M = m)$ probability of observing message m
- $P(M = m|C = c)$ probability that the message was m given the observed cyphertext c

Perfect cypher: $P(M = m|C = c) = P(M = m)$

Shannon's theorem in a perfect cipher $|K| \geq |M|$

One Time Pad a real example of perfect chipher

Algorithm 1 One Time Pad

Require: $len(m) = len(k)$
Require: keys not to be reused
return $k \oplus m$

Brute Force perfect chyphers are immune to brute force (as many "reasonable" messages will be produced). Real world chiphers are not.
A real chipher is vulnerable if there is a way to break it that is faster then brute forcing

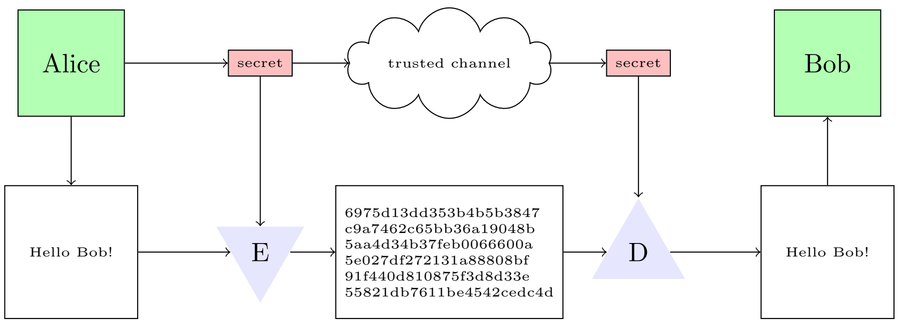
Types of attack

Ciphertext attack analyst has only the chipheertexts

Known plaintext attack analyst has some pairs of plaintext-chiphertext

Chosen plaintext attack analyst can choose plaintexts and obtain their respective ciphertext

3.2 Symmetric encryption



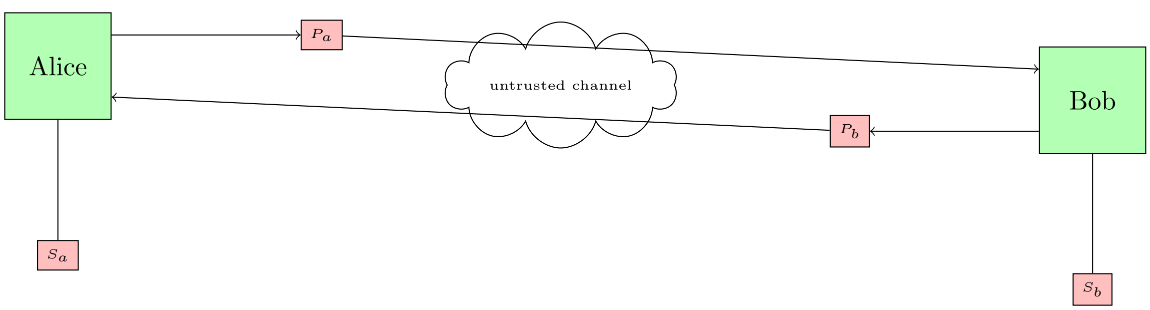
Use **K** to both encrypt and decript the message
Scalability issue
Key agreement issue

3.2.1 Ingredients

Substitution Replace each byte with another (ex: caesar chipher)

Transposition swap the values of given bits (ex: read vertically)

3.3 Asymetric encryption



Each user owns a private and a public key (S_i, P_i), where the public key is publicly available. The cryptoalgorithm is designed so that messages encrypted using P_i can only be decrypted using S_i. This allows Alice to encrypt a message using P_{bob}, and Bob (and nobody else) to decrypt is using S_{bob}. Also, to prove its identity, Bob could send a message encrypted using P_{bob}. When Alice manages to decrypt is using P_{bob}, she can be sure that the message came from Bob

3.4 Hash functions

A function $H : X \to Y$ having $|X| = \infty$ but $|Y| = k \in \mathbb{N}$. This means $|Y| < |X|$, leading to <u>collisions</u>: couples $x_1, x_2 \in X : H(x_1) = H(x_2)$.

Safery properties are proberties needed to ensure robustness of H. In particular, it must be computationally infeasible to find:

preimage attack resistance $x : H(x) = h$ with h known/crafted

second preimage attack resistance $y : y \neq x \wedge H(x) = H(y)$, where x is known/crafted

collision resistance $x, y : H(x) = H(y)$

3.4.1 Attacks to Hash Functions

Preimage attack Given an hash h, the attacker can find x such that $H(x) = h$, or given x, they can find y such that $H(x) = H(y)$. This can be done faster than brute force.
With $|Y| = n$, random collisions happen in 2^{n-1} cases

Simplified collision attack The attacker can generate $x, y : H(x) = H(y)$ faster than brute force.
Random collisions happen in $2^{n/2}$ cases (for the Birthday paradox)

3.5 Digital Signature

To digitally sign a message, we first hash the message. Then, we encrypt the hash with our private key.
This however only guarantees that the sign was produced using our secret key, but someone may have stolen/guessed our private key.

3.5.1 PKI

Public Key Infrastructures is a service entitled to associate an identity to a key. To do so it uses a trusted third party called **Certification Authority**. The CA signs files called **digital certificates**, which bind an identity to a public key.

Top-level CA is a special CA that self-signs its certificates. It is a trusted element. The Root CA can then sign certificates for other CAs. In practice, a Root CA is a real world CA (the state, a regulatory organization...)

Revocation Signatures cannot be revoked, but certificates can be revoked (declared invalid), for example because the private key has been broken.
To do so, a Certificate Revocation List must exist for each CA

4 Authentication

Identification an entity provides its identifier

Authentication an entity provides a proof that verifies its identity

- Unidirectional authentication
- Bidirectional authentication

Three factors authentication

Something I know low cost, easy to deploy, low effectiveness . Possible attack classes are snooping (so change the passwords), cracking (so use strong passwords) and guessing (so don't use your birthday)

- Password
- PIN
- Secret handshake

Something I have reduces the impact of human factor, relatively low cost, high security. Hard to deploy, can be lost (so use a backup factor)

- Door key
- Smart card

Something I am High level of security, no extra hw needed. Hard to deploy, non-deterministic, invasive, can be cloned. Biological entities change, privacy can be an issue, users with disabilities may be restrained.

- DNA
- Voice
- Fingerprint
- Face scan

Single Sign On Like OAuth2: exploit an ad-hoc authentication server, accessible from many apps

5 Access control

- Binary decision: allowed or denied
- Hard to scale (answers must be condensed in rules)
- Questions:
  - How do we design the rules?
  - How do we express them?
  - How do we apply them?

Reference monitor entity that encorces control access policies. Implemented by default in all modern kernels

- Tamper proof
- Cannot be bypassed
- Small enough to be verified/tested

5.1 Access Control Models

Discretionary Access Control Resource owner discretionarily decides the access privileges of the resource. Default in all off-the-shelf OS.

5.1.1 Model

We need to model:

Subjects Who can exercise privileges

Objects On what privileges can be exercised

Actions Which can be exercised

	file1	**file2**	**directory7**	**...**
Alice	Read	Read,Write,Own		...
Bob	Read,Write,Own	Read	Read,Write,Own	...
Charlie	Read,Write		Read	...
...	...	...	...	$\ddots$

5.1.2 HRU model

Basic operations

- Create/destroy subject S
- Create/destroy object O
- Add/remove permission from $[S, O]$ matrix

Transitions atomic sequence of basic operations (as usual)

Safety problem Does it exist a transition that leaks a certain right into the access matrix?

Undecidable problem becomes decidable if

- Mono-operational systems → useless
- Finite number of objects/subjects

5.2 Common implementation

- Reproduction of HRU models
- Sparse access matrix
- Authorizations table (records S-O-A triples)
- Access control list (record by colums: S-A per O)
- Capability List (records by row (O-A by S)

5.3 Issues

- Safety cannot be proven
- Coarse granularity (can't check data inside the objects)
- Scalability and management (each user can compromise security)

5.4 Mandatory Access Control

Administrator single entity establishing access privileges

Secrecy levels strictly ordered set of access classes

Labels used to classify objects

Example

Secrecy levels	**Labels**
Top Secret	Policy
Secret	Energy
For Official Use Only	Finance
Unclassified	Atomic

Lattice Touple <Level, Label>.

Classification obtained by a partial order relationship. $C_1, L_1 \geq C_2, L_2 \leftrightarrow C_1 \geq C_2 \wedge L_2 \subseteq L_1$. Such relation is reflexive, transitive, antisymmetric.

5.4.1 BLP model

No read up cannot read documents with higher security level than mine

No write down cannot write documents having a lower security level that mine (to avoid leaking of information)

Discretionary Security Policy An access matrix can be used to specify discretionay access control

Tranquility Secrecy levels of objects cannot change dinamically

6 Software Security

Good software engineering $\rightarrow$ meet requirements. Security is a <u>non funcional</u> requirement. *The rest of the lesson is history and not particularly interesting*

7 Buffer Overflow

7.1 Memory stack

High	Argc	
0xC0000000	Env pointer	Statically allocated local variables
0xBFF00000	Stack	Function activation records Grows down
	↓ ↑	Unallocated memory
	Heap	Dynamically allocated data Grows up
	.data	Initialized data (ex: global variables)
	.bss	Not initialized data (0s)
0x0804800	.text	Executable code (machine instructions)
Low	Shared Libraries	

7.2 Registers

General purpose registers execute common operations. Store data and addresses.

ESP Contains the address of the last stack operation: Top of the stack

EBP Contains the base of the current funciton frame

Segment 16-bit reisters to keep track of segments and backward compatibility

Control control the execution/operation of the processor

EIP Address of the next instruction to execute

Other EFLAG: 1 bit register containing results of tests performed by the processor

7.3 Code structure

	add	…, …	
main()	…		
	call	0x8048484	← EIP
	…		
	ret		0x80484ce
foo()	…		
	mov	%esp,%ebp	
	push	%ebp	0x8048484
	…		
	mov	%esp,%ecx	…
	pop	%esi	0x80483c1
Entry point→	xor	%ebp,%ebp	0x80483c0

7.4 On function call

Before jumping tho called

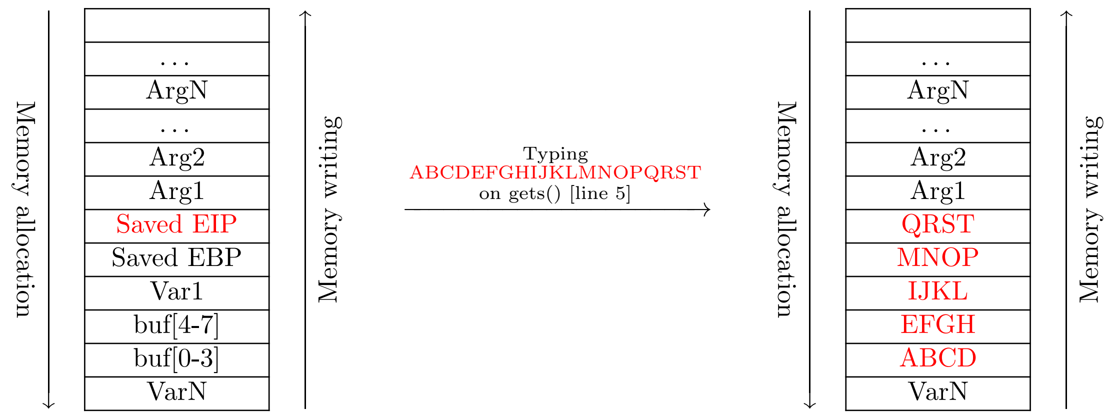
- The EIP is saved on the stack (so we know where to resume execution after return)
- The EBP is saved on the stack (so we can restore the memory)
- The ESP points to the cell after the saved EBP

Before the funciton returns

- The saved EBP is restored
- The saved EBP is popped from the stack
- The return instructions uses the saved EIP to jump back to the caller

7.5 Stack smashing

```c
1 int foo(int a, int b){
2   int c = 14;
3   char buf[8];
4
5   gets(buf);
6
7   c = (a+b)*c;
8   return c;
9 }
```



Possible jumping destinations

- Environment variables
- Built-in functions
- Memory we can control
  - The buffer itself!
  - Some other variable

The address of the buffer/EIP is hard to find! An estimate can be retrieved using a debugger, but it's not precise. Need to have a bigger "landing strip"! NOP sleds are used for this

	...		...	
	Saved EIP		approx address	
	Saved EBP		my code	
	Var1		my code	
	VarN		my code	
	buf[20-23]	→	my code	
	buf[16-19]		0x90909090	Valid landing strip Each cell contains 4 NOPs (0x90) Safety offset of +-4
	buf[12-15]		0x90909090	
approx. address	buf[8-11]		0x90909090	
	buf[4-7]		0x90909090	
	buf[0-3]		0x90909090	

What to execute Shellcode: code to spawn a (privileged) shell. It basically consists in executing execve("/bin/sh")

Writing shellcode

1. Write high-level code
2. Compile and disassembly
3. Analyse and clean up the assembly
4. Extract the opcode
5. Create the shellcode

```
int main(){
  char* hack[2];

  hack[0]="/bin/sh";
  hack[1]=NULL;

  execve(hack[0], &hack, &hack[1]);
}
```

7.6 Defending against Buffer Overflow

Shell code example

Source code level defence

- Use safer libraries: strncpy instead of strcpy, for example
- Use languages with Dynamic Memory Management (like java) to make guessing the buffer address harder

Compiler level defence

- Warnings from the compiler
- Randomized reordering of stack variables
- Canary: insert a control value between the saved EIP/EBP and the local variables, and check it to know if the stack has been compromised.

  Terminator canaries made of '\0', which cannot be written by usual functions

  Random canaries random bytes choosen at runtime

  Random XOR canaries Random canaries, but XORed with part of the structure we want to protect (R=a random number, always the same$\wedge$X=something, like the EIP $\implies$ R$\oplus$X$\oplus$R=R$\oplus$R$\oplus$X=0$\oplus$X=X

OS level defence

- Non-executable stack (can still be breached by returning to standard libraries)
- Address space Layout Randomization: reposition the stack at each execution

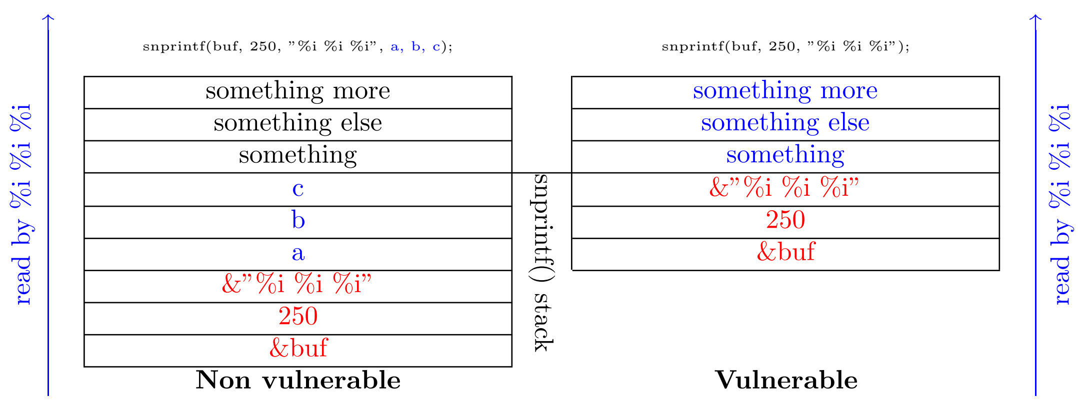
8 Format String Bugs

Format string You know, the strings with "%d" and similar in them

```c
#include <stdio.h>

void test(char* arg){
    char buf[250];
    snprintf(buf, 250, arg);
    printf("buffer: %s\n", buf);
}

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

Two executions of the code above result in the following

```
$ ./code "ciao"
buffer: ciao

$ ./code "%x %x %x"
buffer: f59b87a0 d1772d80 d1772d80        #addresses!
```




```c
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}

```

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

Two executions of the code above result in the following

```
$ ./code "%x %x %x"
buffer: f59b87a0 d1772d80 d1772d897


$ ./code "%3\$x"
buffer: d1772d897          #the third!
```

We can use loops to find interesting positions (design the vulnerability), and then aim for those positions directly (deploy it):

```
$ for i in `seq 1 3`; do echo -n "$i " && ./code "$i\$x"; done
1 buffer: f59b87a0
2 buffer: d1772d80
3 buffer: d1772d897
```

We can also look for specific values:

```
$ for i in `seq 1 3`; do echo -n "$i " && ./code "$i\$x"; done | grep d897
3 buffer: d1772d897
```

8.1 Writing using format string bugs

Specific access

Super powerful placeholder: printf("hello%n",&i) → writes in i the number of chars (bytes) printed so far (in the example it will write 5)

```
$ ./code "AAAA%2$n"
```

Is equivalent to

```
$ ./code "`python -c 'print "AAAA%2$n"'`"
```

Which is equivalent to

```
$ ./code "`python -c 'print "\x41\x41\x41\x41%2$n"'`"
```

We can replace the \x41 with whatever bytes we like (in hex), inserting whatever address we like

```c
void main(){     //padding.c
  printf("%050c\n",'D');
  printf("%030c\n",'D');
  printf("%013c\n",'D');
}
```

```
$ ./padding
00000000000000000000000000000000000000000000000000D        #50
000000000000000000000000000000D  #30
0000000000000D                 #13
```

Using this:

```
$ ./code "`python -c 'print "\x41\x41\x41\x41%50000c%2$n"'`"
```

We are writing the value 50004 (50000 for the padding, 4 for the bytes of the address)

The vulnerability so far $\underbrace{\backslash xcc\backslash xf6\backslash xff\backslash xbf}_{\text{the address of the memory cell we want to modify}}\%\underbrace{6024}_{\text{value we want }-4\text{(address)}}\ c\ \underbrace{8}_{\text{offset on the stack of the target address found using \%x to read)}}\ \$n$

Writing big numbers we usually want to write a valid 32 bit address ad an arbitrary number. This could require a super long padding string (up to 4GB). To reduce the size written, we can split it in 2 16-bit words.
Because using %c we can only increase, and we must perform the writing twice <u>in the same string</u> (as we can only pass one string), we need to do some math:

1. Word with lower <u>absolute value</u>
2. Word with higher <u>absolute value</u>

New vulnerable string 1): use case: 0x45454040 (first half > second half)

$$\underbrace{<\text{tgt+2}><\text{tgt}>}_{\text{target addresses placed on the stack to be read as argument of \%...n (bytes in reverse order)}}\overbrace{\%\underbrace{<\text{low\_val}-\#\text{printed}>}_{0x4040-8}c}^{\text{use padding to write the desired number of chars}}\ \overbrace{\%\underbrace{<\text{stack\_offset}>}_{\text{point to <address>}}\$hn}^{\text{write to <address> using \%hn}}\ \overbrace{\%\underbrace{<\text{high\_val}-\text{low\_val}>}_{0x4545-x4040}c}^{\text{use padding to write the desired number of chars}}\ \overbrace{\%\underbrace{<\text{stack\_offset+1}>}_{\text{point to<address+2>}}\$n}^{\text{write to<address+2 using \%hn>}}$$