# Independence from Obfuscation
## A Semantic Framework for Diversity

Riccardo Pucella

Joint work with Fred B. Schneider

CSFW
July 2006

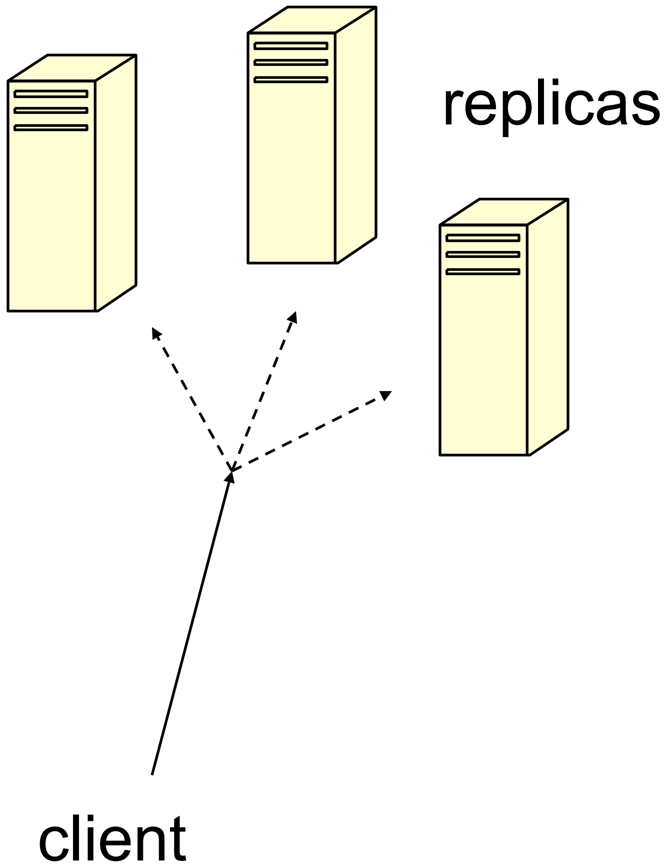
# Why Obfuscation?

Replicated server scenario:

- Attackers exploit implementation details.
- Defense: replica independence

Artificially create diversity:

- Relocate/pad runtime stack
- Rearrange basic blocks and code within basic blocks
- Change system calls or instruction opcodes



# Our Goals

**Ultimate goal:** A precise characterization of obfuscation as a defense mechanism

**Realistic goals:**

- Develop models to understand obfuscation
- Determine effectiveness by comparing to other defenses

# Obfuscators

Obfuscator T transforms programs P into morphs T(P,K) using random key K:

- Source-to-source translation
- Object-level binary rewriting
- Compilation under different strategies

Semantics of morph T(P,K): a set of possible execution histories

# Attacks on Morphs

Attacks equated with inputs (non-assumption):

- **Interface attacks:** obfuscation cannot blunt attacks that exploit the semantics of that (flawed) interface
- **Implementation attacks:** obfuscation can blunt attacks that exploit implementation details

An input is a resistable attack relative to T and K1,…,Kn if T(P,K1),…,T(P,Kn) behave differently on that input

… Depends on what we mean by "differently"

# Equivalence of Executions

"Differently" is in the eye of the beholder:

- Morphs can perform state changes differently
- Morphs can lay out memory differently
- Morphs can represent data differently

"Differently" captured abstractly using a relation $B$

- $(\sigma 1, \ldots, \sigma n) \in B(P, K1, \ldots, Kn)$ iff executions $\sigma 1, \ldots, \sigma n$ have the same behavior
- $B$ need not be an equivalence relation(!)

# How Effective is Obfuscation?

What attacks are blunted?

- Nobody knows!

What attacks are blunted by typing?

- Another commonly advocated defense

But, type systems and obfuscation seem to defend against the same kind of attacks…

Type systems =? obfuscation

# An Exact Type System

For an obfuscator T and keys K1,…,Kn:

- Nonstandard type system that exactly captures resistable attacks relative to T and K1,…,Kn:
  - Before any output, execute the different morphs and compare outputs before proceeding

**Theorem**: Type error signaled if and only if resistable attack relative to T and K1,…,Kn.

# Dealing with Unspecified Keys

Don't know in advance the set of keys, or the set might change (e.g. proactive obfuscation):

- Important to identify attacks relative to unspecified sets of keys

A resistable attack relative to T is a resistable attack relative to T and ***some*** finite set of keys

# A Probabilistic Approximation

1. Choose keys K1, …, Kn at random
2. Use exact type system with keys K1, …, Kn
   - Identifies resistable attacks relative to T and K1,…,Kn
   - May miss resistable attacks relative to T and other keys
   - Some probability of identifying a resistable attack relative to some finite set of keys

More precise type systems:

language- and obfuscator-dependent!

## Example Program:
# Buffer Overflows

```
main(i:int) {
 var x : int;
     buf : int[3];
 x := 99;
 buf[i] := 42;
 print(x);
}
```

No checks on:

- Pointer arithmetic
- Array reference

On inputs 0,1,2

- Output is 99

On input -1

- Output is 42

# Example Obfuscation:
# Address Randomization

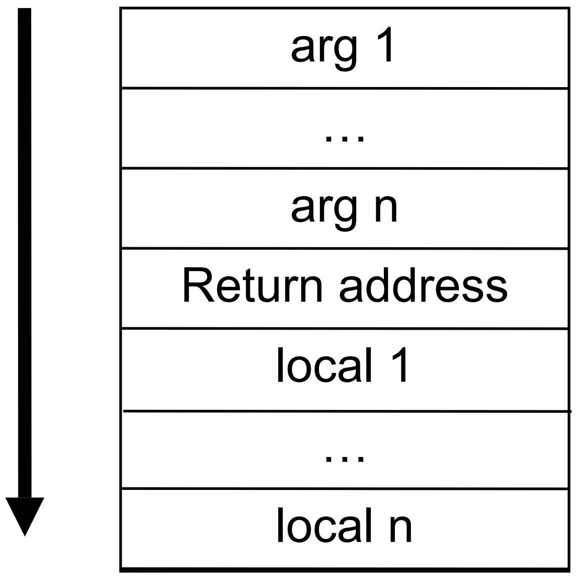
Ensure memory outside a buffer cannot be accessed reliably [Bhaktar et al. 2003]

Obfuscator $T_{addr}$ with keys $(l_0, d, \Pi, M_{init})$

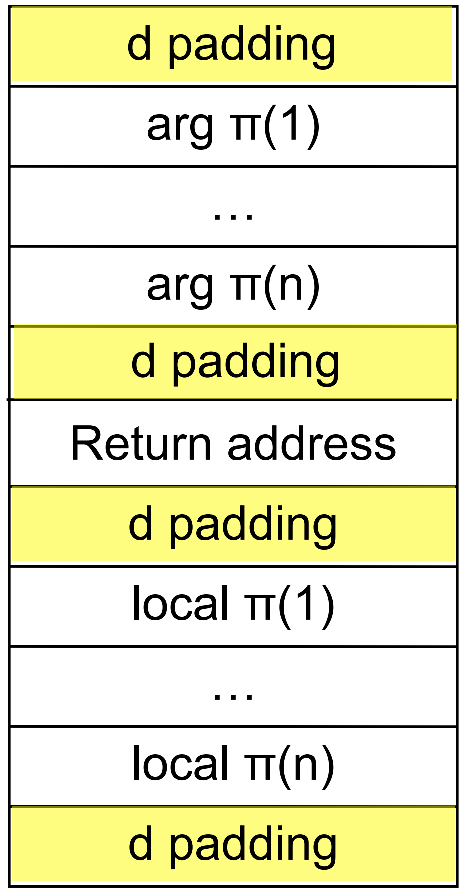
- $l_0$: start of stack
- d: padding size
- $\Pi$: permutations
- $M_{init}$: initial memory

# Implementation of Calls

Usual stack:




$T_{addr}$-morphs stack:



# Resistable Attacks for $T_{addr}$

```
main(i:int) {
 var x : int;
     buf : int[3];
 x := 99;
 buf[i] := 42;
 print(x);
}
```

0,1,2 are not resistable attacks relative to $T_{addr}$

-1 is a resistable attack relative to $T_{addr}$

# An Impossibility Result

**Earlier**: Type systems capture resistable attacks relative to $T_{addr}$ and a fixed set of keys.

**Theorem**: No computable dynamic type system can signal a type error for an input if and only if that input is a resistable attack relative to $T_{addr}$

The best we can do is approximate

# Approximation: Strong Typing

Cf. CCured, Cyclone

- Type of direct values (integer)
- Type of pointers (plus allowed range)

Type error: dereferencing a pointer out of range

**Theorem**: If resistable attack relative to $T_{addr}$, then strong typing signals a type error

# What Approximation Do We Get?

```
main () {
 var a : int[5];
     x : int;
 x := a[10];
 print(x);
}
```

# What Approximation Do We Get?

```
main () {
 var a : int[5];
     x : int;
 x := a[10];
 print(x);
}
```

Appropriately signals a type error

Different morphs with different initial values in a[10] produce different outputs

# What Approximation Do We Get?

```
main () {
 var a : int[5];
     x : int;
 x := a[10];
 print(0);
}
```

Still signals a type error

The value read from `a[10]` has no observable effect!

But all morphs output 0, so no resistable attack present.

# A More Accurate Type System

Track integrity of values by adding new type

- Type **low**: different value in different morphs
- When dereferencing a pointer out of range, value gets type **low**
- PC gets type **low** if control flow depends on value of type **low**

Type error: output depends on a value of type **low**

**Theorem**: If a resistable attack relative to $T_{addr}$, then type system signals a type error

# What Approximation Do We Get?

```
main() {
  var a : int[5];
      x : int;
  x := a[10];
  if (x=0) then
   print(1);
  else
   print(2);
}
```

# What Approximation Do We Get?

```
main() {
  var a : int[5];
      x : int;
  x := a[10];
  if (x=0) then
   print(1);
  else
   print(2);
}
```

Appropriately signals a type error at either of these points

Control flow depends on x, which carries a value of type **low**

# What Approximation Do We Get?

```
main() {
  var a : int[5];
      x : int;
  x := a[10];
  if (x=x) then
    print(1);
  else
    print(2);
}
```

Now every morph outputs 1 because x=x is always true

But signals a type error, even though no resistable attack occurs.

Presumably, we can take care of x=x as a special case…

# What Approximation Do We Get?

```
main() {
 var a : int[5];
     x : int;
 x := a[10];
 if (f(x)) then
  print(1);
 else
  print(2);
}
```

… but undecidable in general whether `f(x)` always true

Just a special case of impossibility theorem

**Key point**: limited by how precisely can track information flow

# Conclusions

- Initiated a theoretical study of obfuscation as a defense mechanism
  - In particular, compared with type systems
- We have ignored the probabilities!
  - In practice, probabilities matter
    - What's the probability that an attack is blunted?
  - Depend on how much diversity is introduced by obfuscation
  - Seem difficult to obtain

# Type Systems vs Obfuscation

- Type systems:
  - Prevent attacks (always - not just probably)
  - If static, add no run-time cost
  - Not always part of the language
- Obfuscation:
  - Works on legacy code
  - Doesn’t always defend