Remote Entrusting by Orthogonal Client Replacement

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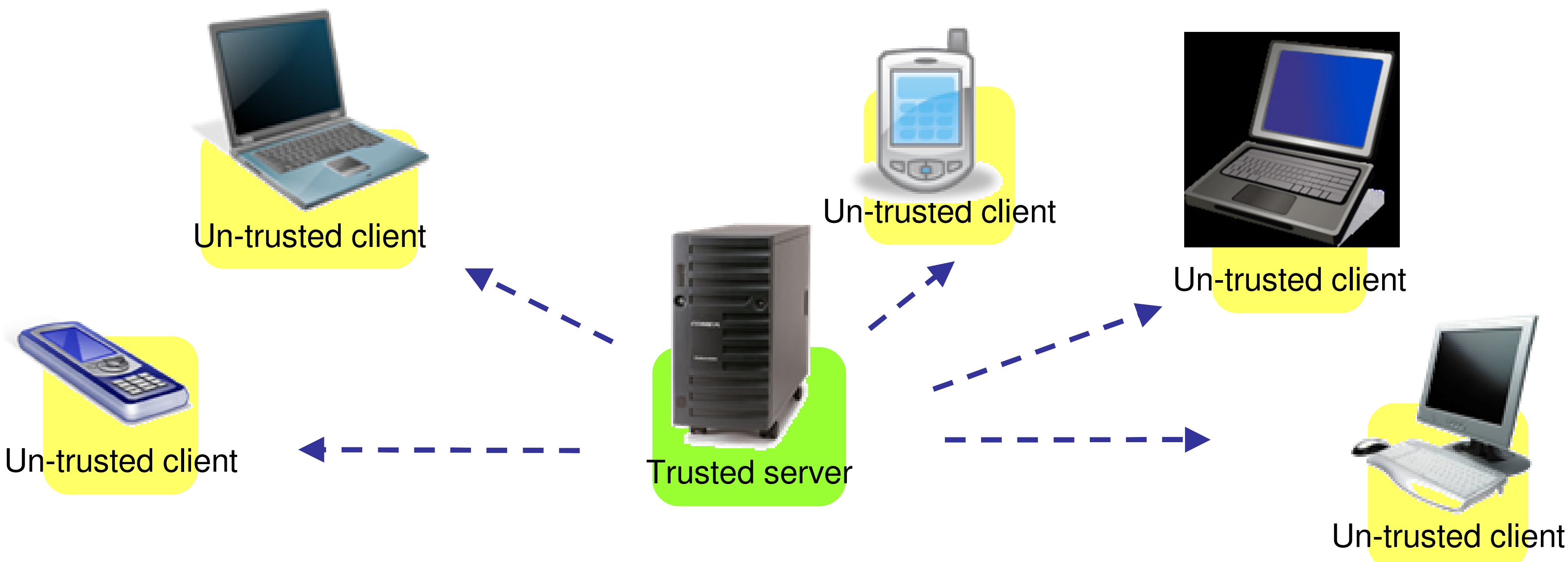
Outline

- Code integrity problem
- Orthogonal replacement
  - Obfuscation
  - Code splitting
- Empirical validation

Remote software trusting

- *Remote entrusting*: A server executing on a trusted host ensuring that an application running on a remote untrusted host (client) is “healthy” (the problem of code integrity)
- Before delivering any service, the server wants to know that the client is executing according to the server’s expectations.



The Attack model

An Attacker can:

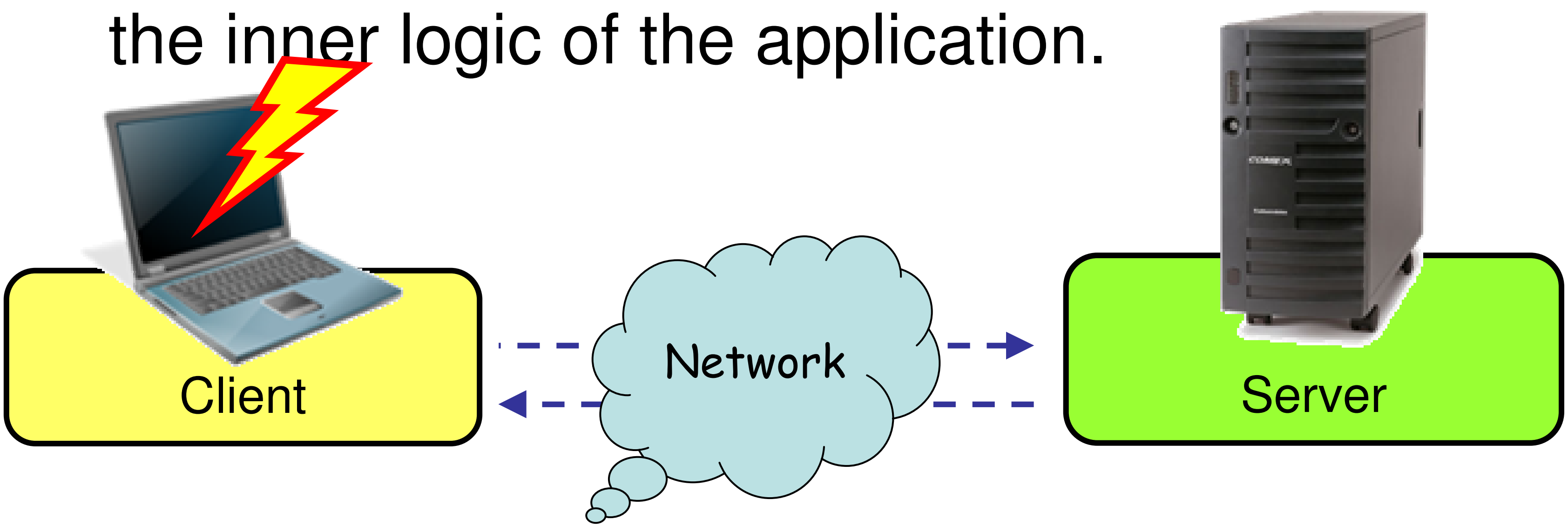
- Use any dynamic/static analysis tool to inspect client's code.
- Read the incoming and outgoing messages.
- Read/write any memory location, network message, file.

Attacks:

- Reverse engineer and make direct code change.
- Runtime modification of the memory.
- Produce (possibly tampered) copies of the client program that run in parallel.
- Interception and tampering of network messages.

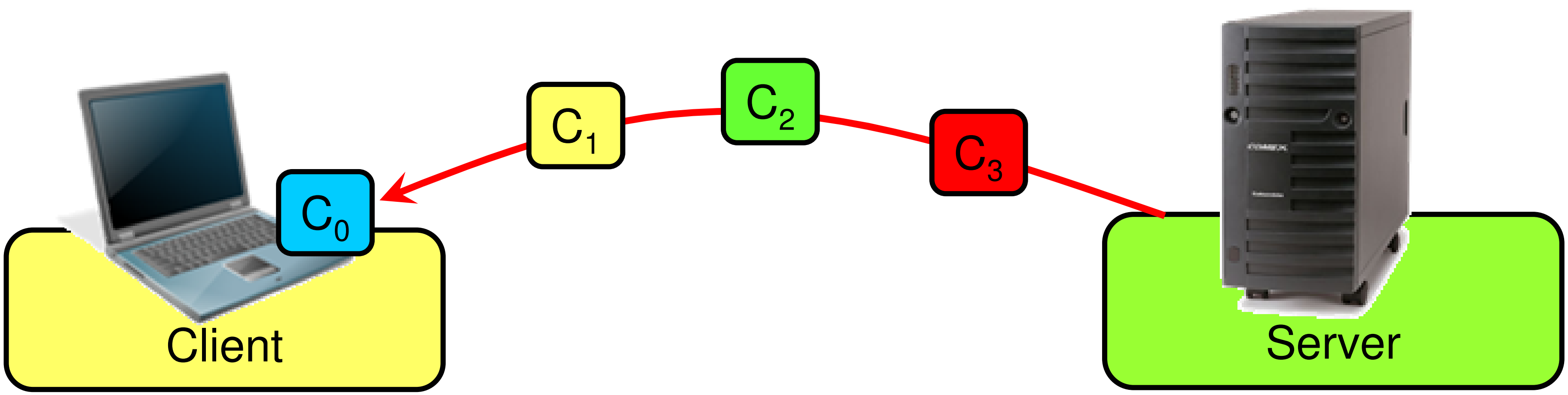
Attacker's goal

- **Goal:** To tamper with the client's code without being detected by the server.
  - Substantial program comprehension effort required by a human adversary to understand the inner logic of the application.



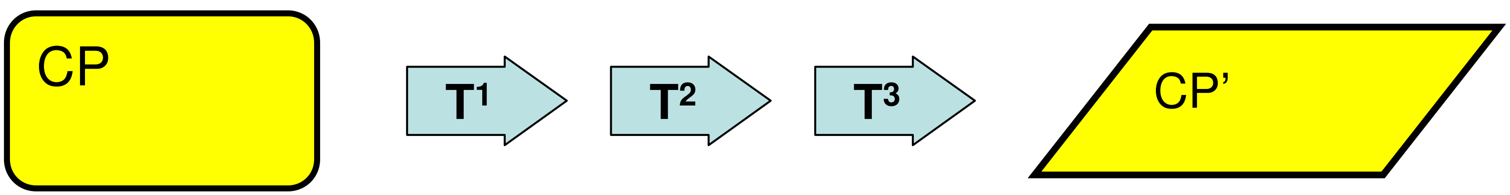
Our approach

- Periodically replace the client code with a new version.
- This is tamper-proofing – provides time limited security and deters attacks.
- We achieve this by applying:
  - Obfuscation techniques
  - Splitting applications
- Before application of the technique, we identify a *Critical Part* (CP) of the application which is security sensitive.



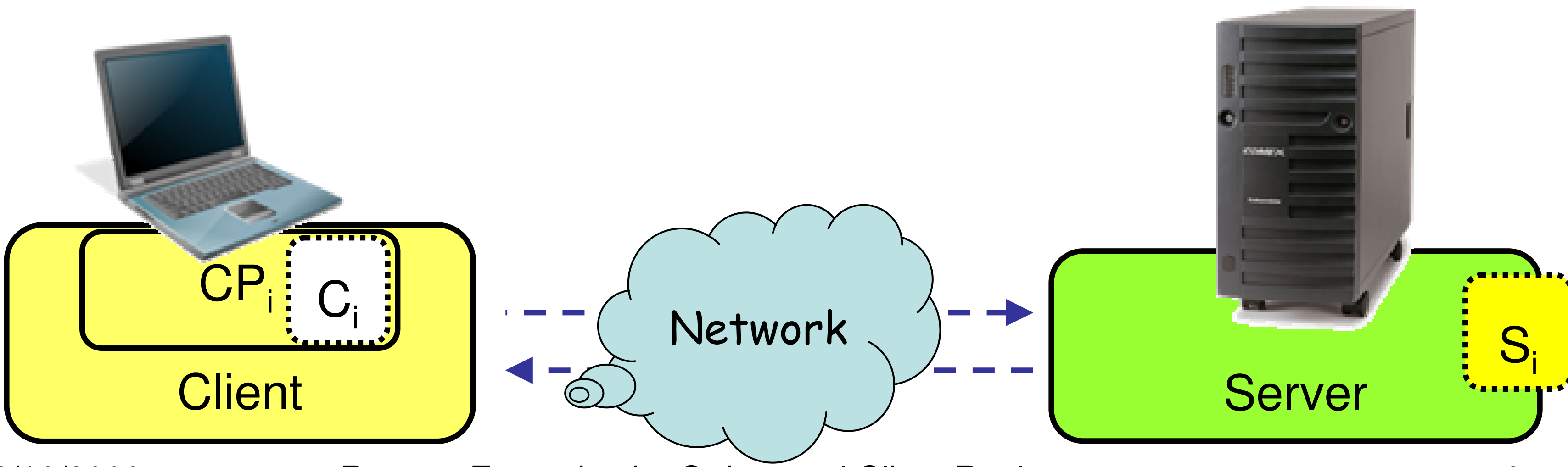
Obfuscation

- Transforming a program CP into an equivalent one CP' that is harder to reverse engineer, while maintaining its semantics.
  - Potency: obscurity added to a program
  - Resilience: how difficult is to automatically de-obfuscate
  - Cost: computation overhead of CP'

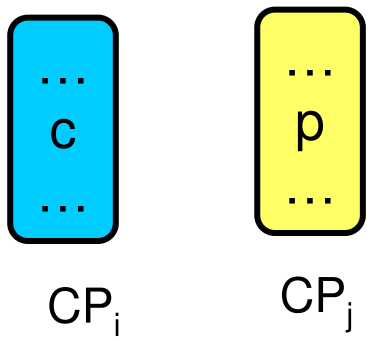


Splitting

- The code of CP_i can be split into (C_i, S_i) where:
  - C_i remains on the client
  - S_i runs on the server
- This process ensures that
  - the code left on the client is orthogonal with respect to the previous clients
  - An expired client can not longer be used (it would not work with the new server)



Orthogonality



<u>Statement orthogonality</u>

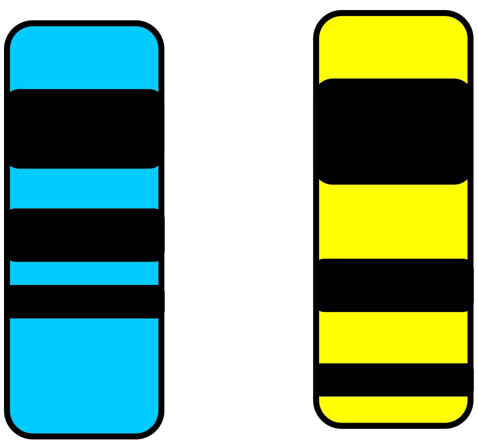
$c \perp p$ if:

the understanding of the of role of ***c*** in $\mathbf{CP_i}$ does not reveal information about the role of ***p*** in $\mathbf{CP_j}$

<u>Program orgononality</u>

$\mathbf{CP_i \perp CP_j}$ if:

they contains only* orthogonal statements



*Not possible to transform or move to the server:

- System calls
- Library calls
- Input output operations

Orthogonal client generation

CP $C_1,\ldots,C_{i-1}$

↓

repeat

CP_i = RandomTransform (CP)

$CP = CP_i$

(C_i, S_i) = MoveCompToServer(CP_i, $C_1,\ldots,C_{i-1}$)

until $(C_i \perp C_1) \wedge \ldots \wedge (C_i \perp C_{i-1})$

↓

(C_i, S_i)

Transformation

repeat

CP_i = RandomTransform (CP)

$CP = CP_i$

(C_i, S_i) = MoveCompToServer($CP_i, C_1,\ldots,C_{i-1}$)

until $(C_i \perp C_1) \wedge \ldots \wedge (C_i \perp C_{i-1})$

- Pool of semantic preserving transformations from a catalog of obfuscations [CTL97]
- Propagations of annotations about black statements and performance information
- The goal is to obstruct code comprehension

Splitting

repeat

CP_i = RandomTransform (CP)

CP = CP_i

(C_i, S_i) = MoveCompToServer$(CP_i, C_1,\ldots,C_{i-1})$

until $(C_i \perp C_1) \wedge \ldots \wedge (C_i \perp C_{i-1})$

Leave on the client:

- Statements of CP_i that are orthogonal to all previous $C_1 \ldots C_{i-1}$
- Invariable part (black)
- Performance intensive statements

Acceptance condition

repeat

CP_i = RandomTransform (CP)

$CP = CP_i$

(C_i, S_i) = MoveCompToServer$(CP_i, C_1,\ldots,C_{i-1})$

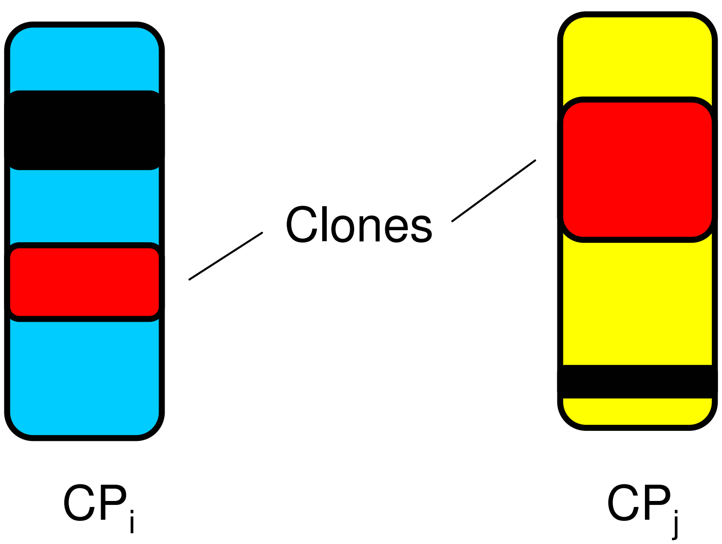
until $(C_i \perp C_1) \wedge \ldots \wedge (C_i \perp C_{i-1})$

- The new client
  - is orthogonal
  - is not just black statements (performance)
- Iterate in case the condition is not met

Empirical validation

Clone based orthogonality

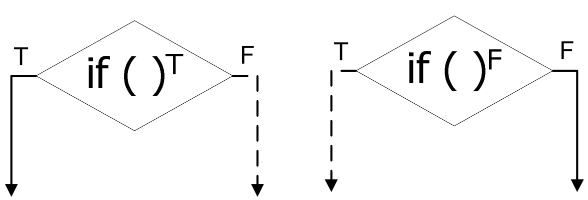
- Orthogonality from a program comprehension point of view is hard to define and quantify
- Practical and computable approximation of orthogonality: based on clones



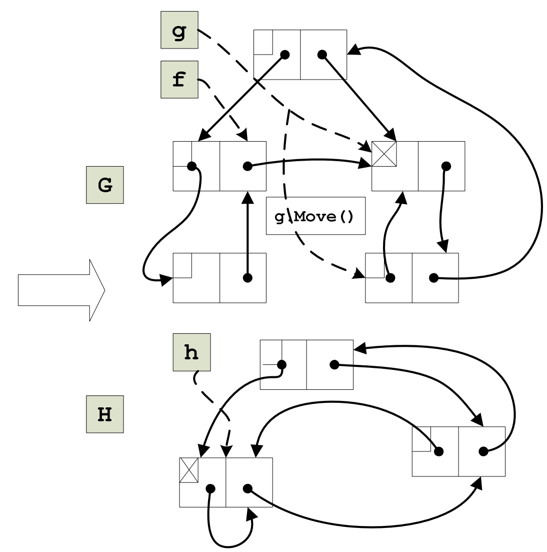
<u>Statement orthogonality</u>
$c \perp p$ if:
the understanding of the role of ***c*** in $\mathbf{CP_i}$ does not reveal information about the role of ***p*** in $\mathbf{CP_j}$

Alias based opaque predicates

- Opaque predicate: conditional expression whose value is known to the obfuscator, but is difficult for an adversary to deduce statically
- Precise inter-procedural static analysis is intractable




```
Node g, h;
Method P(…,Node f)
{
      g = g.Move();
      h = h.Move();
      h = h.Insert(new Node)
…
      if (f==g)? …
      if (g==h)F …
…
      f.Token = False;
      g.Token = True;
      if (f.Token)? …
…
```



Alias based opaque predicates

Aliases :
f = = g
g ! = h
Update :
updateAlias ( )

```
class A {
int f1 ;
int f2 ;
void m ( ) {
  f1 = 1 ;
  f2 = f1 ++;
  int tmp = f1 ;
  tmp = tmp - f1 ;
  f1 = f1 + f2 ;
  }
}
```

```
class A {
int f1 ;
int f2 ;
void m ( ) {
   int tmp ;
   if ( f ==g ) {
       f1 = 1 ;
       updateAlias( ) ;
       f2 = f1 ++;
   }
   else {
      updateAlias( ) ;
      tmp = f1 +f2 / 5 ;
      f1 = f2 - tmp ;
   }
   if ( g != h ) {
         updateAlias( ) ;
         tmp = f1 ;
         tmp = tmp - f1 ;
         updateAlias( ) ;
         f1 = f1 +f2 ;
     }
     else {
         f1 = tmp / f2 ;
         tmp = f2%59+f2 ;
         updateAlias( ) ;
         }
     }
}
```

Case studies

- CarRace (on-line game)
  - CP_{race} = 220 loc
- Chat application
  - CP_{chat} = 110 loc
- On line applications
- Written in Java (~1K loc each)
- Source code is sensitive to malicious modifications

Clone size threshold

Small threshold

- Too many iterations of the algorithm
  - exponential grown of the source code
- Most of the detected clones are false positives
- Improvements do not add security

Large threshold

- Algorithm is fast
- Too many false negatives
  - Clients contain clones that could leak information to an attacker

repeat

CP_i = RandomTransform (CP)

CP = CP_i

(C_i, S_i) = MoveCompToServer($CP_i, C_1, \ldots, C_{i-1}$)

until $(C_i \perp C_1) \wedge \ldots \wedge (C_i \perp C_{i-1})$

Clone size threshold

Application	Min. clone length		Clones
	Statements	Tokens	
CarRace	1	14	123
	2	28	33
	3	42	6
	4	56	1
	5	70	0
ChatClinet	1	12	69
	2	24	27
	3	36	5
	4	48	1
	5	60	0

Generation Performance

Application	No. of clients	No. of clones
CarRace	10	1
	50	9
	100	21
	500	160
	1000	347
ChatClient	10	1
	50	7
	100	11
	500	97
	1000	218

- **Application lifetime 5 years**
- **A replacement every 2 days**

Attacks

- Opaque predicates could be attacked through dynamic analysis (debugging)
  - Removing branches that are not executed could cause the elimination of useful code
  - We could add predicates that infrequently evaluate to True (False) and if removed cause the application to malfunction
  - Use correlated opaque predicates (if such a thing exists)

Future work

- Clone size threshold estimation requires further investigation
- Implementation of a full catalog of obfuscations
  - e.g., variable splitting/encoding of the code left on the client
- Evaluating how long a piece of code can resist before been attacked
  - Correct estimation of the replacement frequency