Introduction to Obfuscation. Black-box Security

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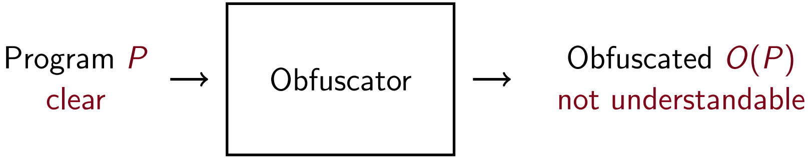
Idea of Obfuscation



Program P clear → Obfuscator → Obfuscated $O(P)$ not understandable

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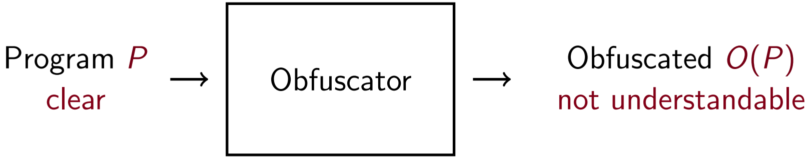

Program P
clear
$\longrightarrow$ Obfuscator $\longrightarrow$
Obfuscated $O(P)$
not understandable

Three properties:

- Functionality preserving
- Increase of code size, time & space requirements are restricted (usually by constant factor)
- Obfuscated program is not understandable

```
                                           $_=’ev
                                       al("seek\040D
           ATA,0,                  0;");foreach(1..3)
       {<DATA>;}my               @camel1hump;my$camel;
  my$Camel  ;while(             <DATA>){$_=sprintf("%-6
9s",$_);my@dromedary           1=split(//);if(defined($
_=<DATA>)){@camel1hum        p=split(//);}while(@dromeda
 ry1){my$camel1hump=0      ;my$CAMEL=3;if(defined($_=shif
        t(@dromedary1    ))&&/\S/){$camel1hump+=1<<$CAMEL;}
       $CAMEL--;if(d   efined($_=shift(@dromedary1))&&/\S/){
      $camel1hump+=1  <<$CAMEL;}$CAMEL--;if(defined($_=shift(
     @camel1hump))&&/\S/){$camel1hump+=1<<$CAMEL;}$CAMEL--;if(
     defined($_=shift(@camel1hump))&&/\S/){$camel1hump+=1<<$CAME
     L;;}$camel.=(split(//,"\040..m‘{/J\047\134}L^7FX"))[$camel1h
      ump];}$camel.="\n";}@camel1hump=split(/\n/,$camel);foreach(@
      camel1hump){chomp;$Camel=$_;y/LJF7\173\175‘\047/\061\062\063\
      064\065\066\067\070/;y/12345678/JL7F\175\173\047‘/;$_=reverse;
       print"$_\040$Camel\n";}foreach(@camel1hump){chomp;$Camel=$_;y
        /LJF7\173\175‘\047/12345678/;y/12345678/JL7F\175\173\0 47‘/;
         $_=reverse;print"\040$_$Camel\n";}’;;s/\s*//g;;eval;   eval
           ("seek\040DATA,0,0;");undef$/;$_=<DATA>;s/\s*//g;(   );;s
             ;^.*_;;;map{eval"print\"$_\"";}/.{4}/g; __DATA__   \124
               \1   50\145\040\165\163\145\040\157\1 46\040\1  41\0
                    40\143\141  \155\145\1 54\040\1   51\155\  141
                    \147\145\0  40\151\156 \040\141    \163\16 3\
                     157\143\   151\141\16  4\151\1     57\156
                     \040\167  \151\164\1   50\040\      120\1
                     45\162\   154\040\15    1\163\      040\14
                     1\040\1   64\162\1      41\144       \145\
                     155\14    1\162\       153\04        0\157
                      \146\     040\11     7\047\         122\1
                      45\15      1\154\1  54\171          \040
                      \046\         012\101\16            3\16
                      3\15           7\143\15             1\14
                      1\16            4\145\163           \054
                     \040            \111\156\14         3\056
                    \040\         125\163\145\14         4\040\
                    167\1        51\164\1  50\0         40\160\
                  145\162                              \155\151
                \163\163                                \151\1
              57\156\056
```

Outline

1. Applications of Obfuscation
   - Classification of Threats
   - Applications in Software Protection
   - Applications in Mobile Agents
   - Applications in Cryptography
   - More Applications

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    - Defining Security of Obfuscation
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More attacks?

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Situation: company distribute (sell) software products.

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- Watermarks protection
  - Deleting watermarks in obfuscated program is much harder

Protection of IF Operator

Consider a program containing the following construction:

```
If (some condition) then
    do something important
    else do nothing (or some not interesting things)
```

Adversary attack: destroy this IF operator i.e. get a program with unconditional important module.

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  - Network monitoring system
- Keys protection
  - Buying agents

Network Monitoring Systems

First interesting example of mobile agent needed protection is network monitoring and management systems.

We have: a huge network consisting of nodes, and a monitoring agent installed on each node.

Some observations:

- Agents interacts with their hosts
- Agents interacts with central (the only trusted) node. We call it control center.
- We can't protect agents against just deleting (uninstalling them)
- We want to protect the "state" of agents and their proper execution

Buying Agent

Another important example is buying agent.

What do we have: a set of “sellers” with installed buying agents. These agents have a task to purchase a specific good if some conditions (usually on price) holds

Aspects:

- Buying agents have keys to the credit card or electronic money.
- Adversary is always able to delete an agent.
- Agents owner wants to prevent key’s extraction and changing conditions of purchase or even buying wrong good.

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- Constructing homomorphic encryption schemes
- Realizing random oracles in cryptosystems

New Public-Key Cryptosystems

General idea: given a private-key (symmetric) cryptosystem publish obfuscated encryption algorithm $O(E_k)$ as a public key.

Analysis:

- We must be sure that key extraction of $O(E_k)$ is computationally hard
- Moreover, rewriting $O(E_k)$ to any efficient program computing D_k must be computationally hard
- Conclusion: starting symmetric cryptosystem should have sufficient difference in encrypting and decrypting algorithms

Constructing Homomorphic Encryption

Given good enough obfuscator it's easy to construct a homomorphic encryption.

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Construction: as such homomorphic encryption we can take just any public key cryptosystem:

> Input: $E(x), E(y)$
> Program algorithm: using private key decrypt x and y, compute $x + y$ (respectively xy), then encrypt it.
> Output: $E(x + y)$ (respectively, $E(xy)$)

If we are able to obfuscate P and Q in the way that extracting private key and intermediate results (x and y) is computationally hard than we are done!

More Applications

- Diversity producing (every user receive his own version)
  Makes virus attacks harder
- Guaranteed slowdown of encrypting procedure in cryptosystems
  Makes brute-force attacks harder
- Digital Rights Management software
  Protection against extracting secret keys from players for copyrighted media files

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Question: Your ideas of applications?

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Example: security of pseudorandom generators

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Simulation: “For any property that could be extracted from the new system almost the same property can be extracted from the ideal model”

Security Definitions in Cryptography (2)

1. Define ideal model
2. Security = adversary cannot compute more than in ideal model

Proof instrument:

Simulation: "For any property that could be extracted from the new system almost the same property can be extracted from the ideal model"

Example: security of zero-knowledge proofs

Ana and BAna

We are interested in 2 types of polynomial-time analyzers:

- Ana is a source-code analyzer that can read the program.

$$Ana(P)$$

- BAna is a black-box analyzer that only queries the program as an oracle.

$$BAna^{P}(time(P))$$

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Black-Box security

Ana can't get more information than BAna could

Black-box Security

Randomized algorith O is an Obfuscator if three following conditions hold:

1. (functionality) $\forall$ TM M: $O(M) \approx M$
2. (effectiveness) $\exists p$: $M(x)$ terminates in t steps $\Rightarrow O(M)(x)$ terminates in $p(t)$ steps.

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1. (functionality) $\forall$ TM M: $O(M) \approx M$
2. (effectiveness) $\exists p$: $M(x)$ terminates in t steps $\Rightarrow O(M)(x)$ terminates in $p(t)$ steps.
3. (black-box security) For every PPT A there exists PPT S such that for all TMs M:

$$\left| Pr\{A(O(M)) = 1\} - Pr\{S^M(1^{|M|}) = 1\} \right| = \nu(|M|).$$

Unobfuscatable Function Family

Family $\mathcal{H} = \cup H_k$
H_k is a set (distribution) of functions $B^{n_k} \rightarrow B^{m_k}$

- $h \in H_k$ computable in poly(k) time
- $\exists \pi : \mathcal{H} \rightarrow \{0, 1\}$ such that
  - $|Pr\{S^h(1^k) = \pi(h)\} - 1/2| = \nu(k)$
  - $\exists A$ such that for every TM M computing h, $A(M) = \pi(h)$

Unobfuscatable 2-Functions Family

Family $\mathcal{G} = \cup G_k$

G_k is a set (distribution) of pairs of functions $B^{n_k} \longrightarrow B^{m_k}$

- $(g_1, g_2) \in G_k$ computable in poly(k) time
- $\exists \pi : \mathcal{G} \longrightarrow \{0, 1\}$ such that
  - $|Pr\{S^{g_1,g_2}(1^k) = \pi(g_1, g_2)\} - 1/2| = \nu(k)$
  - $\exists A$ such that for every TMs M_1, M_2 computing g_1, g_2, $A(M_1, M_2) = \pi(g_1, g_2)$

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Existence of unobfuscatable function families and 2-finction families. What follows from what?

Counterexample

Cannibalistic construction:

$$C_{\alpha,\beta}(x) \;=\; \begin{cases} \beta, & x = \alpha \\ 0, & \text{otherwise} \end{cases}$$

$$D_{\alpha,\beta}(C) \;=\; \begin{cases} 1, & C(\alpha) = \beta \\ 0, & \text{otherwise} \end{cases}$$

$$Z_k(x) \;= 0^k$$

Intuition: it is difficult to distinguish pairs $C_{\alpha,\beta}, D_{\alpha,\beta}$ from pair $Z_k, D_{\alpha,\beta}$ given only black box access to these programs.

Technical Details

We leave out technical details:

- Truncated version of D
- Combining pair of functions into a single one.

Extensions of Impossibility Result

More impossibilities of obfuscation:

- Unobfuscatable functional properties (not only predicates)
- Computationally easy but still unobfuscatable programs (in TC_0 class)
- Attack (deobfuscation algorithm) is known in advance
- Obfuscator might preserve functionality only approximately
- Impossibility of obfuscation for sampling algorithms

Home Problem 1

Whether the family $f_\alpha(x) = x \cdot \alpha$ is obfuscatable with black-box security?

Summary

Main points:

- Rough idea of applications: cryptosystem design, mobile agents technology, software protection.

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- Rough idea of applications: cryptosystem design, mobile agents technology, software protection.
- Black-box security: obfuscated program tells no more than input-output behaviour.
- There exists unobfuscatable function families

Reading List

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Thanks for attention. Questions?