Secure Programming Lecture 16: Software Protection

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Outline

Overview

Man-At-The-End Attacks

Defences

- Code signing
- Obfuscation
- Tamperproofing
- Watermarking

Summary

Recap

We have looked at:

- examples of vulnerabilities and exploits
- particular programming failure patterns
- security engineering, adding security features
- tools: static analysis for code review
- languages: built-in features for security

In this lecture we look at the special case of adding *security features to protect software* itself.

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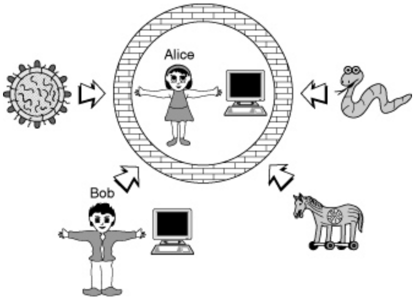
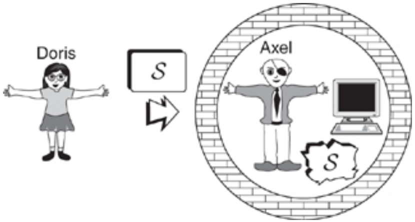
Inside vs outside threats





- Bob wants to attack Alice
- Security perimeter stops bad things getting in or information leaking out

- Axel wants to attack Doris
- Security features must protect how digital assets are used

Note: *insider threats* more generally refers to threats on left picture when insiders deliberately violate security policy.

MATE and R-MATE

Man-At-The-End (MATE) Attacks

An adversary has physical access to a device and compromises it by inspecting, reverse engineering or tampering with its hardware or software

Remote Man-At-The-End (R-MATE) Attacks

In distributed systems where untrusted clients communicate with trusted servers, a malicious user gets an advantage by compromising an untrusted device.

It would be better to use gender neutral names like **Person-at-the-end** and **Remote Person-at-the-end** just as **Middle Person** is replacing “man-in-the-middle”.

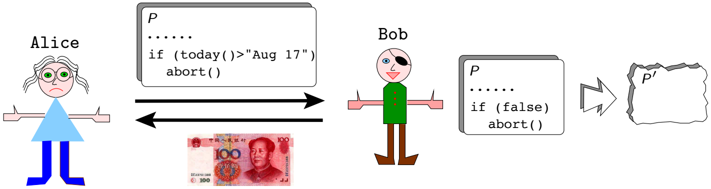
MATE attack scenarios

Example goals of an attacker include:

1. Software piracy
2. License check removal
3. Malicious reverse engineering
4. DRM key extraction
5. Protocol discovery
6. Violation of export/supply chain controls

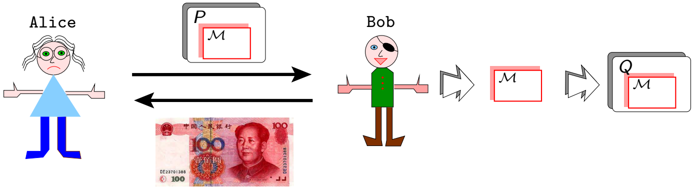
Mostly, these attack *non*-availability where there is an attempt to deny access to an asset, e.g., unless it has been paid for.

License check removal



- Alice sells a time-limited license for her software
- Bob removes the license check to use it indefinitely
- Defence: Alice makes her program *tamperproof*

Malicious reverse engineering



- Alice’s P has a trade secret algorithm $\mathcal{M}$
- Bob copies $\mathcal{M}$ into his program (“code lifting”).
- Defence: Alice *obfuscates* her code to make reverse engineering difficult

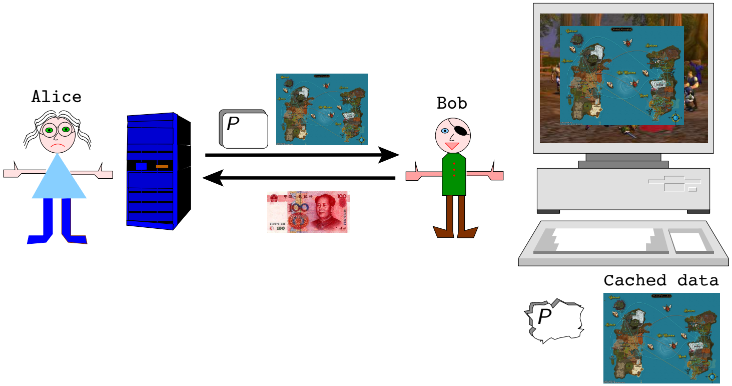
R-MATE attack scenarios

Example goals of an attacker include:

1. Cheating in networked computer games
2. Accessing or altering distributed medical records
3. Attacking wireless sensor networks
4. Hacking smart meters to disrupt supply

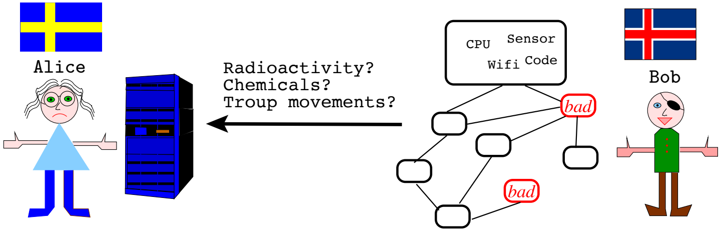
These examples attack confidentiality and integrity as well as availability.

Cheating in networked computer games



- Alice runs online game with paid-for inventory
- Bob re-uses cached data: advantage, free resources
- Defence: *replay-resilient protocol*

Wireless sensor network attacks



- Alice collects data from a wireless sensor network
- Bob interferes with some of the sensors
- Defences: *anomaly detection*, *remote attestation*.

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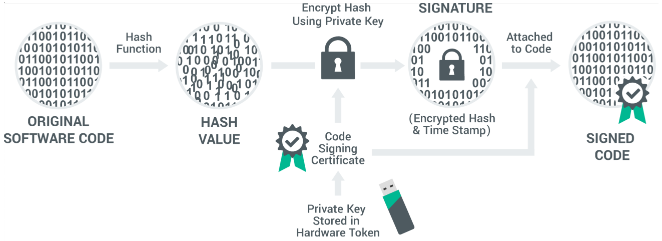
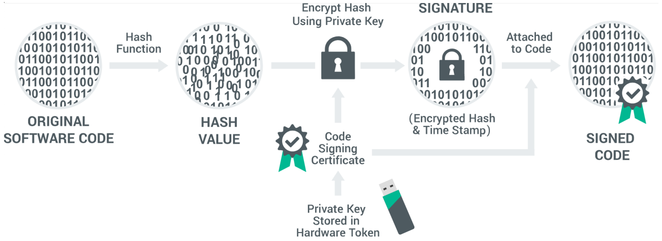
Code signing



- Cornerstone for code integrity and authenticity
- Detects tampering before code execution
- Aims to protect recipient from unsafe code (malware)

With a trusted (secure) platform it can also be used to provide protection against MATE. (**Q.** How?)

Code signing



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Exercise. Explain (or find out about) two kinds of vulnerabilities in signing for code safety.

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Program obfuscation

Here is a program `burton1.c`:

```
char O,o[];main(l){for(;~l;O||puts(o))O=(O[o]=
~(l=getchar())?4<(4^l>>5)?l:46:0)?-~O&printf("%02x ",l)*5:!O;}
```

What does this program do?

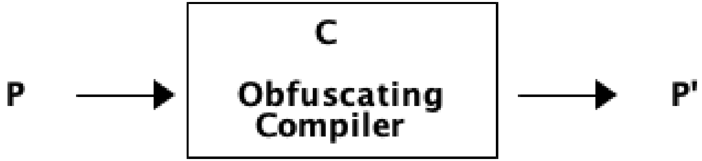
Program obfuscation

```
bash-3.2$ gcc burton1.c --no-warnings -o burton1
bash-3.2$ echo "David" | ./burton1
44 61 76 69 64 0a David.
```

This is a winner from the 2018 International Obfuscated C Code Contest. It won as the best one-liner, a judge noted: *One line, one array, one loop and one statement but it prints many bytes. It won.*

Similar contests are available in other languages. Most entries are intended as fun puzzles, rather than serious efforts at software protection.

Obfuscating compilation



An obfuscating compiler *C* transforms a program *P* into a *functionally equivalent* program *P′*.

The idea is that *P′* conceals the code of *P* to be "inscrutable" so an attacker cannot learn information about its operation (algorithms, or embedded data such as cryptographic keys).

Question. What properties should *C* have?

Practical obfuscation

Many intuitively obfuscating techniques can be used:

- Rename identifiers
- Use equivalent expressions (e.g., bit shift multiply)
- Code and data: reorder, duplicate, add dummies
- Flatten control flow (e.g., use jump tables)
- Merge and split functions (inline, outline)
- Introduce pointer aliases. Add concurrency.
- Use *opaque predicates*.
- Use a custom abstract machine

Combining these transformations can make human understanding hard and thwart automated code analysis. Various obfuscation tools (commercial, non-commercial) are available.

Exercise. Which operations are *guaranteed* to make analysis difficult? (hard question)

Obfuscation in theory

Black box simulator

The *black-box simulator* S^P of P can only observe the input-output behaviour of P, nothing about its code or timing.

We would consider C an effective obfuscator if an attacker cannot learn anything more about P by examining $C(P)$ than she can learn from the *black-box* (input-output) functional behaviour of P, captured by S^P.

Obfuscation in theory

Virtual Black-Box Security

C is *virtual black box secure* if for all P, for all attacks A which examine the obfuscation $P' = C(P)$, then $A(P') \simeq_c S^P$.

$\simeq_c$ denotes *computational indistinguishability* which means restriction to computationally bounded attackers, whose power depends on some security parameter (e.g., limiting CPU time).

The power of general obfuscation

In fact, many cryptographic primitives can be *derived* from obfuscation.

Symmetric to Asymmetric Crypto

Given a secret key K and symmetric encryption function E_K, publish its obfuscated version $C(E_K)$. Thus anyone can encrypt but only the owner who knows K can decrypt.

Homomorphic Encryption

Homomorphic encryption allows general computation on encrypted data. For any boolean operation f, the plain program P computes $E_K(f(D_K(x)))$. Its obfuscated version hides the key K and encryption method.

Impossibility of (general) obfuscation

A celebrated result of Barak et al shows that it is *impossible* to construct an obfuscating compiler that satisfies virtual black box security.

The proof constructs a counterexample.

Imagine a program `Secret` that operates in two modes (1) recognise some secret value S, or (2) recognises itself by comparing i/o behaviour and outputs S if it receives itself as input.

The black-box behaviour hides the secret S, but any obfuscated version $C(\texttt{Secret})$ must reveal S when given itself as input. So C is not virtual black-box secure.

Barak et al. *On the (Im)possibility of Obfuscating Programs.* CRYPTO 2001. See Chapter 5 of Surreptitious Software for a listing of `Secret`.

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Software Tamperproofing

Tamperproofing aims to make sure a program executes as intended by its author, even when the person running may try to disrupt, monitor or change execution.

Two aspects, captured as functions in code (or environment):

- **Check** to see if tampering has occurred
- **Respond** somehow, imposing a penalty

The penalty might be to exit the program or degrade its operation.

Question. How/why is this requirement stronger than integrity?

Tamperproof Checking

Checking may examine different things:

- **Code checking**: has program been changed?
- **Result checking**: is result of computation correct?
- **Environment checking**: are we running in a debugger?

Tamperproof Responding

Responding may take different actions:

- **Termination**
- **Restore** recover the program to intended state
- **Degrade** return incorrect results; slow down operation
- **Report** phone home to owner
- **Punish** destroy program, data or environment

In each the first 4 cases, response may be designed to be stealthy to avoid alerting user (or helping attacker defeat system).

Pervasive Hashing

One technique is to to use multiple hashing methods and compute multiple hashes on fragments of code.

Then spread the hash computation repeatedly throughout the code.

To help prevent attackers figuring out the scheme, tamperproofing is combined with obfuscation.

The Skype VoIP clients used this technique.

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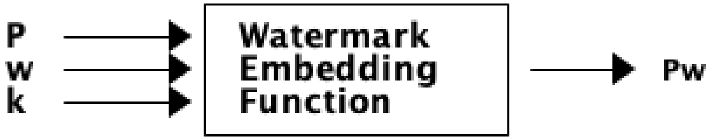
Digital Watermarking

Digital Watermarking hides one digital signal inside another, perhaps covertly (i.e., invisibly).

Software Watermarking



A watermark embedding function transforms a program P into a watermarked program $P_w = embed_k(P, w)$.

- A secret key k is needed to guide embedding
- It should be recoverable, perhaps probabilistically, to someone who has the key k (or more generally).
- It should be *robust* (not removable)
- Have *high credibility* (low FP, FN accuracy)

Applications

Various applications of watermarking, depending on what data is embedded:

- **Track Authorship**: copyright owner
- **Track Purchaser**: purchaser/licensee (fingerprinting)
- **Record Rights**: usage restrictions
- **Integrity**: cryptographic hash of code

The last case is essentially the same as code signing.

Watermarking techniques

Numerous methods:

- Embed meta data directly (strings in code)
  - use “opaque predicates” to make robust
  - or code signing
- Encode information in obfuscation operations
  - e.g., permutation of code blocks
- Use a public **blockchain** to record metadata, hash values
  - Non-Fungible Tokens (NFTs)

Using opaque predicates

```
public class Fibonacci {
   public int fibonacci (int n) {
     String copyright = "Copyright (C) by Clever Coders, Inc";
     if complexTest()
       n = length(copyright);
     if (n <= 2)
       return 1;
     else
       return fib(n-1) + fib(n-2);
   }
}
```

An opaque predicate is one whose value is a constant, known to the programmer, but is not obvious from the code and so must be computed at run time.

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Protecting software and information usage rights is often required and a range of countermeasures have been developed.

- **Code signing**: cryptographic assurance about integrity and origin
- **Obfuscation**: raises attacker effort for reversing
- **Watermarking**: visibly/invisibly trace software/data
- **Tamperproofing**: detect modification and abort
- **Hardware security**: lock code/execution to a device
- **Advanced crypto**: compute on encrypted data

The last two methods are both becoming more practical and in future may replace (or augment) earlier ones.

Review Questions

Software protection defence methods

- Compare and contrast each of the defence measures.
- Do any of the methods improve or detract from the situation with potentially exploitable code vulnerabilities?
- Consider the Android Repackaging attack studied in labs. How could you defend against it?

Software protection attack methods

- What methods are open to the attacker against each of the defences listed?
- Discuss the potential use of cryptographically oriented attacks against software protection methods (for example, .

References and credits

Some of this lecture is based on

- Surreptitious Software by Christian Collberg and Jasvir Nagra.

Pictures of the attack scenarios are used with permission from Christian Collberg’s slides.

The image of code signing is from Comodo’s page How Does EV Code Signing Work?.

The example of watermarked images is from the paper *Transparent Robust Image Watermarking* by Swanson, Zhu and Tewfik, International Conference on Image Processing, Sept 1996.