Software Protection: How to Crack Programs, and Defend Against Cracking

MGU, Spring 2015

www.cs.arizona.edu/~collberg

About me

- PhD from 

- Five years on the faculty at 

- One year at 

中国科学院自动化研究所
INSTITUTE OF AUTOMATION CHINESE ACADEMY OF SCIENCES
- Currently Professor at 

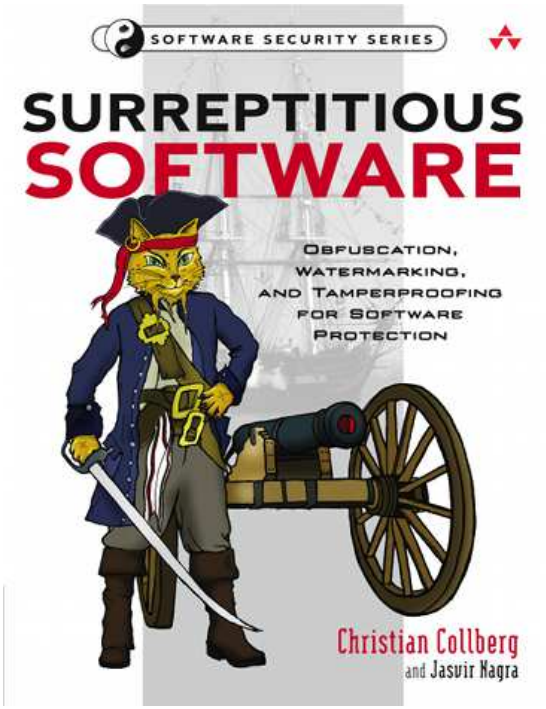
Professional Interests

- Software Protection (`tigress.cs.arizona.edu`)
- Compilers
- Programming Languages
- Scientific Ethics
- Secure Provenance (`haathi.cs.arizona.edu`).

Personal Interests

- Travel (38 countries so far. . .)
- Photography:
  `www.cs.arizona.edu/~collberg/#travel`
- Foreign Languages
- Music:

Education



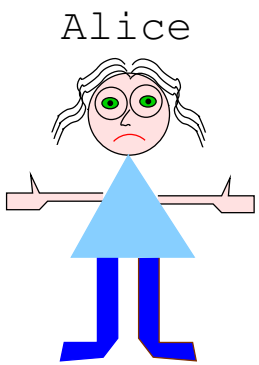
- I teach courses on programming languages, compilers, computer security.

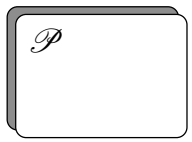
Contact me

- www.cs.arizona.edu/~collberg
- collberg@gmail.com

MATE Scenarios

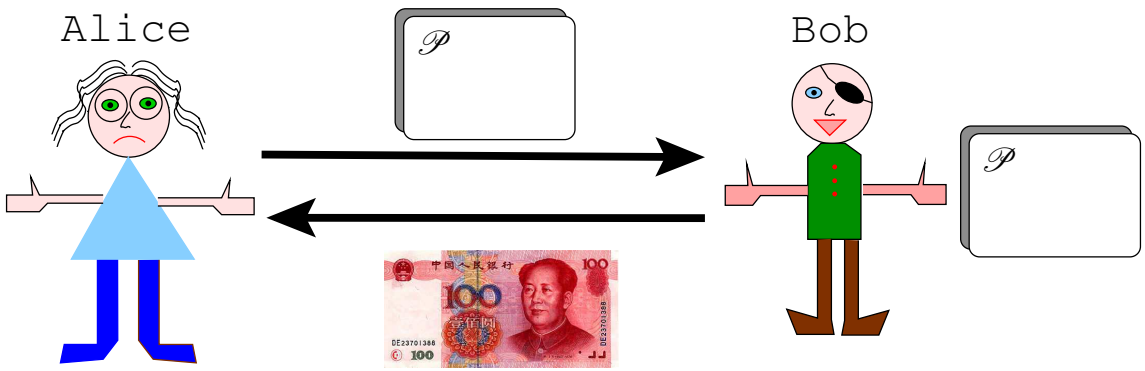
Software piracy





- Alice is a software developer.

Software piracy



- Alice is a software developer.
- Bob buys one copy of Alice's program.

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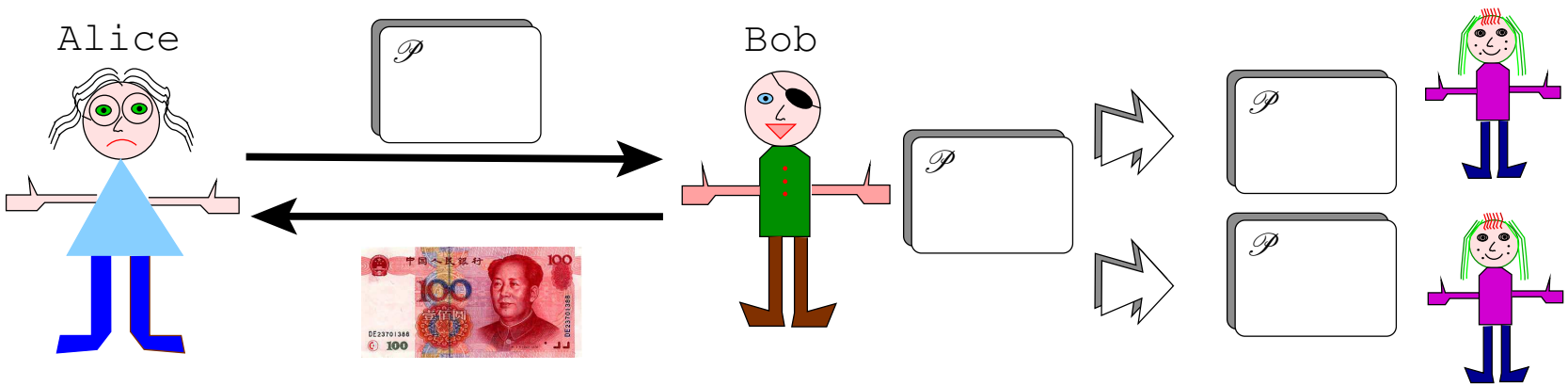
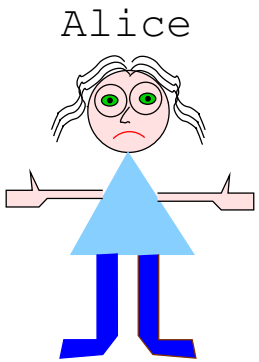


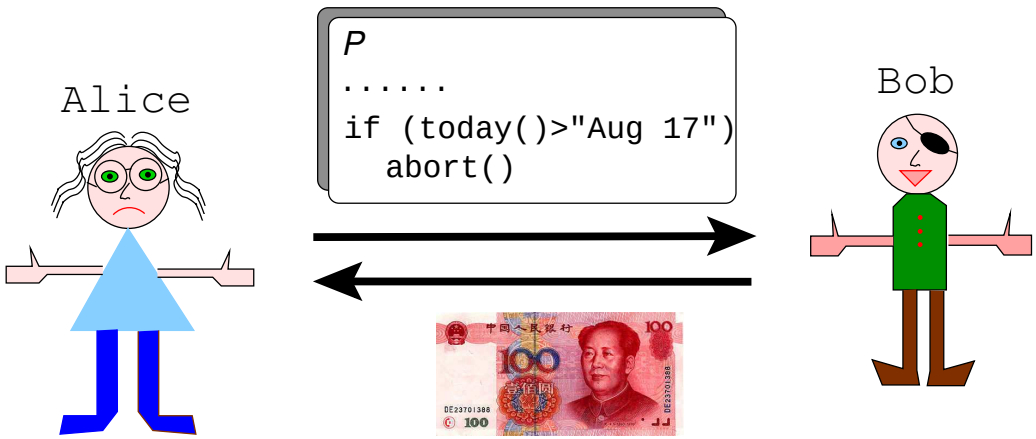
- Alice is a software developer.
- Bob buys one copy of Alice's program.
- Bob illegally sells copies to his friends.

License check tampering




```
P
......
if (today()>"Aug 17")
  abort()
```

License check tampering



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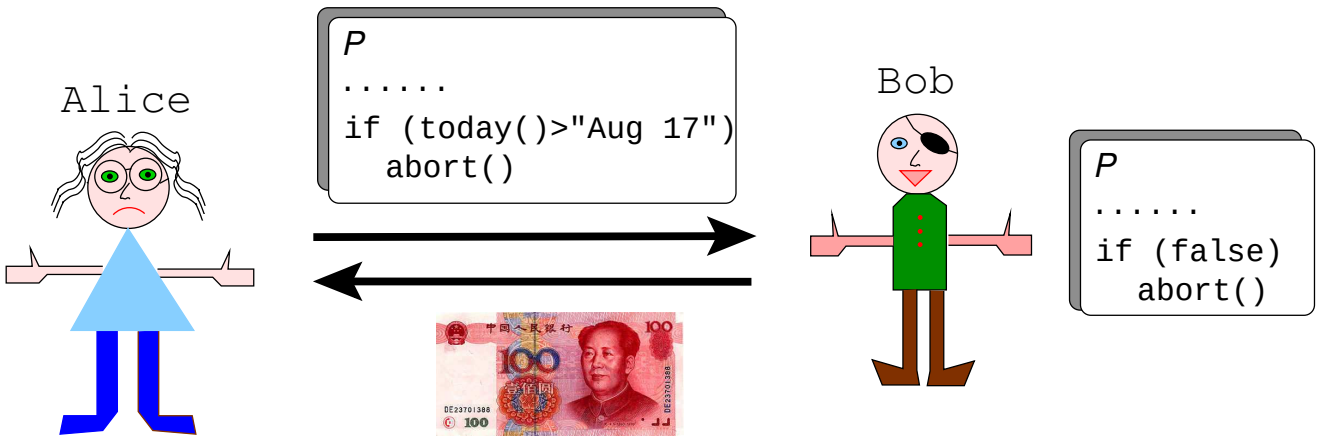

- Bob removes license checks to be able to run the program whenever he wants.

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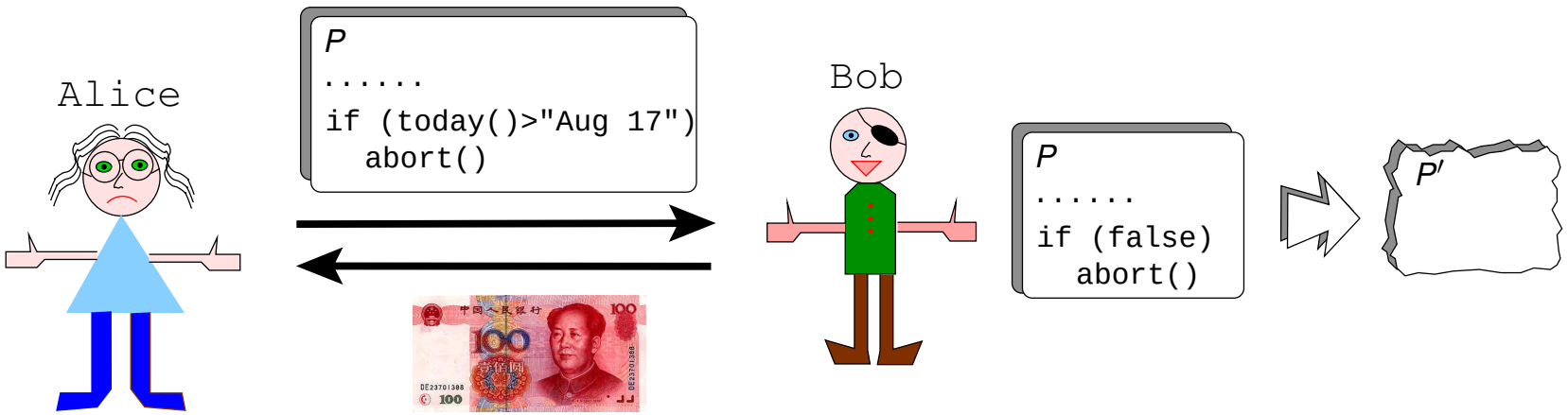
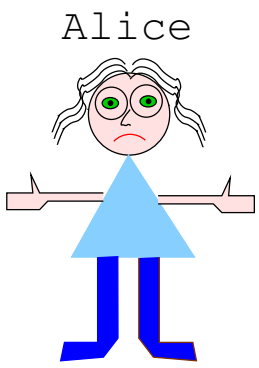
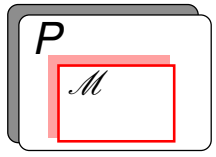


- Bob removes license checks to be able to run the program whenever he wants.
- Alice protects her program so that it won't run after being tampered with.

Malicious reverse engineering





- Alice's program contains a valuable trade secret (a clever algorithm or design).

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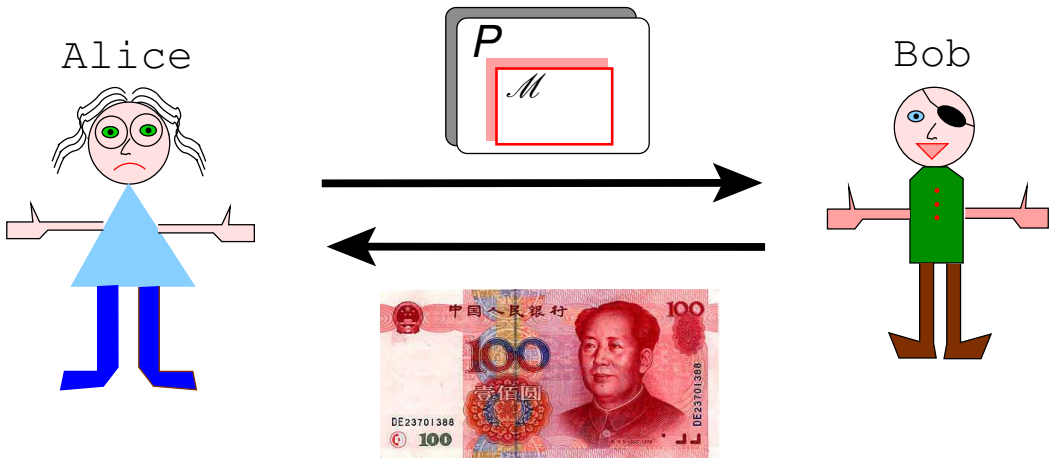

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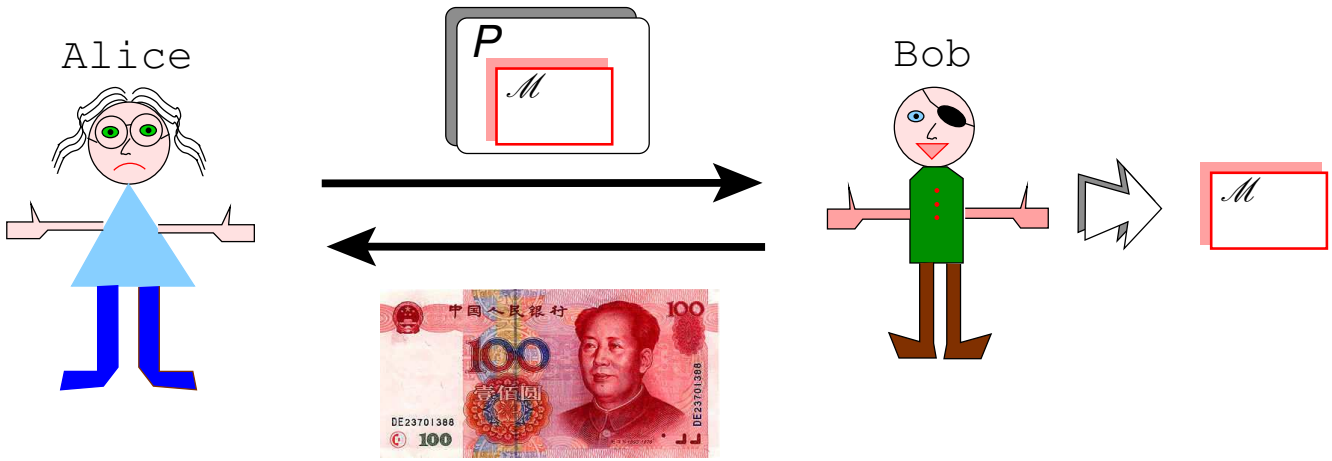

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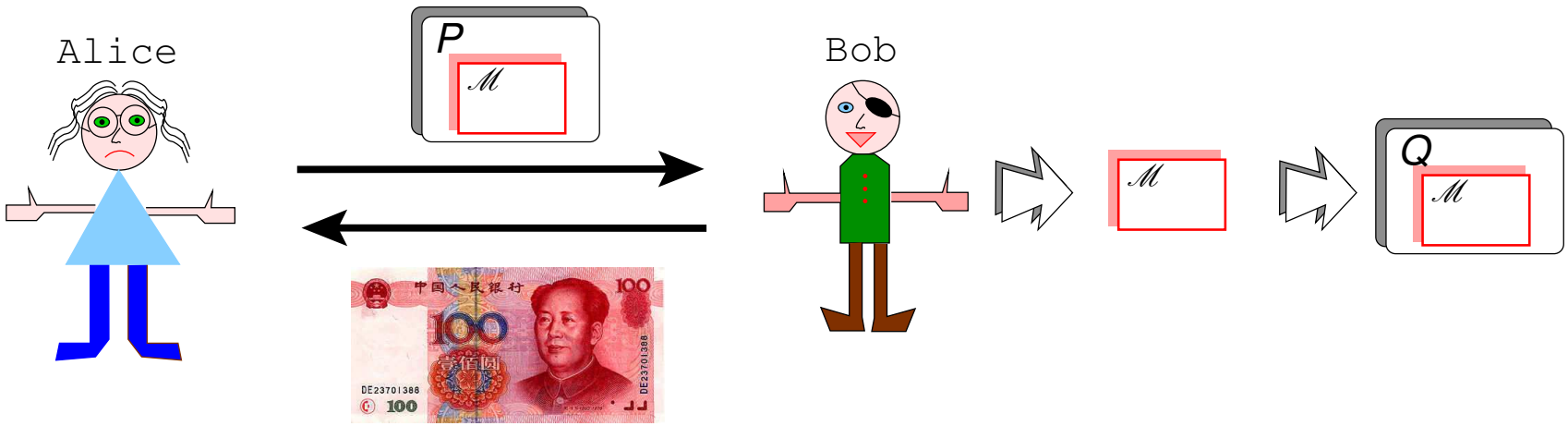

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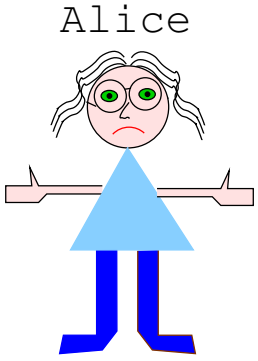

- A DRM media player contains cryptographic keys that unlock and play encrypted music files.

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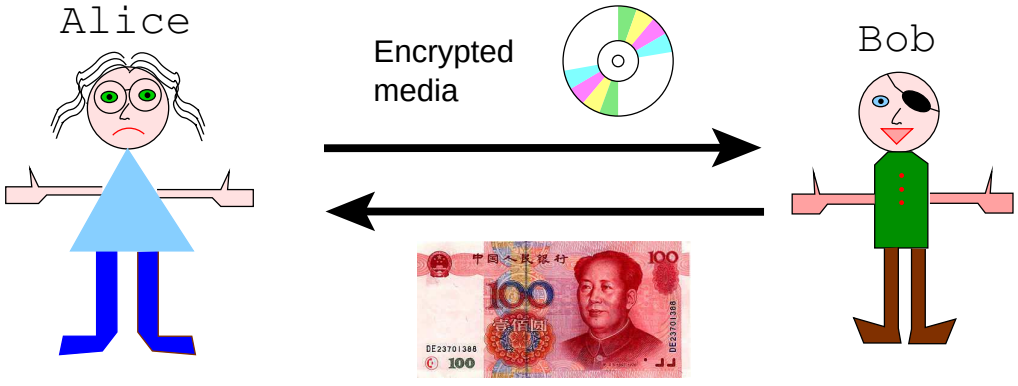

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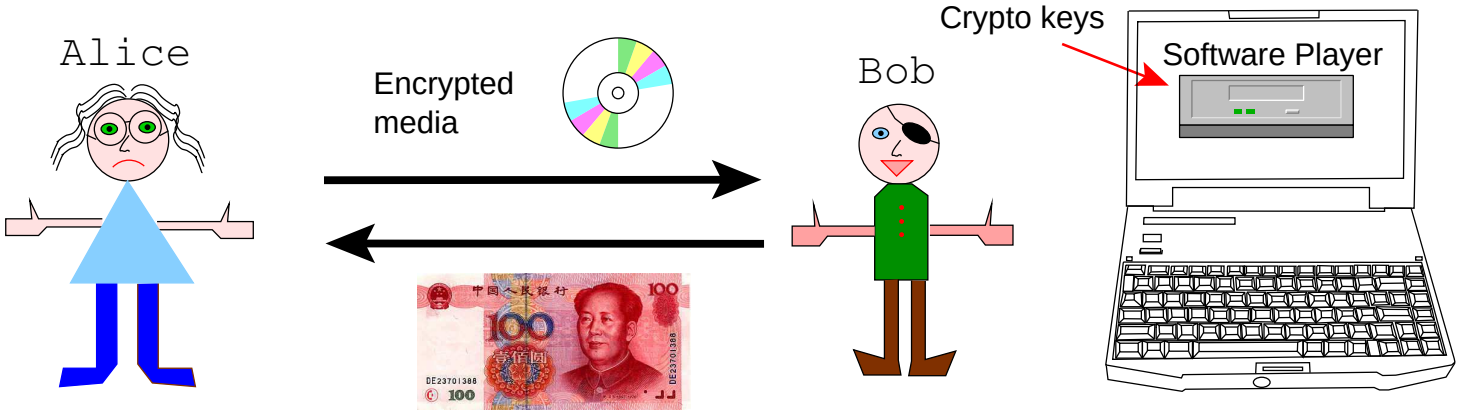

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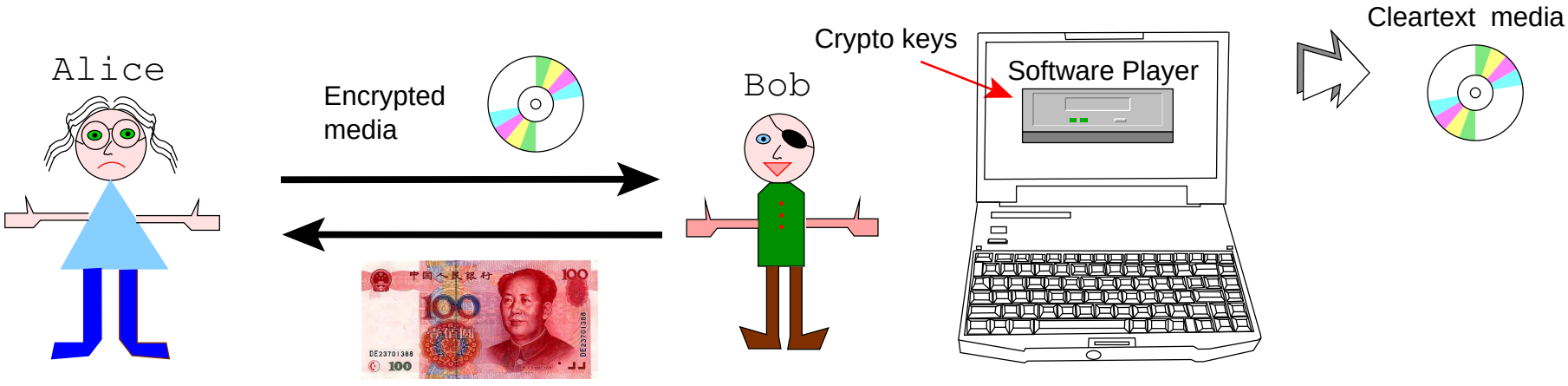

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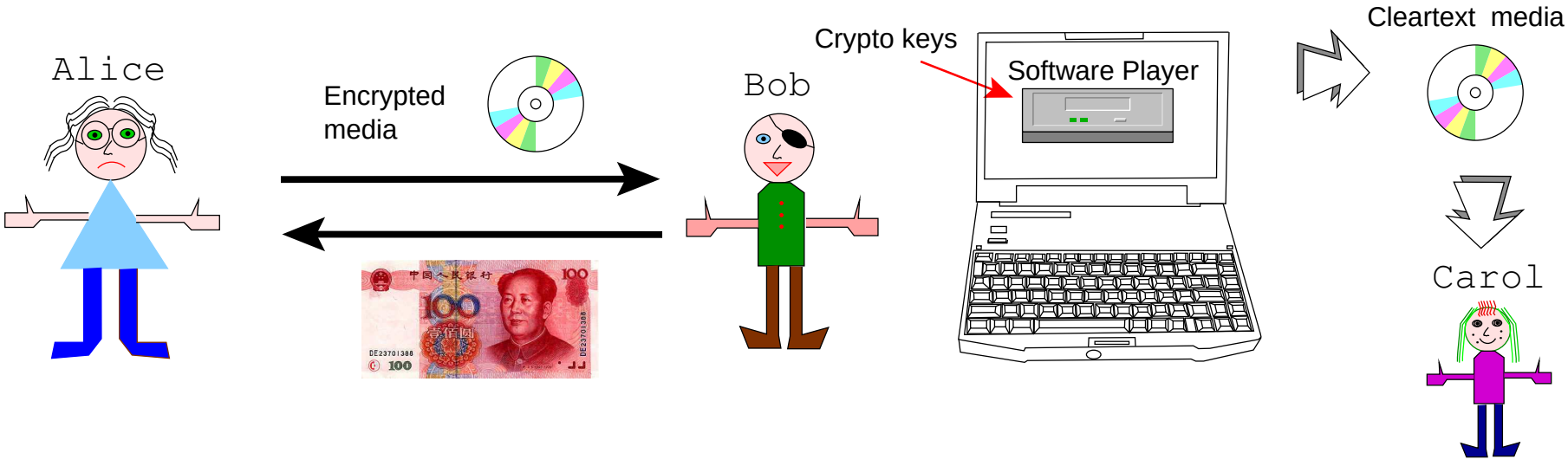

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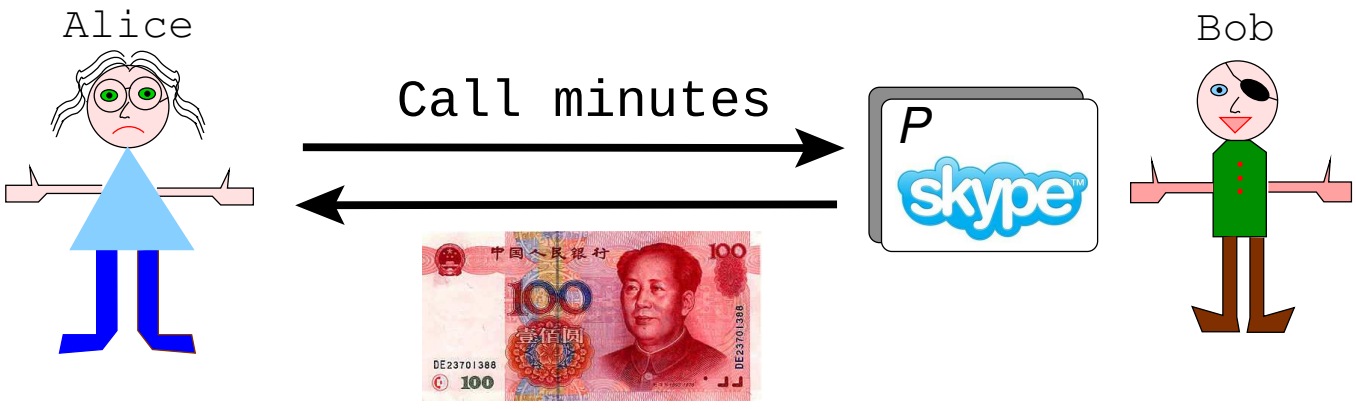
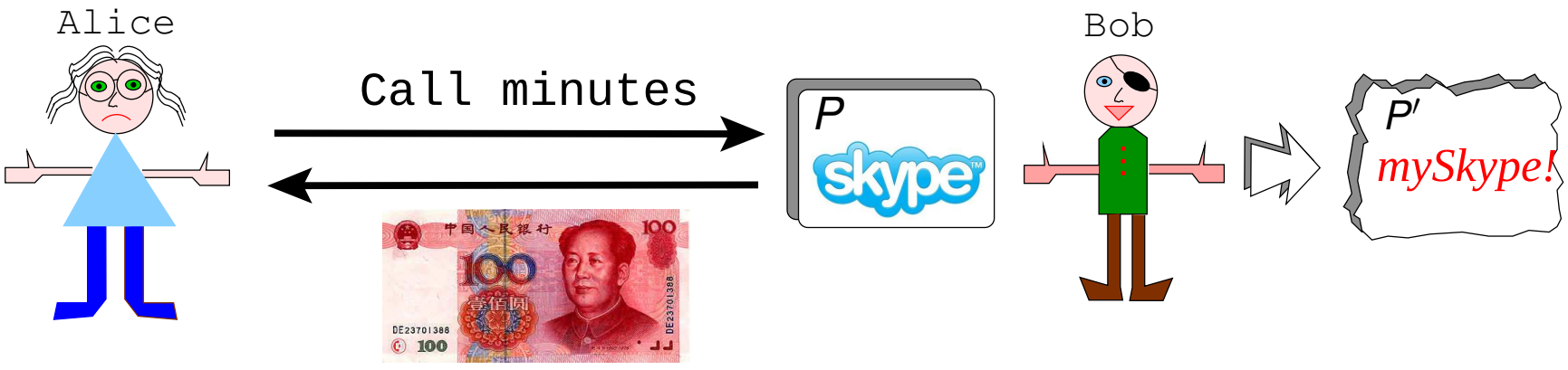
Protocol discovery



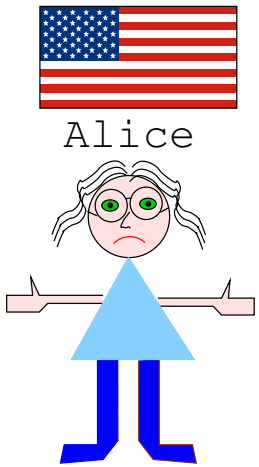
- Alice sells voice-over-IP call minutes.

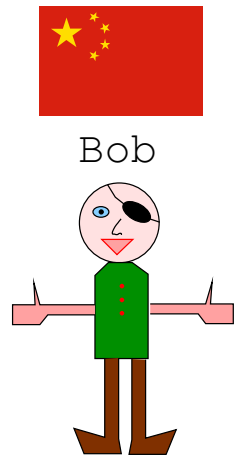
Protocol discovery



- Alice sells voice-over-IP call minutes.
- Bob examines the VoIP client to discover proprietary protocols to build his own rival client.

Protecting military software





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Protecting military software

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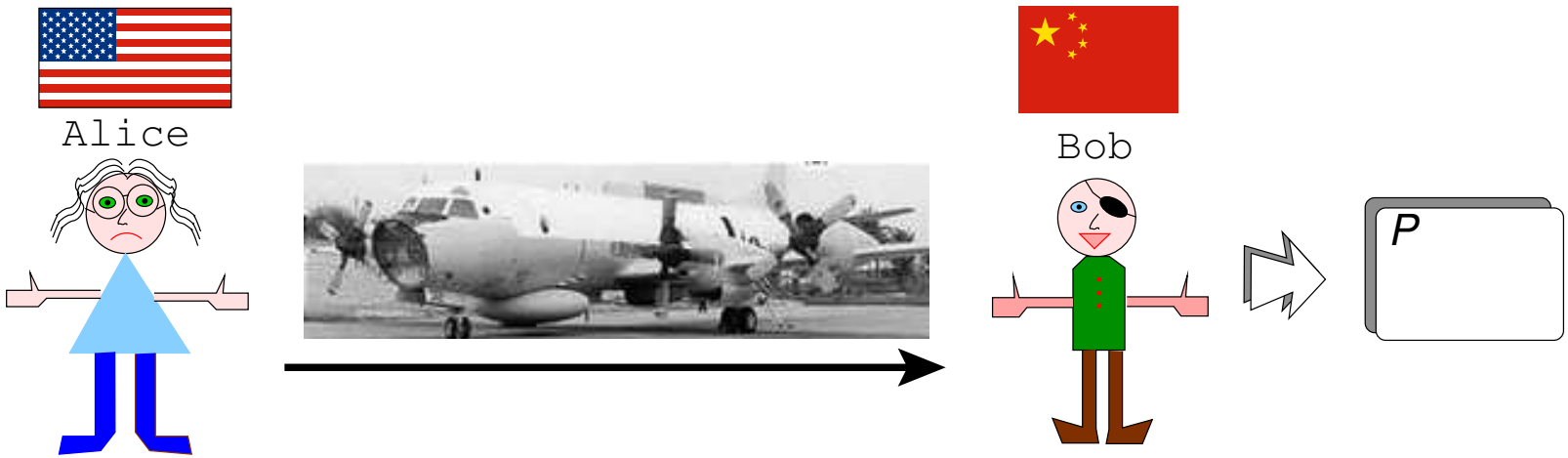

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The Man-At-The-End Problem

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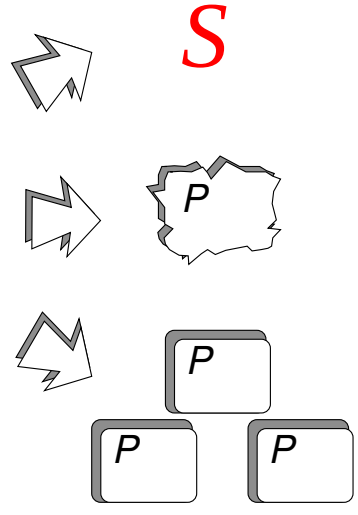

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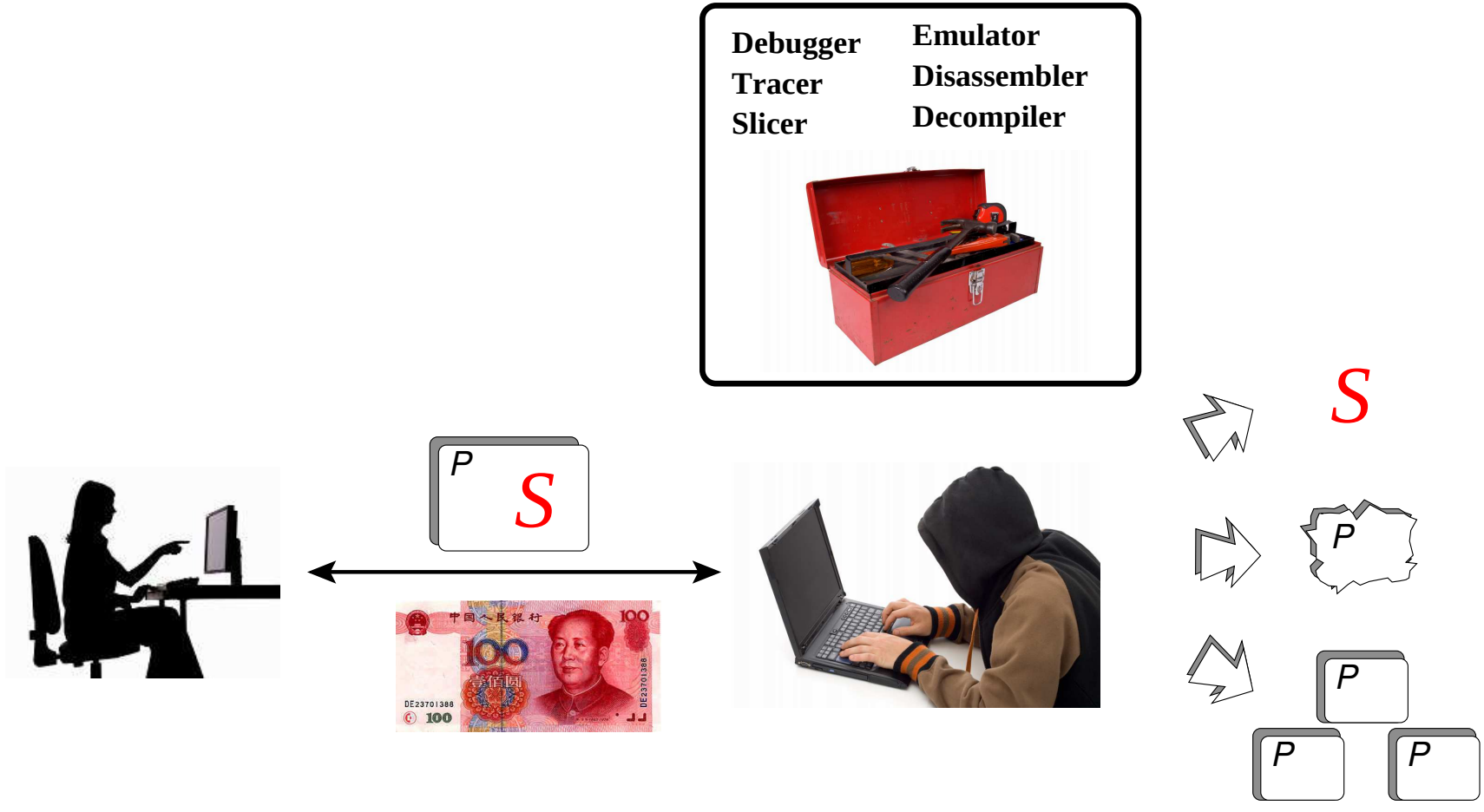
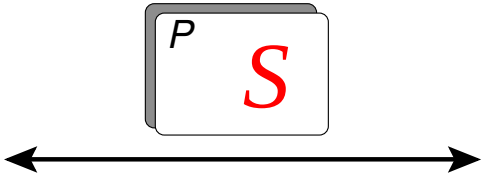
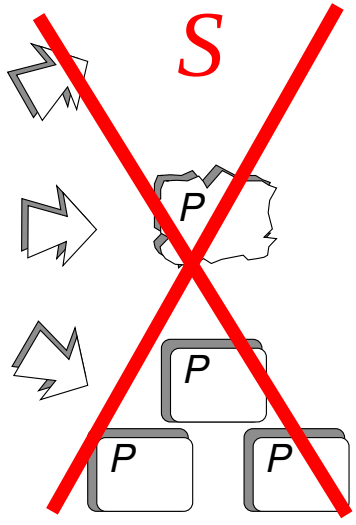


The Man-At-The-End Problem

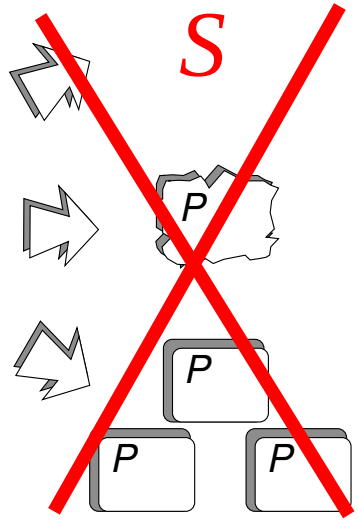
Debugger **Emulator**
Tracer **Disassembler**
Slicer **Decompiler**





The Man-At-The-End Problem

1. Static/Dynamic Analysis
2. Modify
3. Test
4. Did it work?



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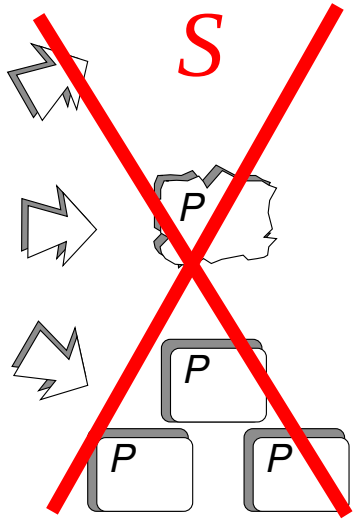
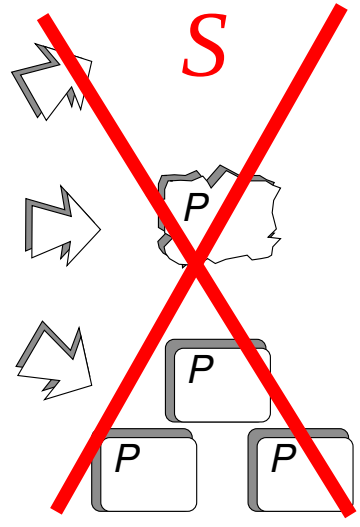


The Man-At-The-End Problem

1. Static/dynamic analysis
2. Select code
3. Select transformation
4. Apply transformation
5. Done?



The Man-At-The-End Problem

Code Transformations

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3. Select transformation
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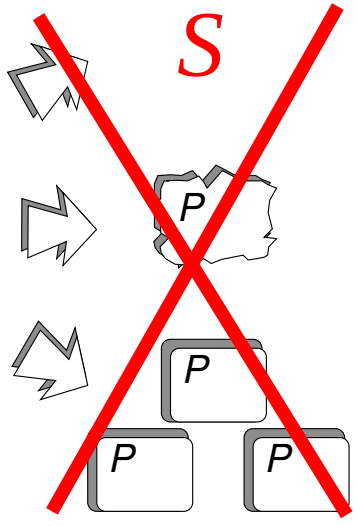
```



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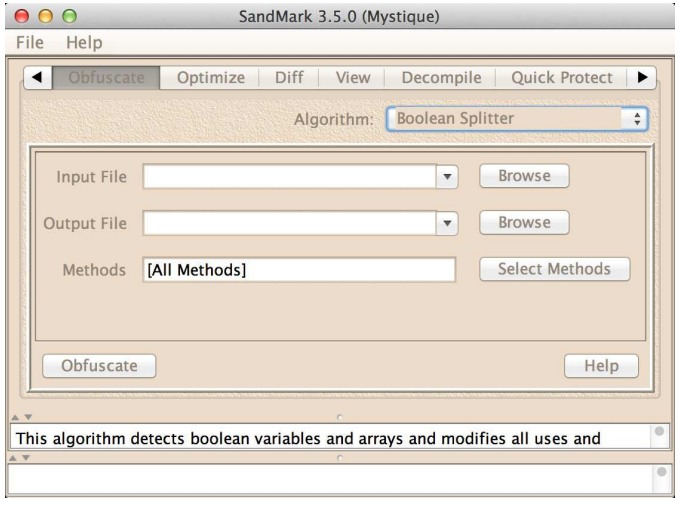
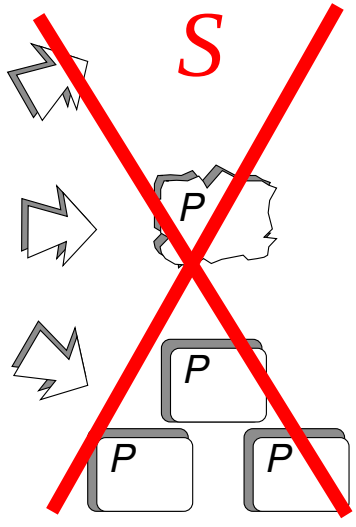
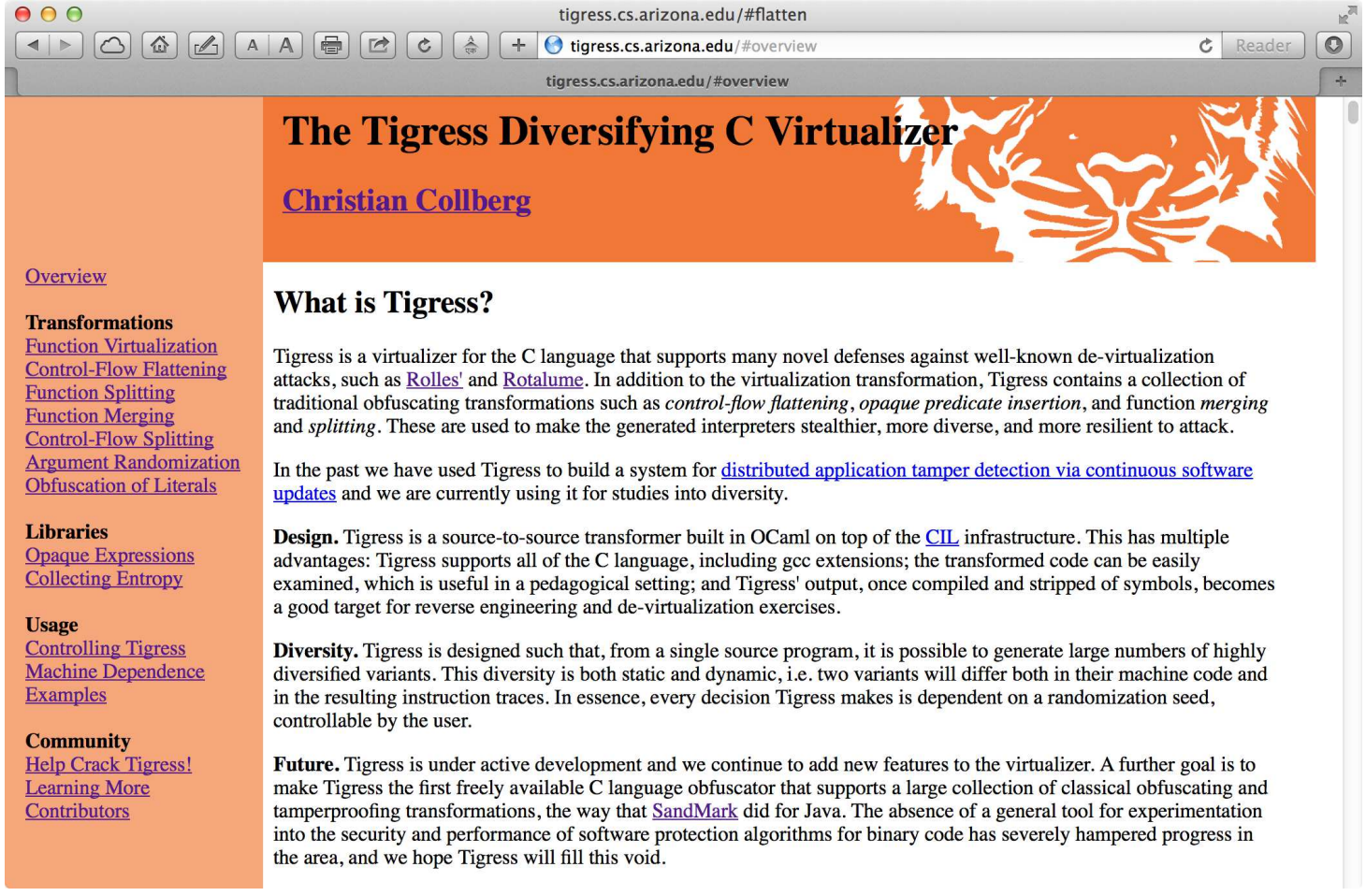


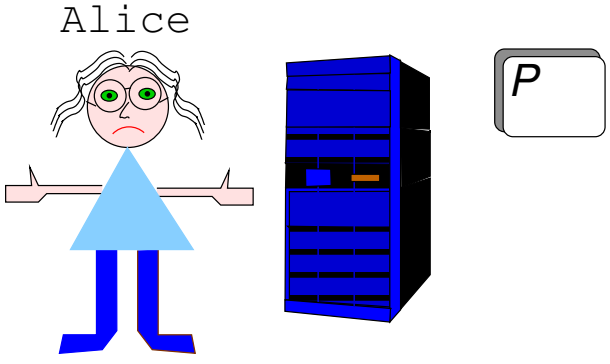


Tigress


tigress.cs.arizona.edu/#flatten
tigress.cs.arizona.edu/#overview
Reader
tigress.cs.arizona.edu/#overview
The Tigress Diversifying C Virtualizer
Christian Collberg
Overview
Transformations
Function Virtualization
Control-Flow Flattening
Function Splitting
Function Merging
Control-Flow Splitting
Argument Randomization
Obfuscation of Literals
Libraries
Opaque Expressions
Collecting Entropy
Usage
Controlling Tigress
Machine Dependence
Examples
Community
Help Crack Tigress!
Learning More
Contributors
What is Tigress?
Tigress is a virtualizer for the C language that supports many novel defenses against well-known de-virtualization attacks, such as Rolles' and Rotalume. In addition to the virtualization transformation, Tigress contains a collection of traditional obfuscating transformations such as control-flow flattening, opaque predicate insertion, and function merging and splitting. These are used to make the generated interpreters stealthier, more diverse, and more resilient to attack.
In the past we have used Tigress to build a system for distributed application tamper detection via continuous software updates and we are currently using it for studies into diversity.
Design. Tigress is a source-to-source transformer built in OCaml on top of the CIL infrastructure. This has multiple advantages: Tigress supports all of the C language, including gcc extensions; the transformed code can be easily examined, which is useful in a pedagogical setting; and Tigress' output, once compiled and stripped of symbols, becomes a good target for reverse engineering and de-virtualization exercises.
Diversity. Tigress is designed such that, from a single source program, it is possible to generate large numbers of highly diversified variants. This diversity is both static and dynamic, i.e. two variants will differ both in their machine code and in the resulting instruction traces. In essence, every decision Tigress makes is dependent on a randomization seed, controllable by the user.
Future. Tigress is under active development and we continue to add new features to the virtualizer. A further goal is to make Tigress the first freely available C language obfuscator that supports a large collection of classical obfuscating and tamperproofing transformations, the way that SandMark did for Java. The absence of a general tool for experimentation into the security and performance of software protection algorithms for binary code has severely hampered progress in the area, and we hope Tigress will fill this void.

R-MATE Scenarios

Scenario: Protecting networked computer games



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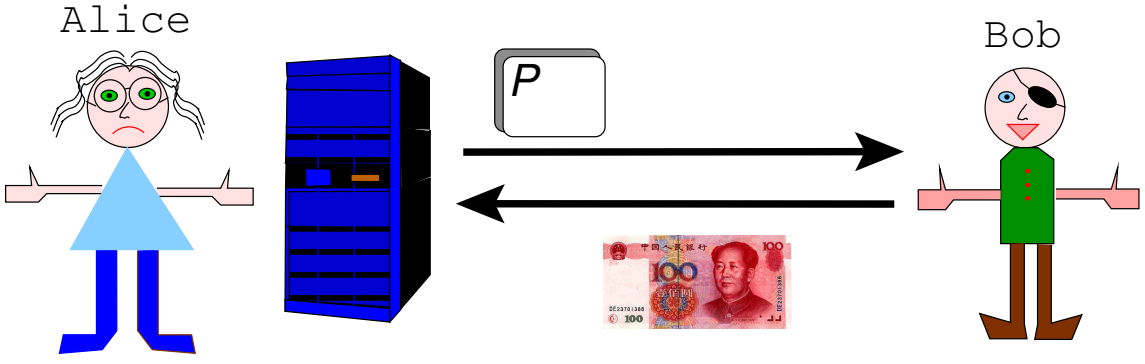

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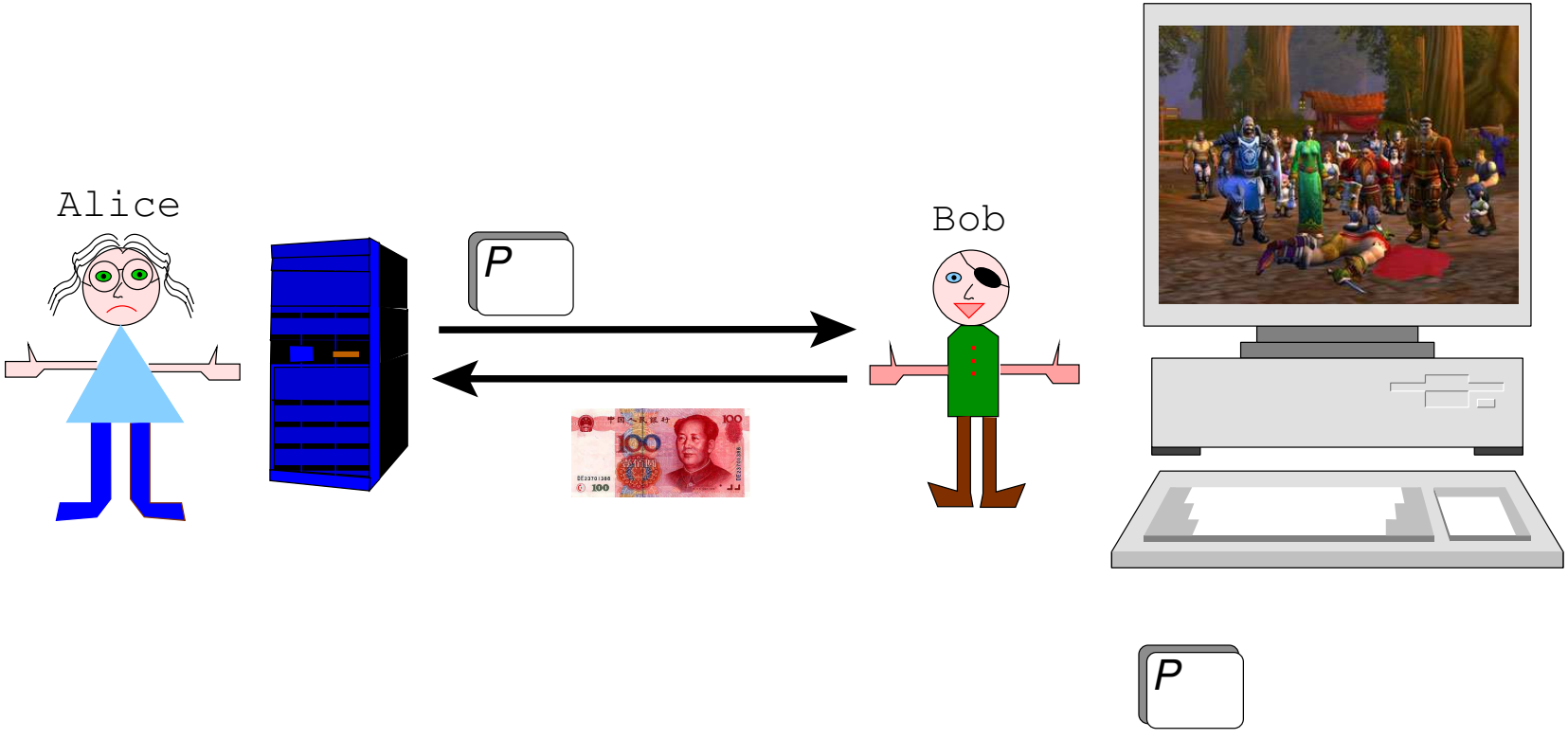

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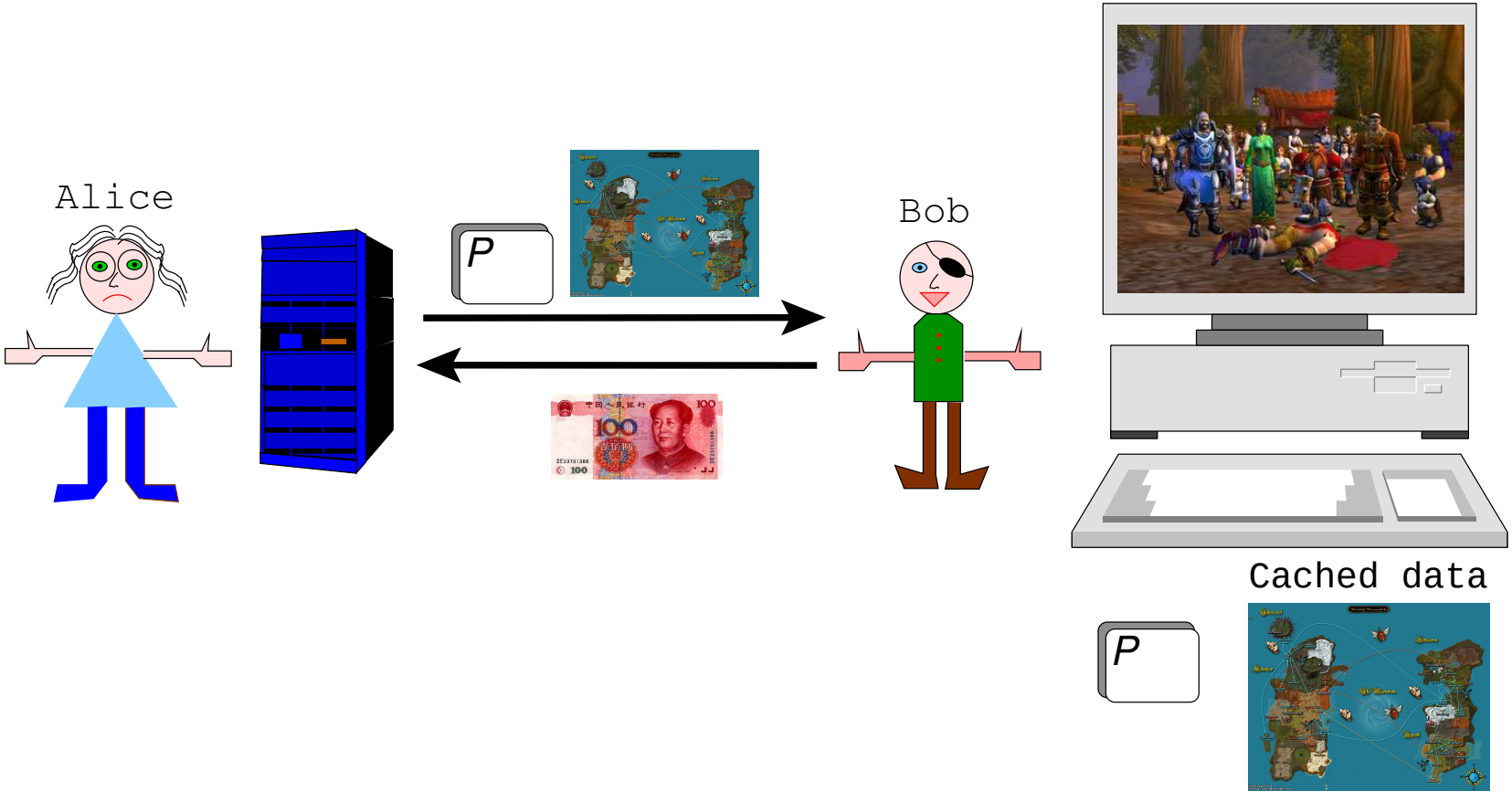

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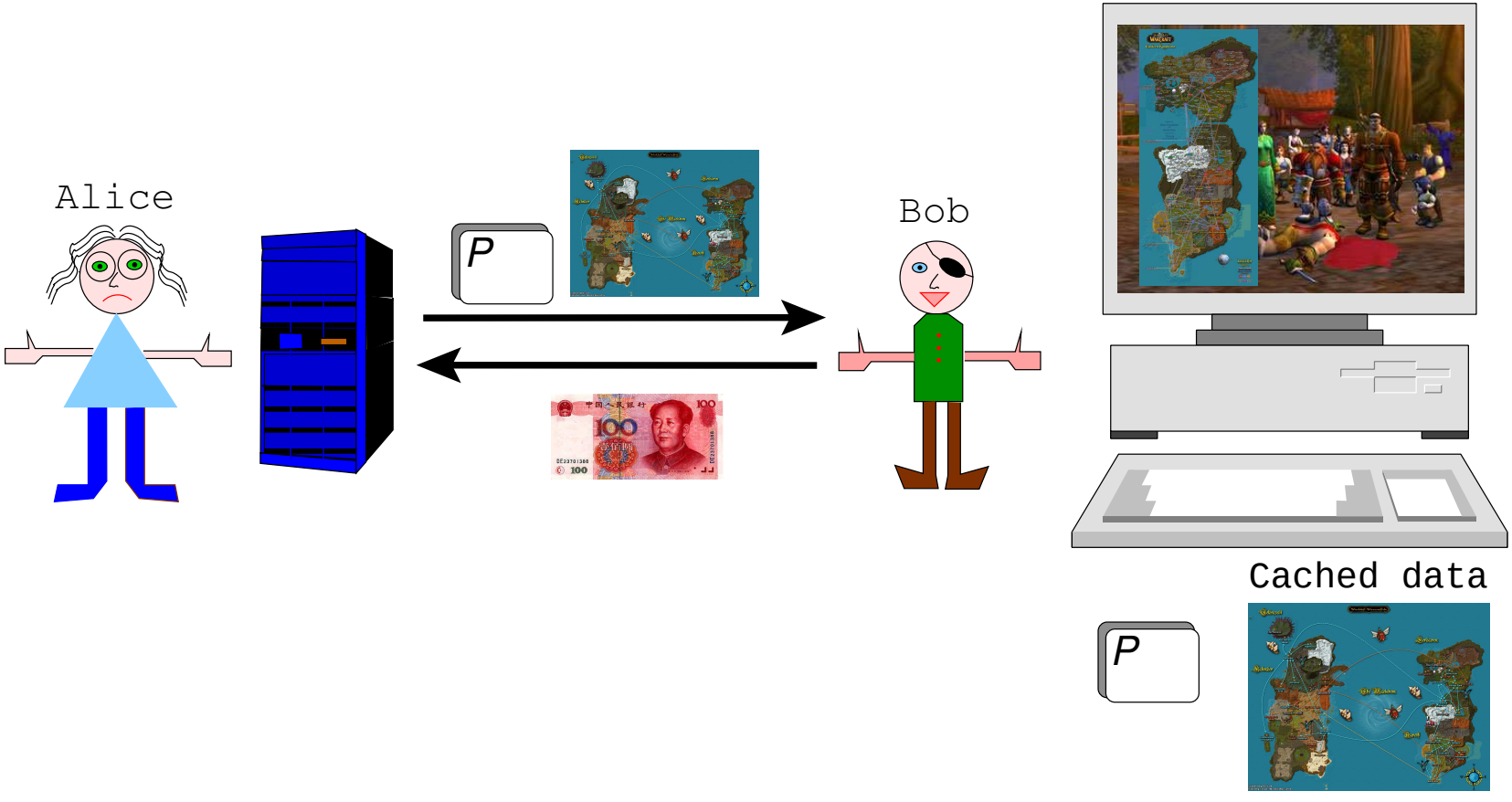

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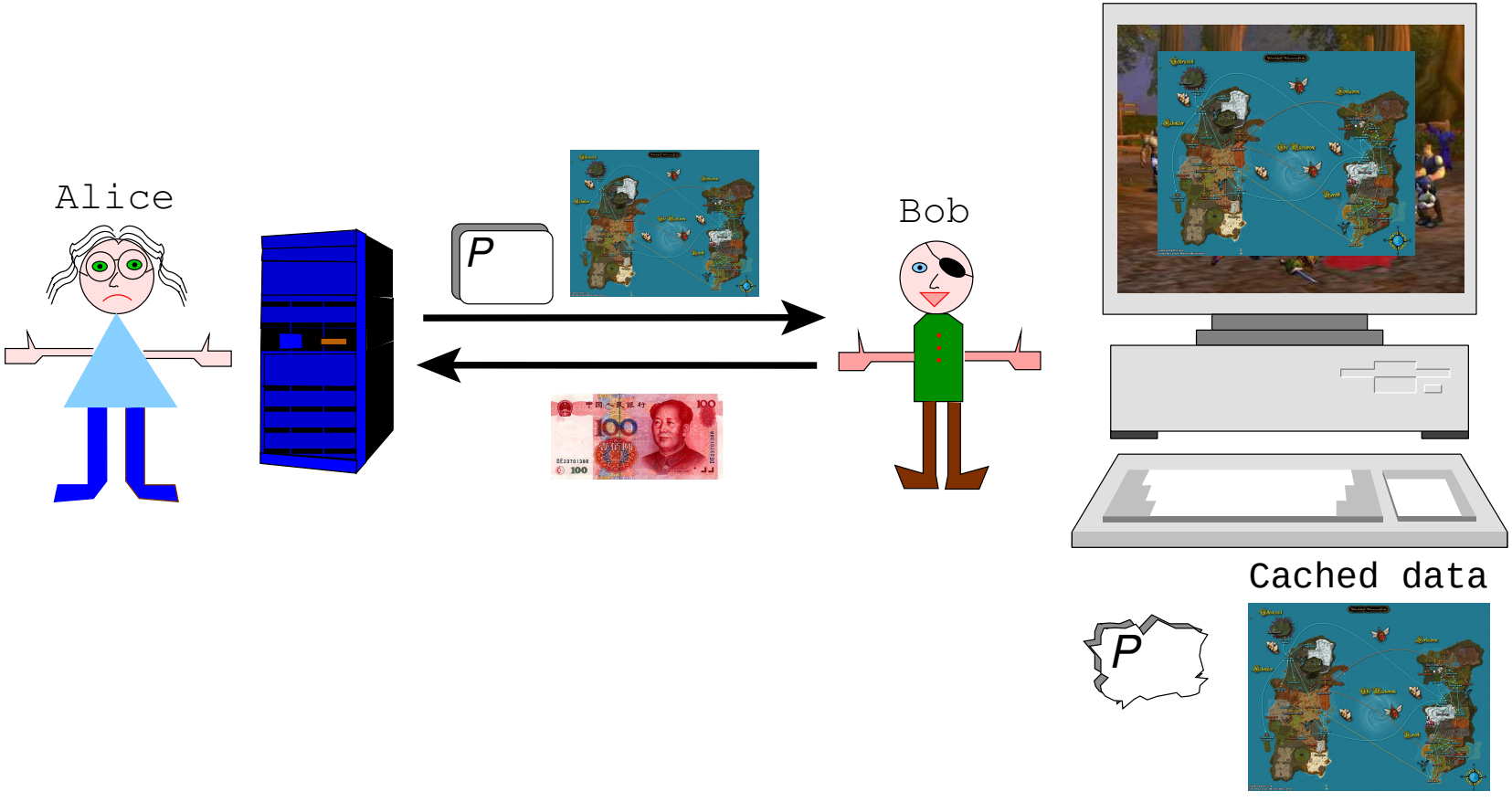
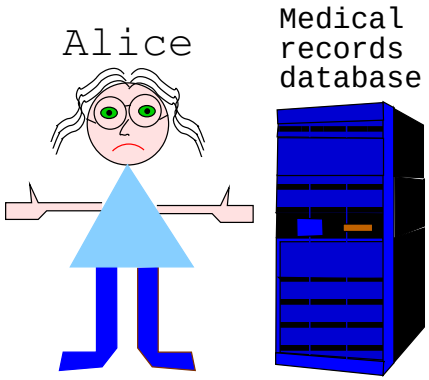


Scenario: Protecting medical records



- Medical records must be protected from improper access and improper modification.
- Records are stored on one secure site, accessed from multiple (sometimes mobile) devices.

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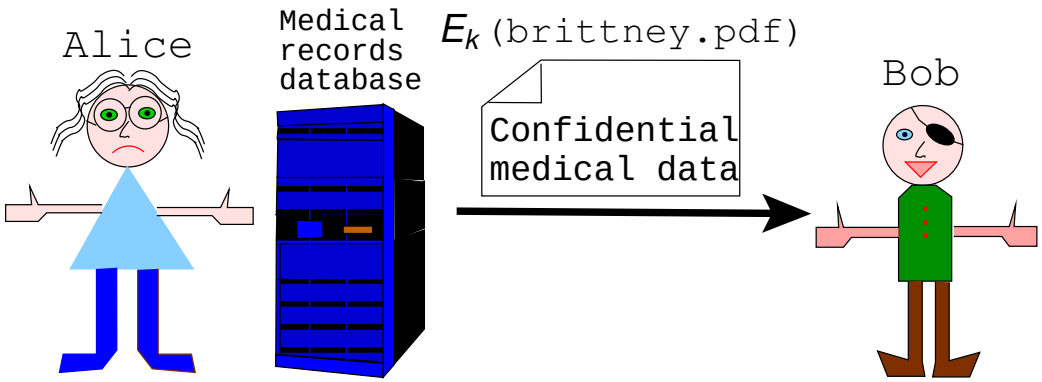

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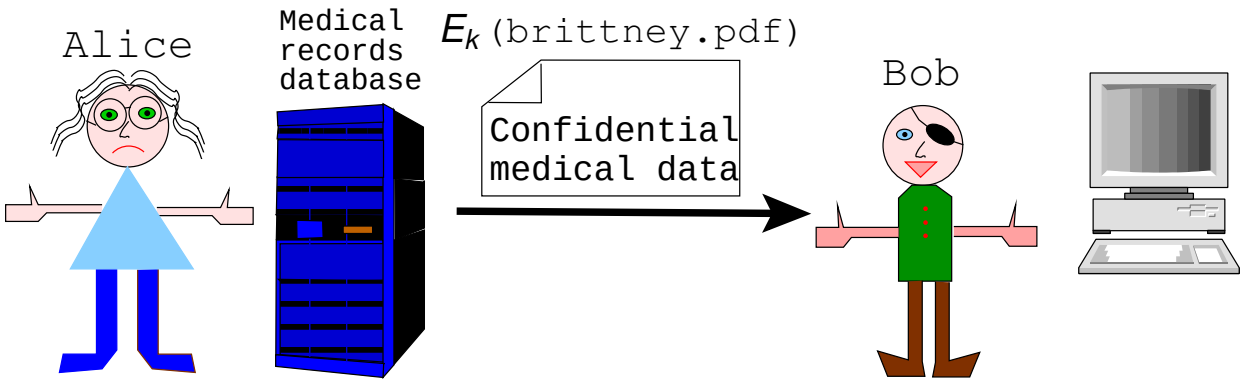

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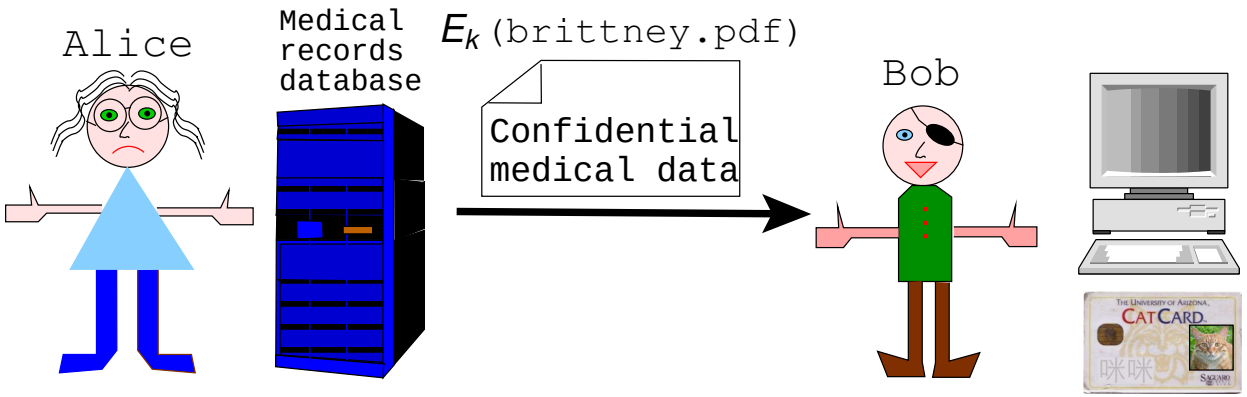

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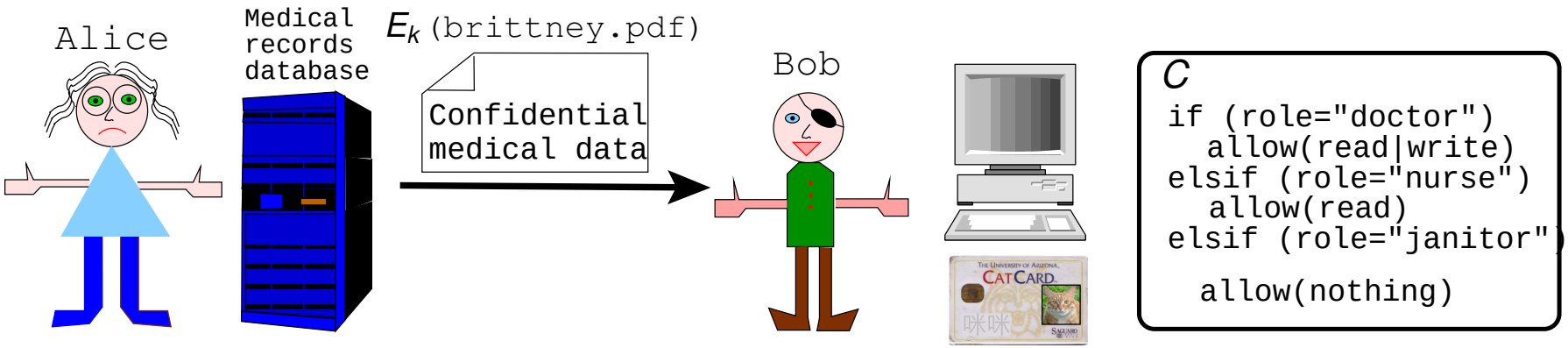

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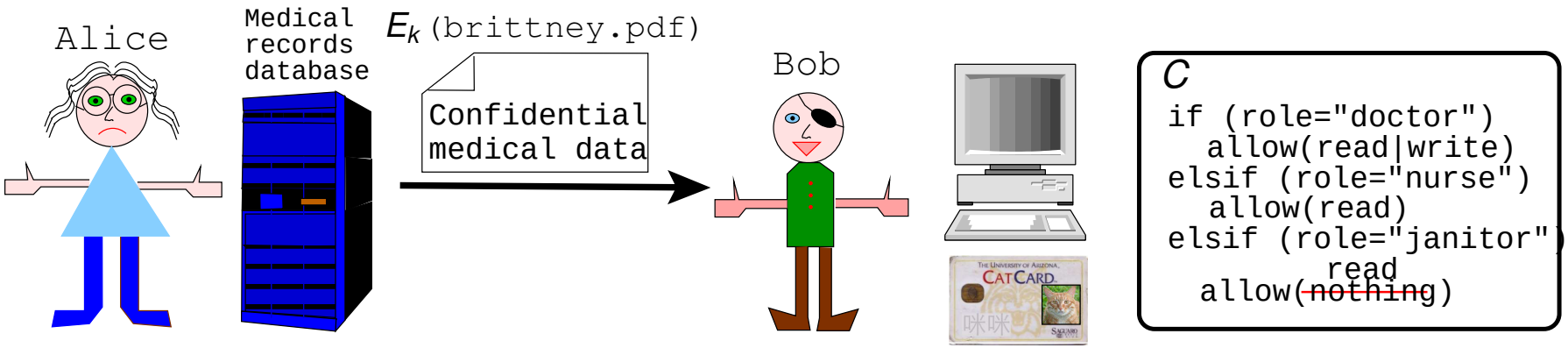

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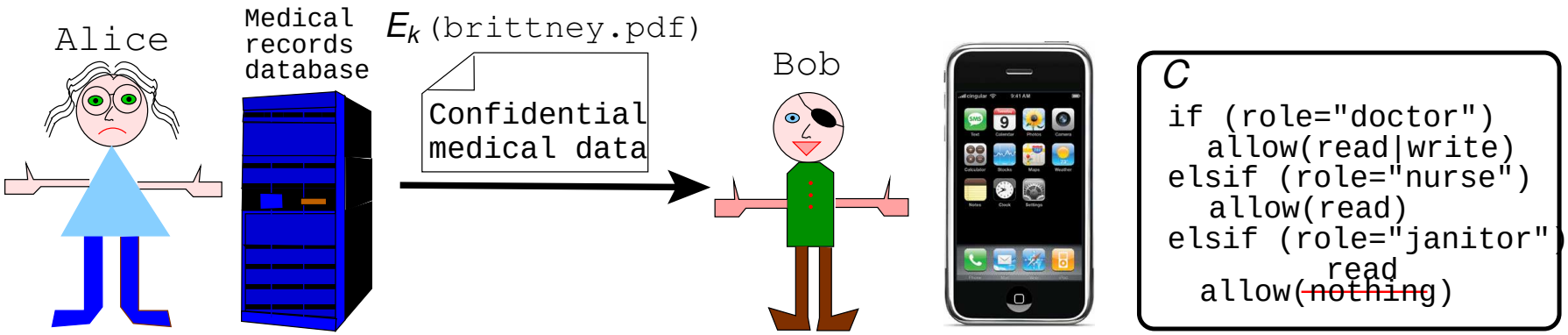
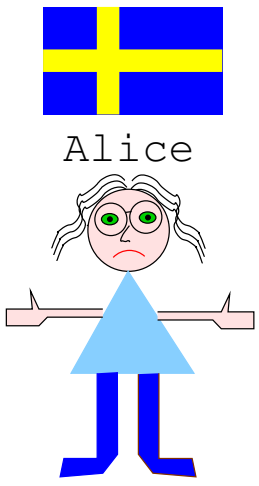
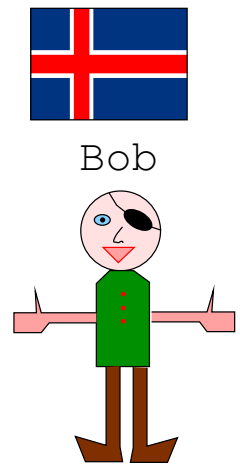


- Medical records must be protected from improper access and improper modification.
- Records are stored on one secure site, accessed from multiple (sometimes mobile) devices.

Scenario: Wireless sensor networks





- Sensor networks are common in military scenarios.

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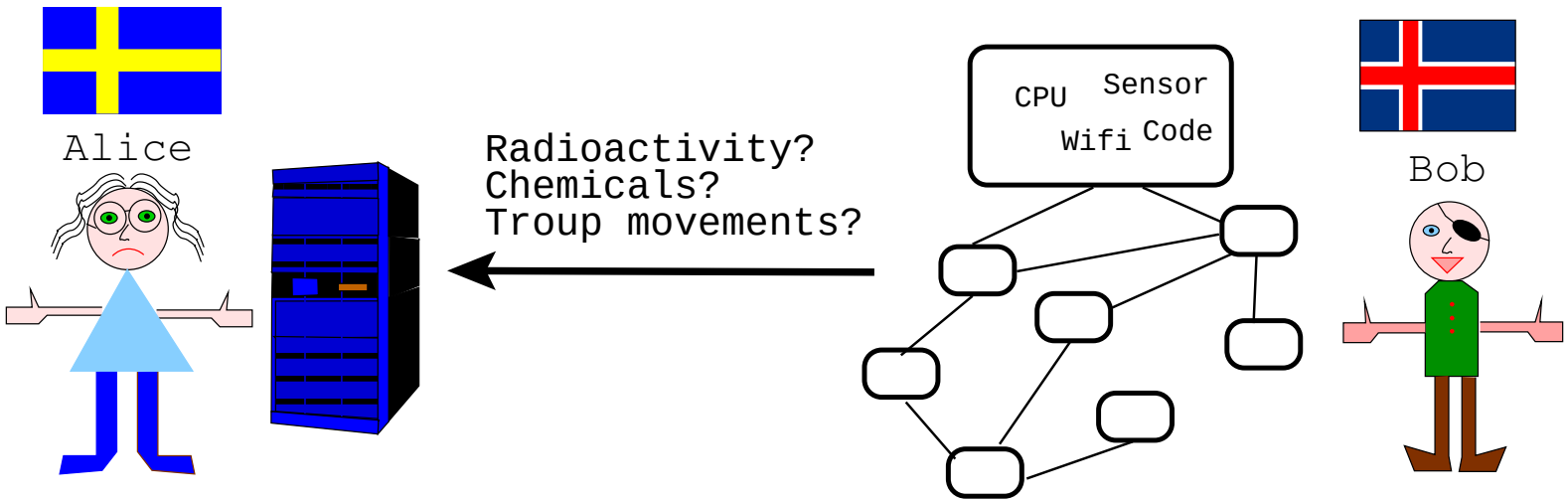

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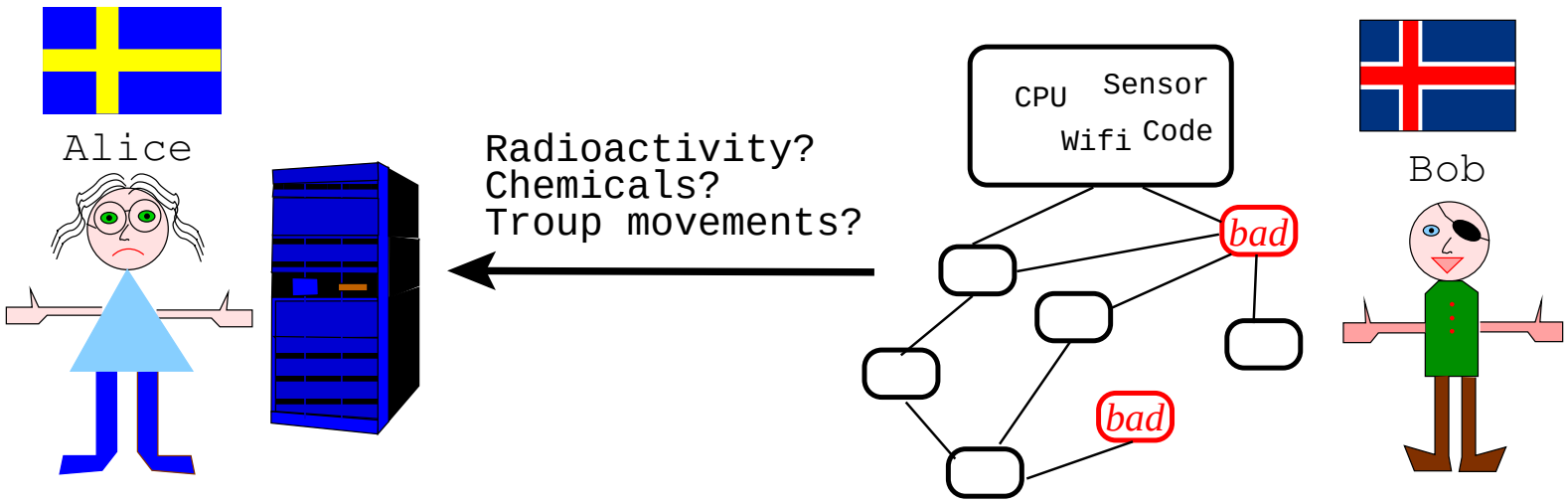
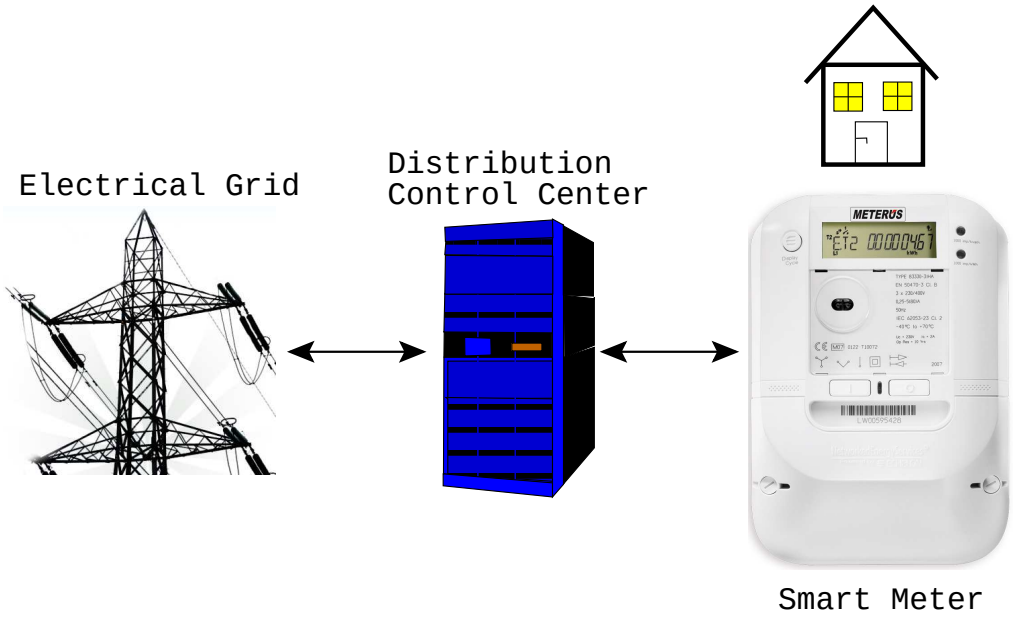


- Sensor networks are common in military scenarios.
- The enemy can intercept/analyze/modify sensors.

Scenario: Advanced Metering Infrastructure



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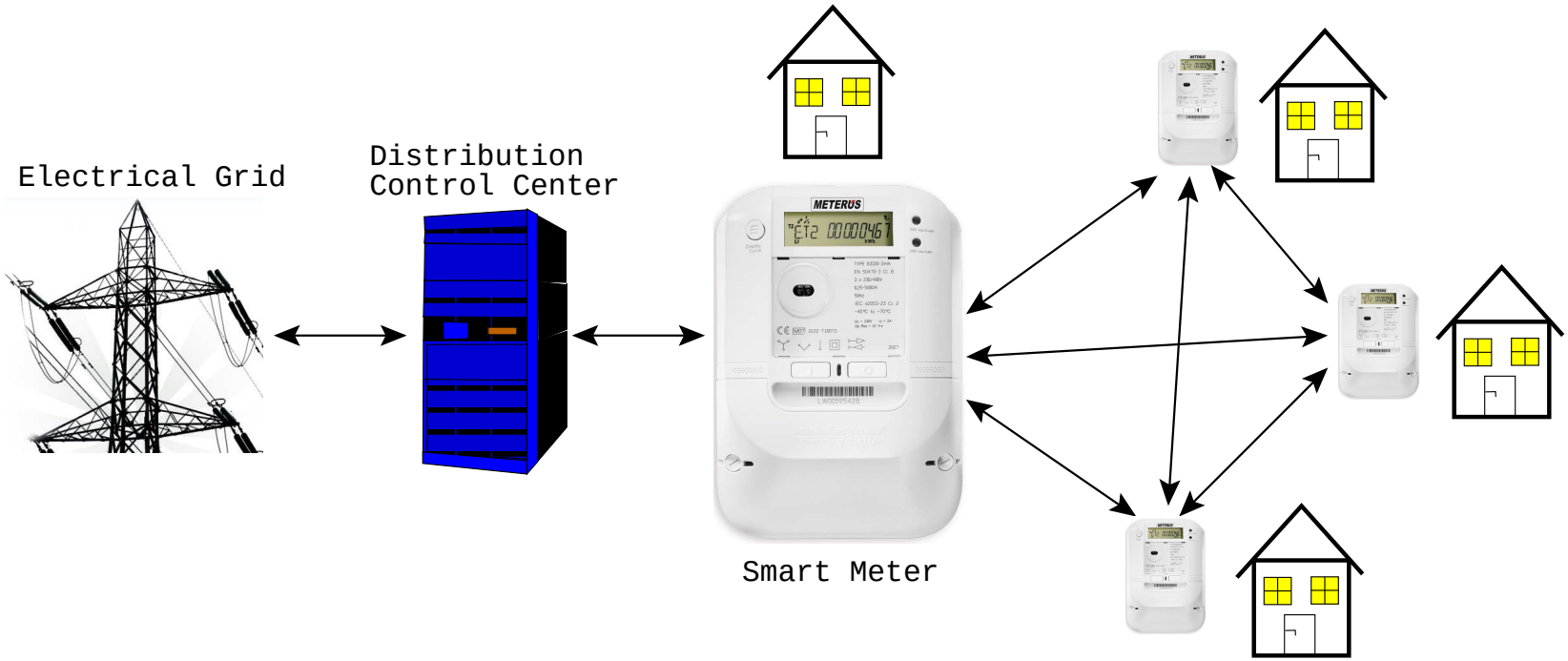

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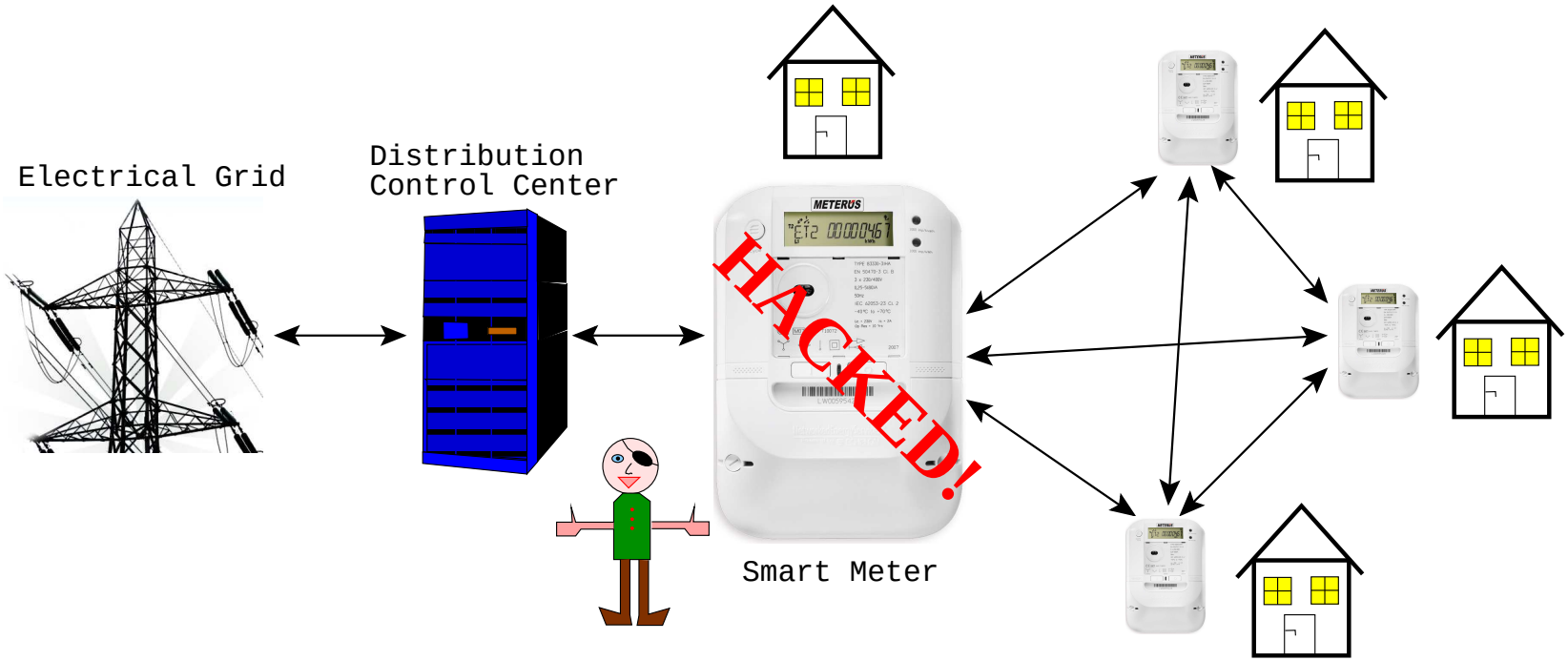

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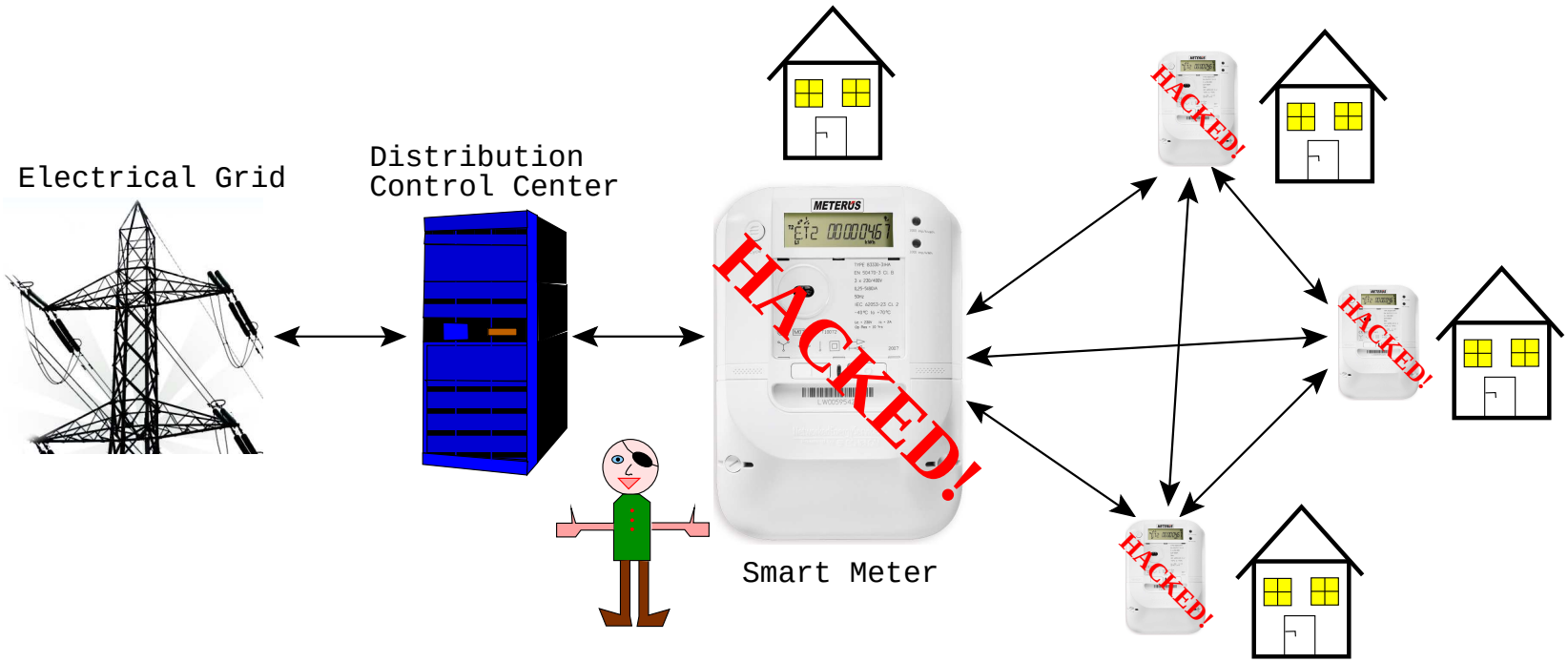

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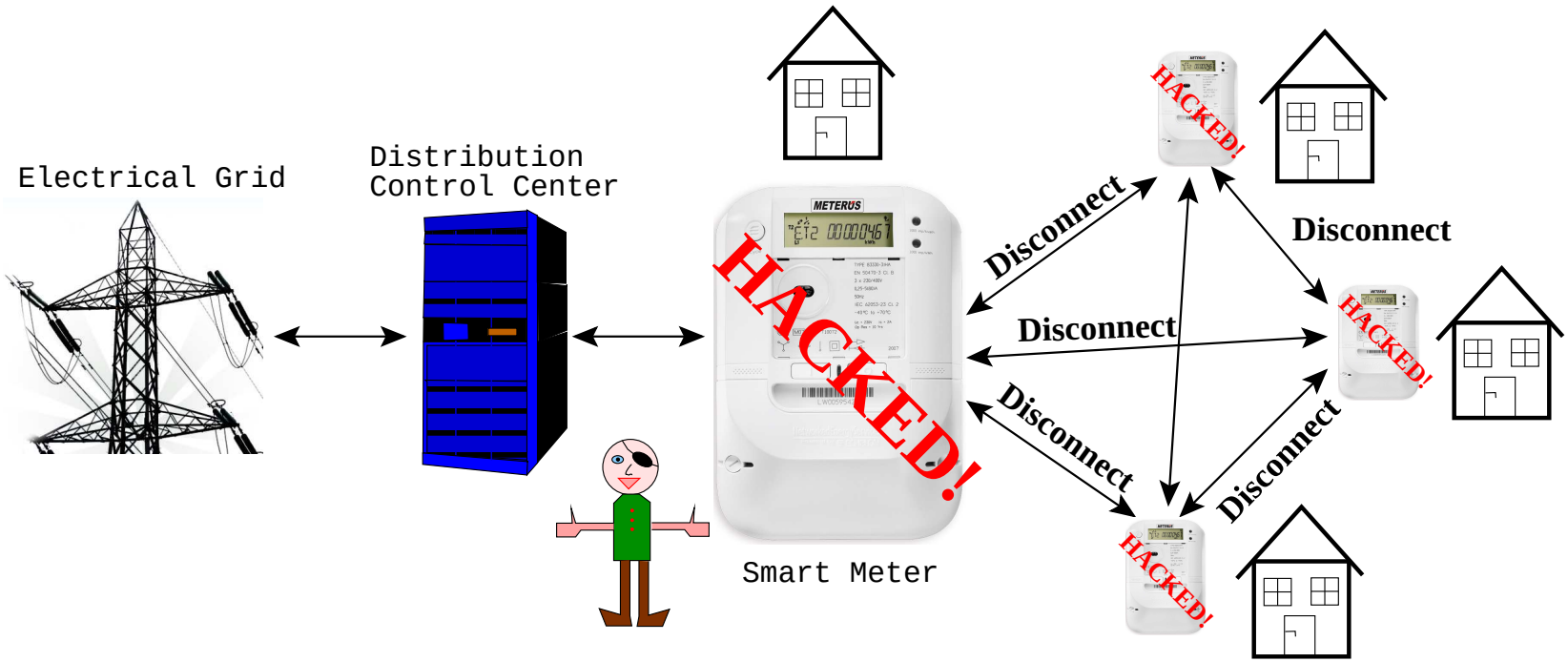

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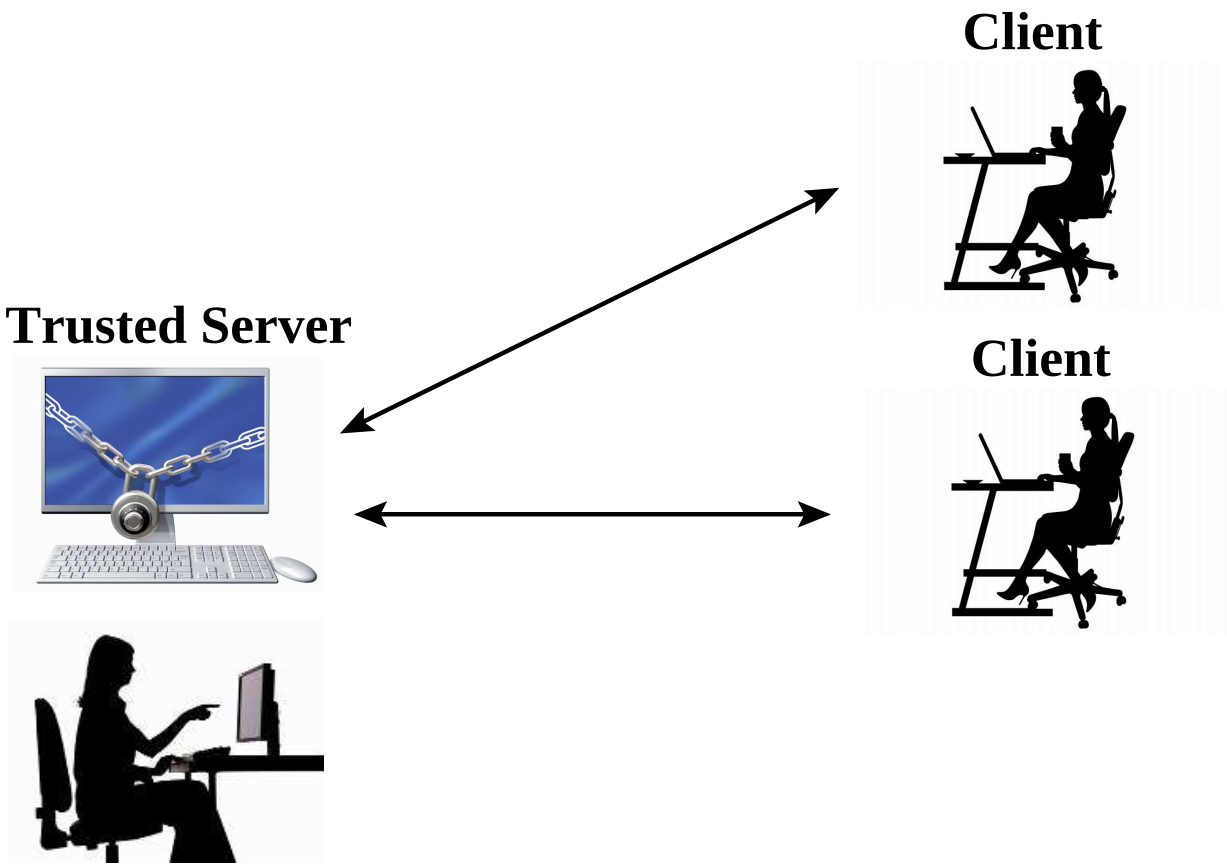
The Remote Man-At-The-End Problem



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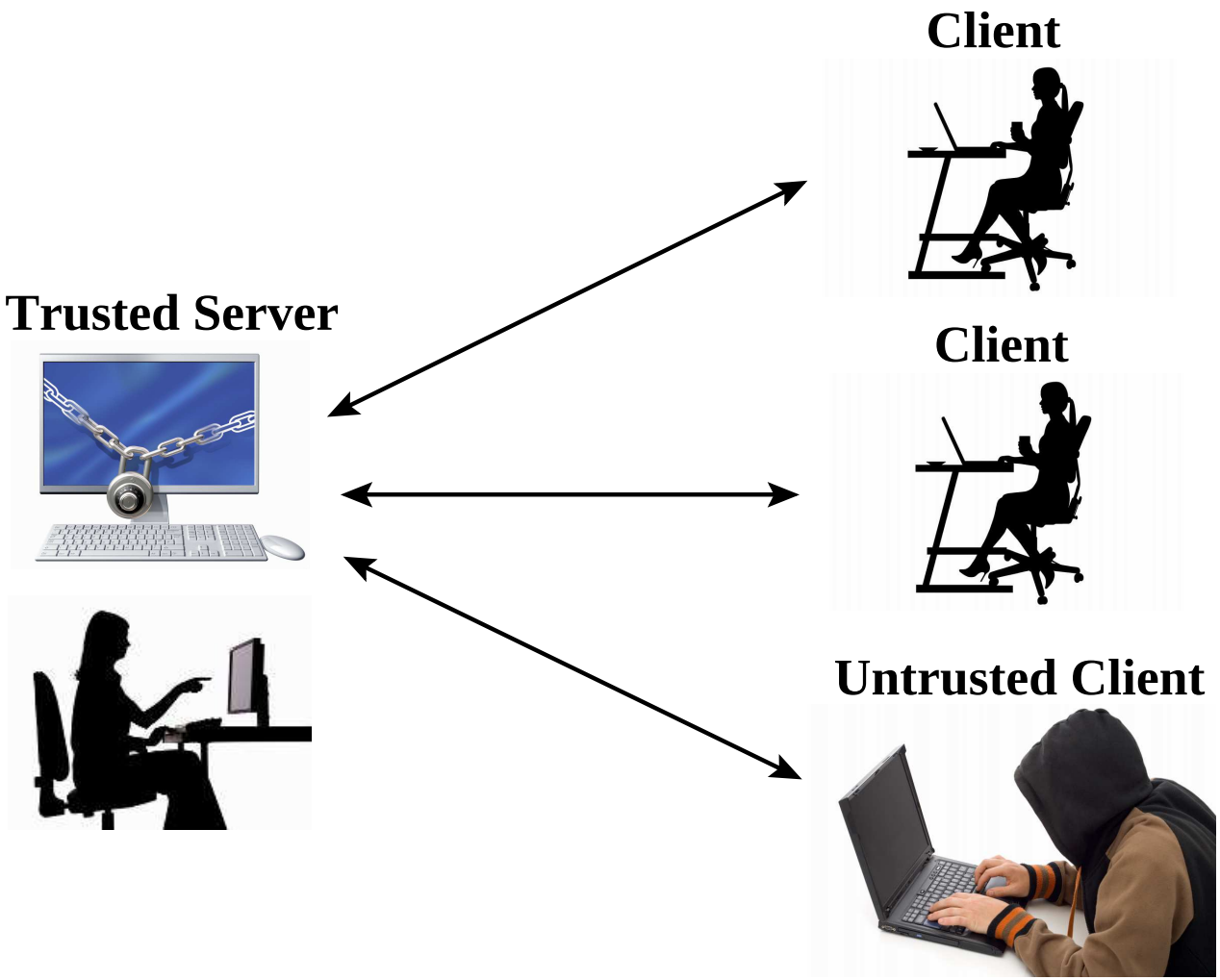

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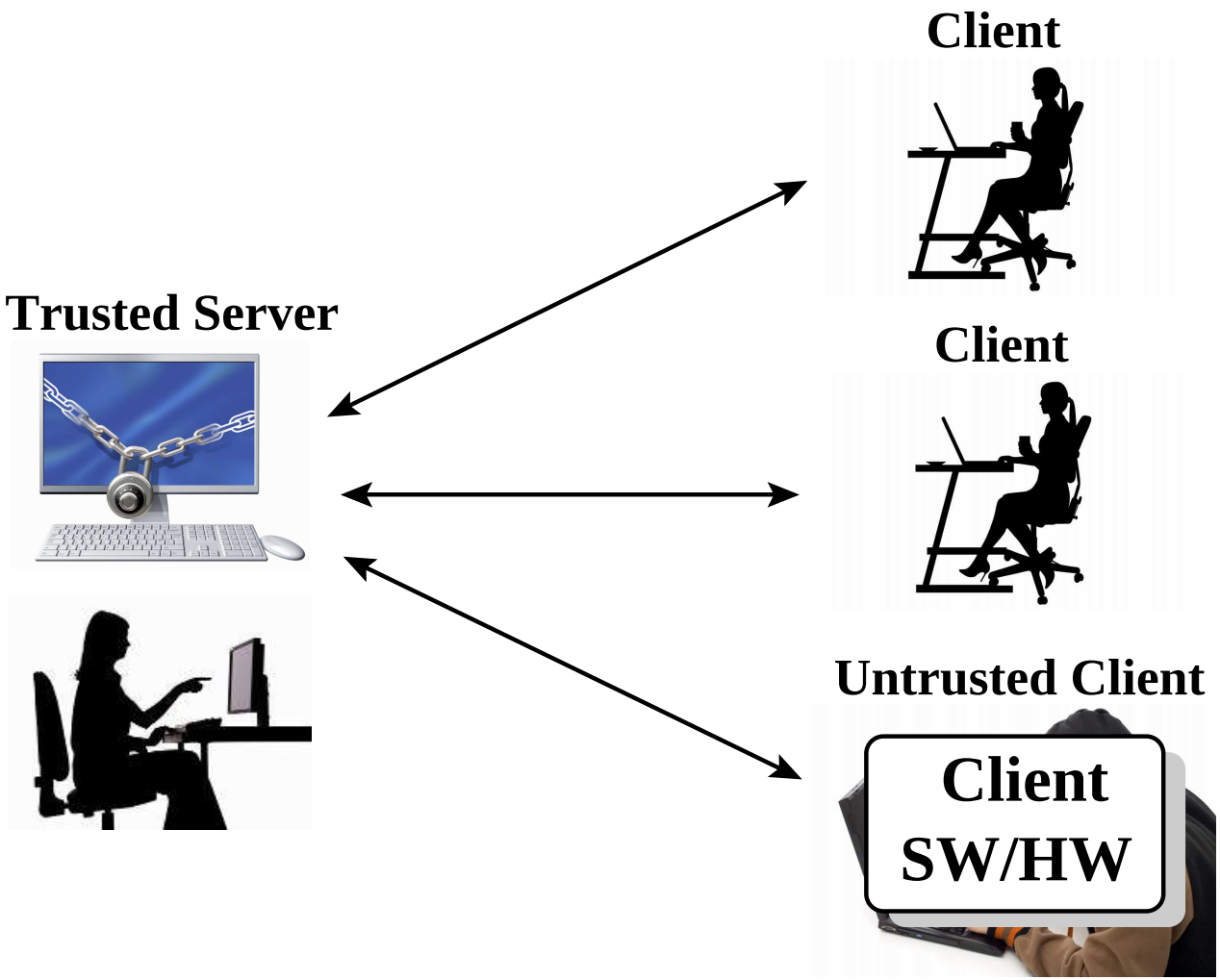

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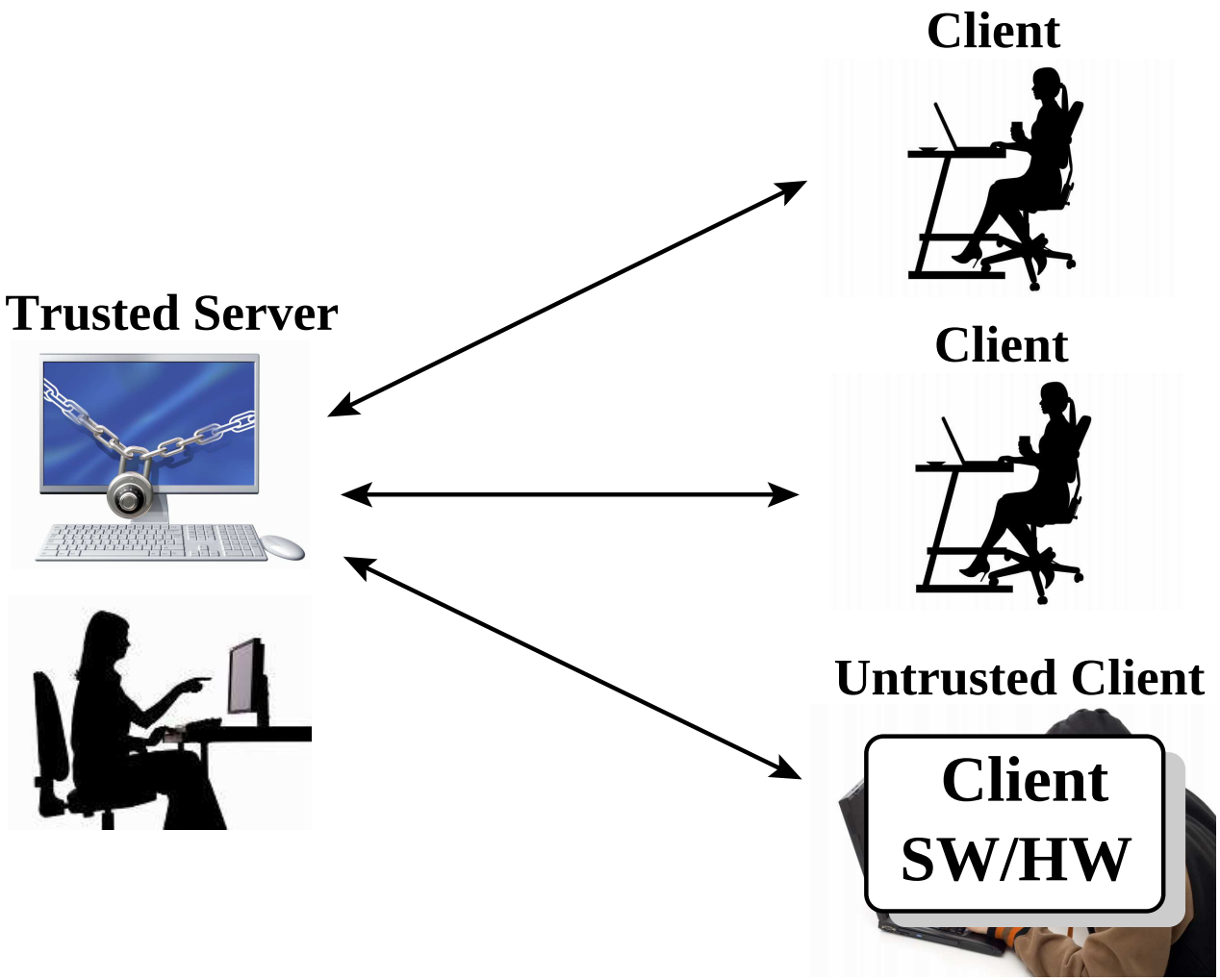

Debugger
Tracer
Slicer
Emulator
Disassembler
Decompiler

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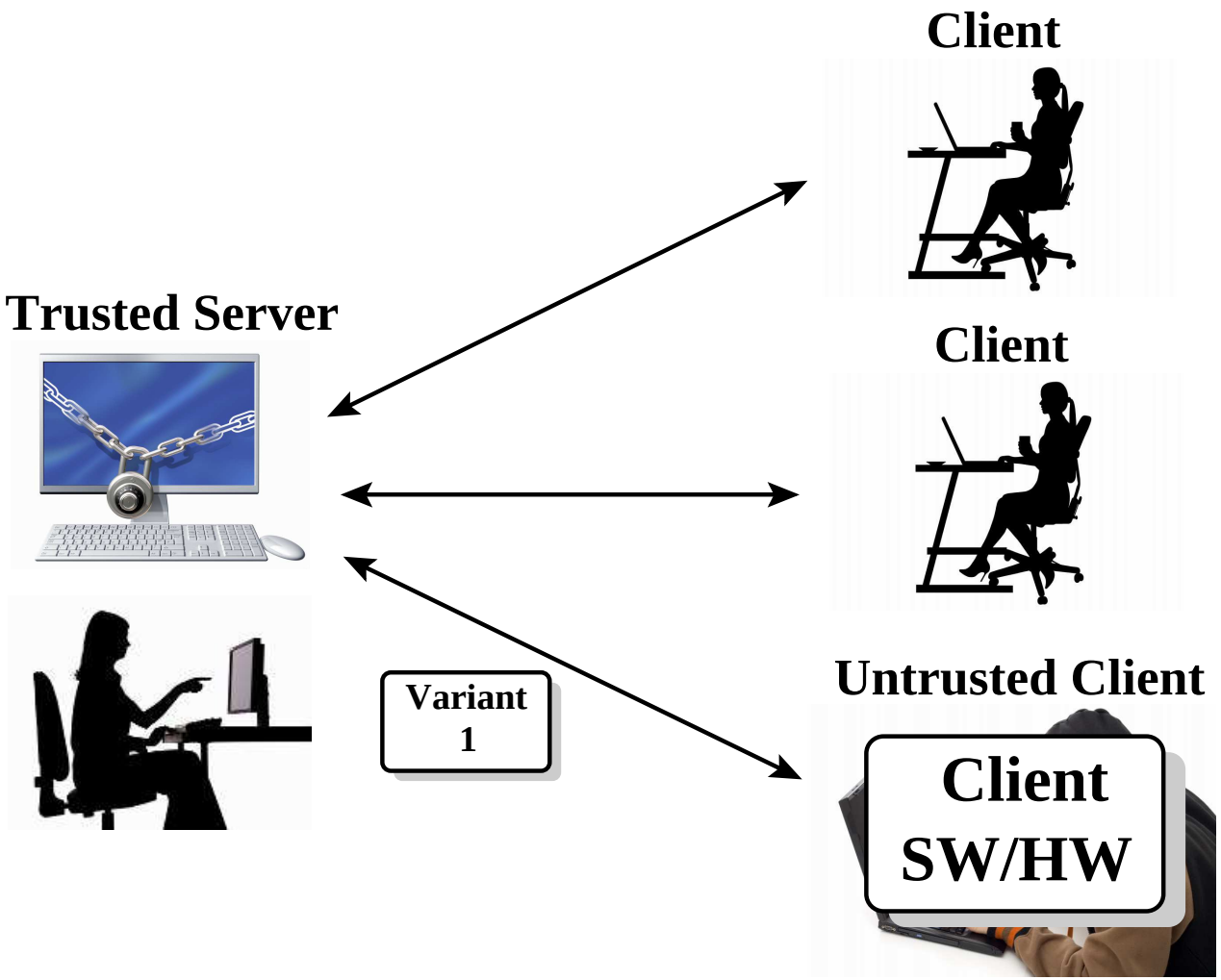

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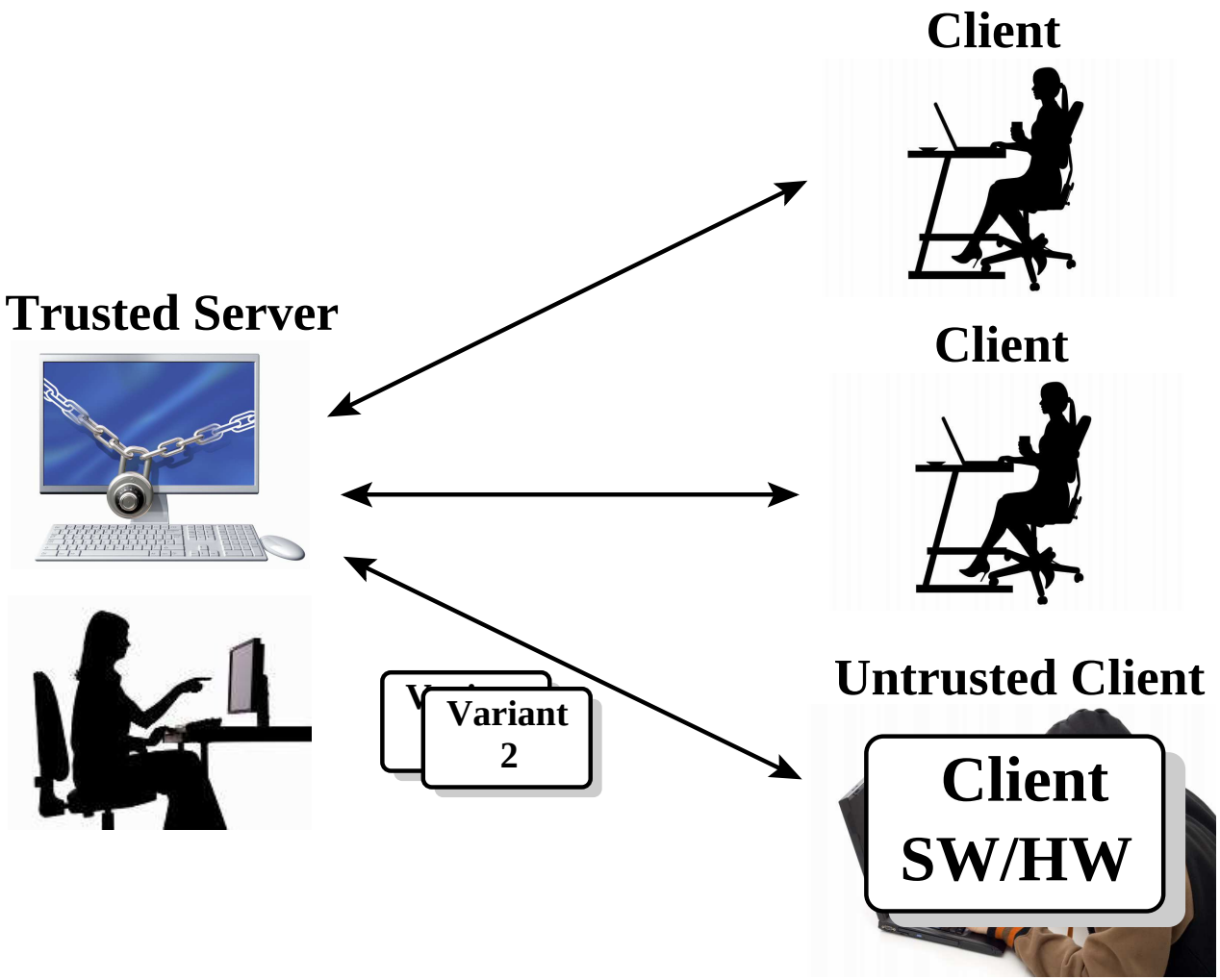

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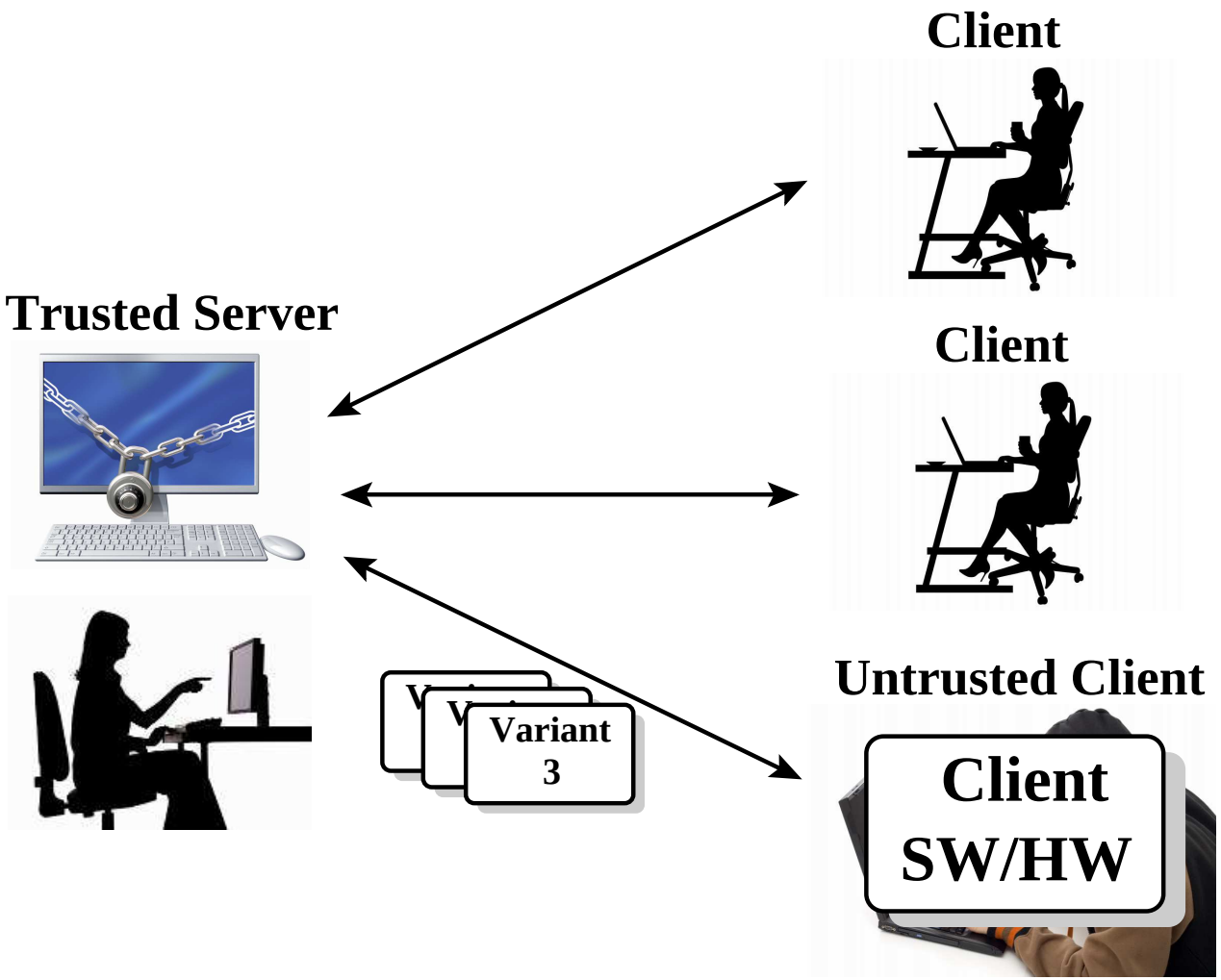

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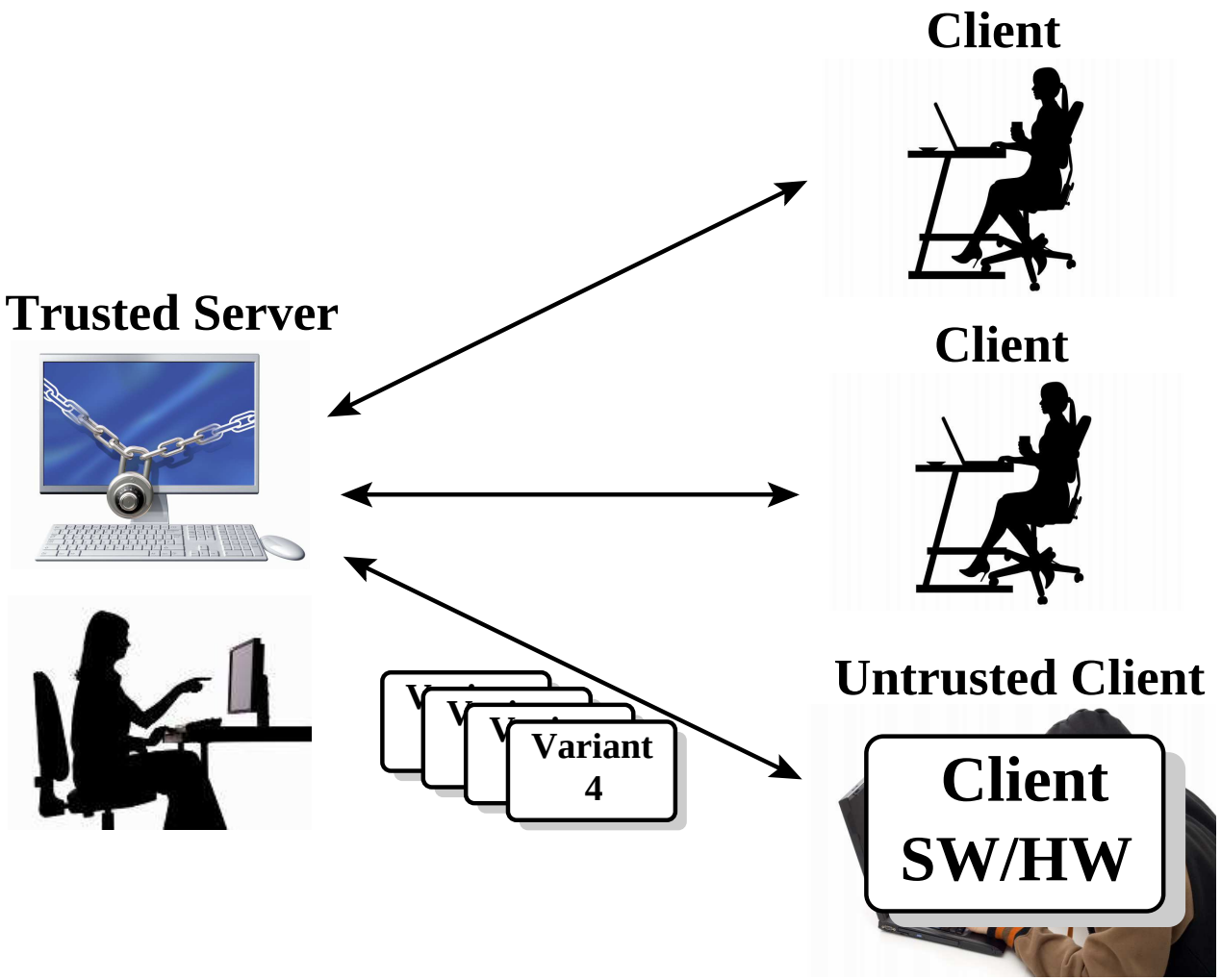

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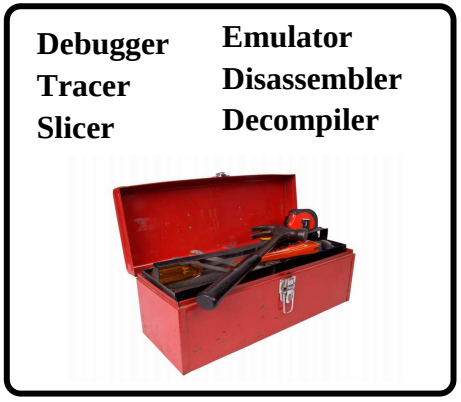
Self−protect against tampering!



Definition (Man-At-The-End (MATE) Attacks)

MATE attacks occur in any setting where an adversary has physical access to a device and compromises it by inspecting, reverse engineering, or tampering with its hardware or software.

Detect remote tampering!

Self−protect against tampering!

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Definition (Remote MATE (R-MATE) Attacks)

R-MATE attacks occur in distributed systems where untrusted clients are in frequent communication with trusted servers over a network, and where a malicious user can get an advantage by compromising an untrusted device.

Code Obfuscation

Code obfuscation

- To obfuscate a program means to

  transform it into a form that is more difficult for an adversary to understand or change than the original code.

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  transform it into a form that is more difficult for an adversary to understand or change than the original code.

- Vague definition of *difficult*:

  The obfuscated program requires more human time, more money, or more computing power to analyze than the original program.

Code obfuscation — Example obfuscated code

```
public class C {
 static Object get0(Object[] I) {
  Integer I7, I6, I4, I3; int t9, t8;
  I7=new Integer(9);
  for (;;) {
   if (((Integer)I[0]).intValue()%((Integer)I[1]).intValue()==0)
       {t9=1; t8=0;} else {t9=0; t8=0;}
   I4=new Integer(t8);
   I6=new Integer(t9);
   if ((I4.intValue()^I6.intValue())!=0)
     return new Integer(((Integer)I[1]).intValue());
   else {
     if ((((I7.intValue()+ I7.intValue()*I7.intValue())%2!=0)?0:1)!=1)
        return new Integer(0);
     I3=new Integer(((Integer)I[0]).intValue()%
           ((Integer)I[1]).intValue());
     I[0]=new Integer(((Integer)I[1]).intValue());
     I[1]=new Integer(I3.intValue());
    }
  }
```

Code obfuscation — Example original code

```
public class C {
   static int gcd(int x, int y) {
      int t;
      while (true) {
         boolean b = x % y == 0;
         if (b) return y;
         t = x % y; x = y; y = t;
      }
   }
}
```

- An obfuscation tool turns the original code into obfuscated code.
- We want obfuscating transformations that make the program as hard to understand as possible.

Types of obfuscation

1. Abstraction transformations
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2. Data transformations
   - Replace data structures with new representations!
3. Control transformations
   - Destroy if-, while-, repeat-, etc.!
4. Dynamic transformations
   - Make the program change at runtime!

Obfuscation example: original program

```
int main() {
    int y = 6;
    y = foo(y);
    bar(y,42);
}
```

```
int foo(int x) {
    return x*7;
}
```

```
void bar(int x, int z) {
    if (x==z)
        printf("%i\n",x);
}
```

After abstraction transformation

```
int main() {
    int y = 6;
    y = foobar(y,99,1);
    foobar(y,42,2);
}
```

```
int foobar(int x, int z, int s) {
    if (s==1)
        return x*7;
    else if (s==2)
        if (x==z)
            printf("%i\n",x);
}
```

- It appears as if `main` calls the same function twice!

After data transformation

```
int main() {
    int y = 12;
    y = foobar(y,99,1);
    foobar(y,36,2);
}
```

```
int foobar(int x, int z, int s) {
    if (s==1)
        return (x*37)%51;
    else if (s==2)
        if (x==z) {
            int x2=x*x % 51,     x3=x2*x % 51;
            int x4=x2*x2 % 51,   x8=x4*x4 % 51;
            int x11=x8*x3 % 51; printf("%i\n",x11);
        }
}
```

After control transformation

```
int foobar(int x, int z, int s) {
   char* next = &&cell0;
   int retVal = 0;

   cell0: next = (s==1)?&&cell1:&&cell2; goto *next;
   cell1: retVal=(x*37)%51; goto end;
   cell2: next = (s==2)?&&cell3:&&end; goto *next;
   cell3: next = (x==z)?&&cell4:&&end; goto *next;
   cell4: {
      int x2=x*x % 51,   x3=x2*x % 51;
      int x4=x2*x2 % 51, x8=x4*x4 % 51;
      int x11=x8*x3 % 51;
      printf("%i\n",x11); goto end;
   }
   end: return retVal;
}
```

Anti-Tamper

What is code tampering?

- Bob wants to modify the program binary so that it does something different than we want:
  - remove functionality (license check)
  - change data (password, cryptographic key)
  - add functionality (print, save game)
- Tamperproofing the code makes it stop working if Bob changes as little as a byte of the binary!

Two phases of tamperproofing

- Tamperproofing has to do two things:
  1. detect tampering
  2. respond to tampering

Two phases of tamperproofing

- Tamperproofing has to do two things:
  1. detect tampering
  2. respond to tampering
- Essentially:

  ```
  if (tampering-detected()) abort
  ```

  but this is too unstealthy!

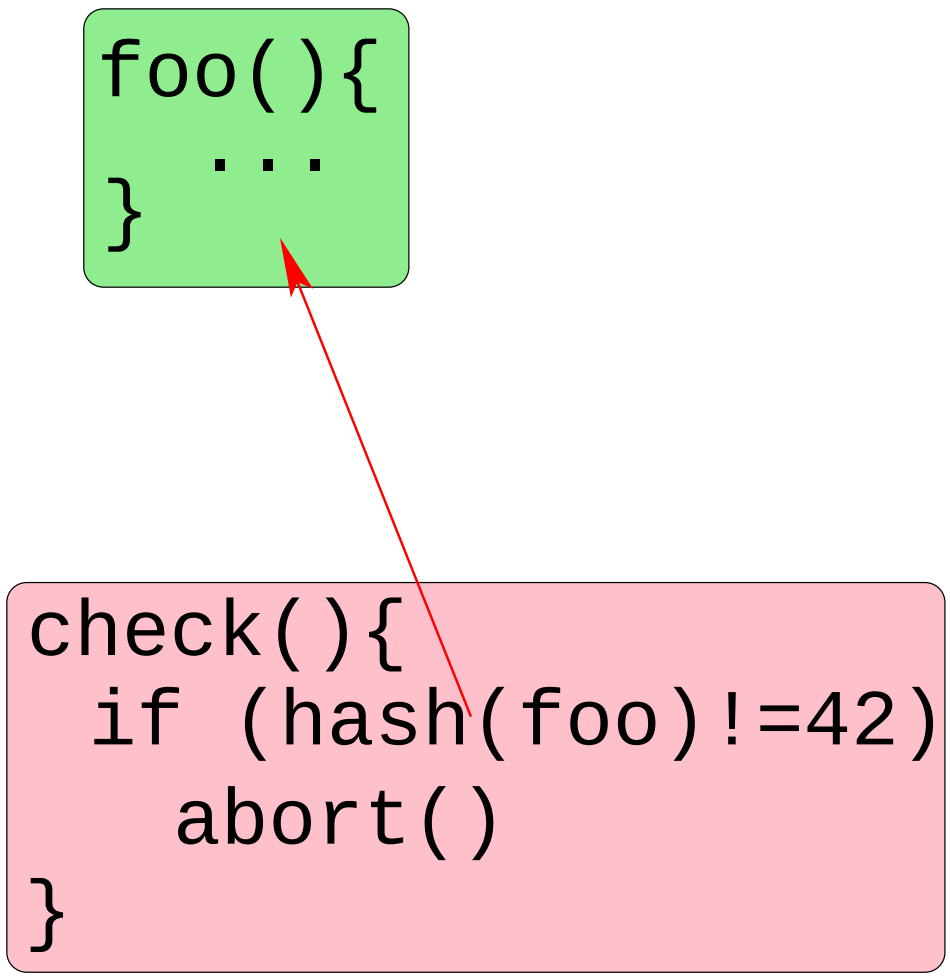
Two phases of tamperproofing

- Detection:
  1. has the code been changed?
  2. are variables in an OK state?

Two phases of tamperproofing

- Detection:
  1. has the code been changed?
  2. are variables in an OK state?
- Response:
  1. refuse to run,
  2. crash randomly,
  3. phone home, . . .

Algorithm Chang & Atallah: Checker network



Hash functions

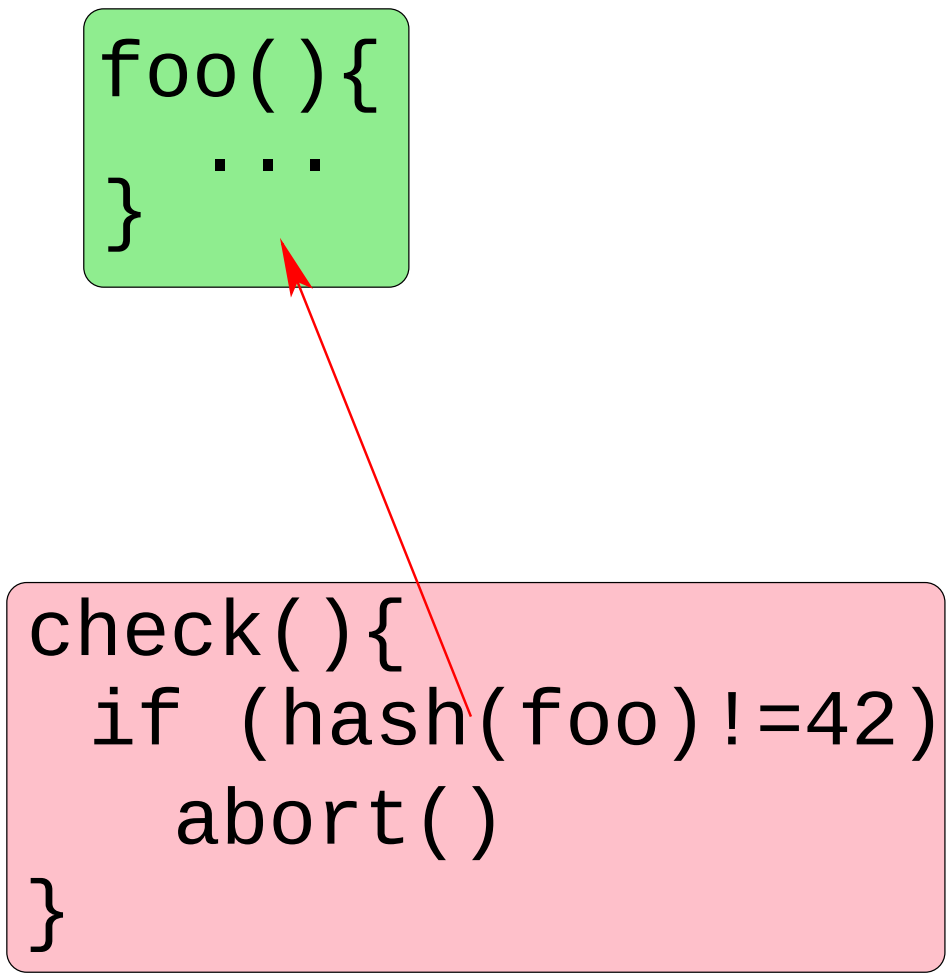
```
uint32 hash1 (addr_t addr,int words) {
   uint32 h = *addr;
   int i;
   for(i=1; i<words; i++) {
      addr++;
      h ^= *addr;
   }
   return h;
}
```

Hash functions

```
void important_function () {
    ...
}

int main () {
    int v = hash (important_function,1000);
    if (v != 0x4C49F346) {
        crash the program
    }
    important_function(...)
}
```

Algorithm Chang & Atallah: Checker network



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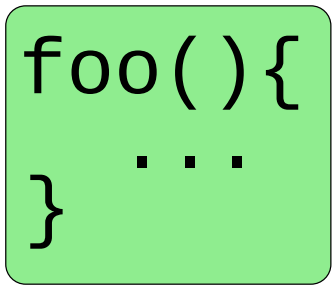

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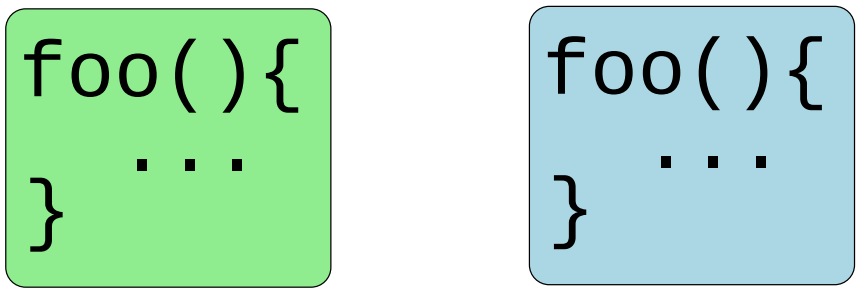

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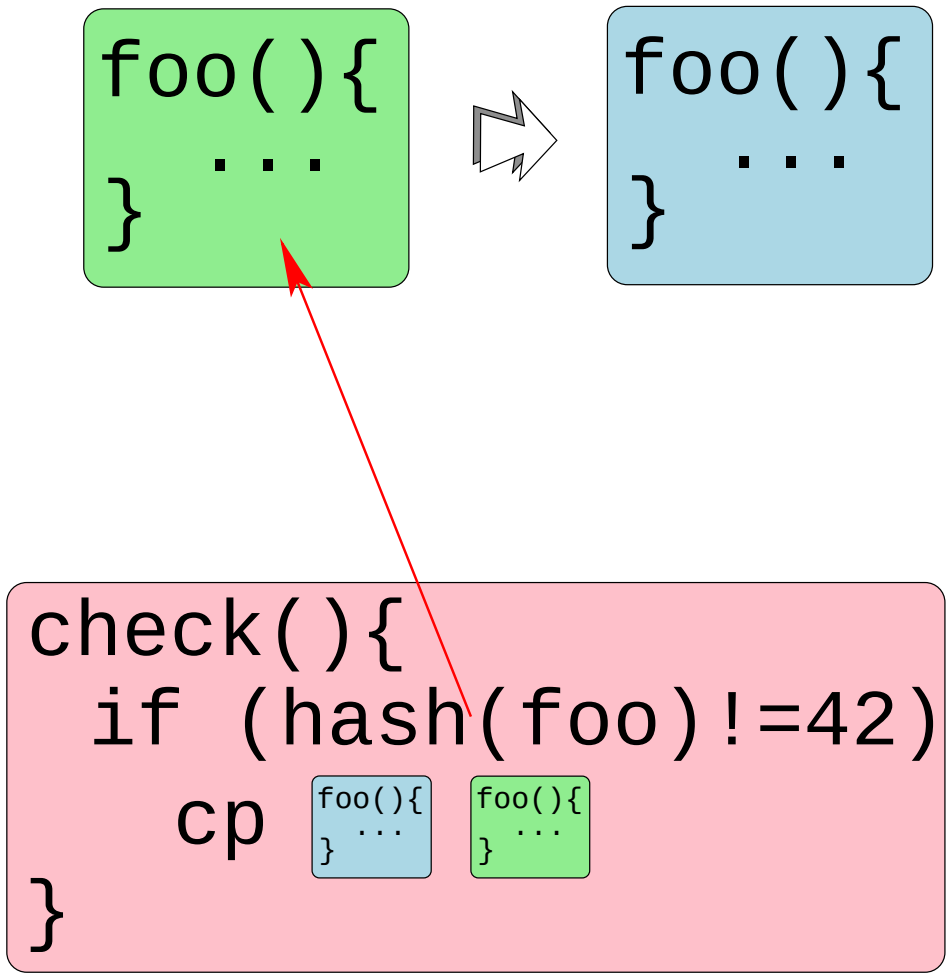

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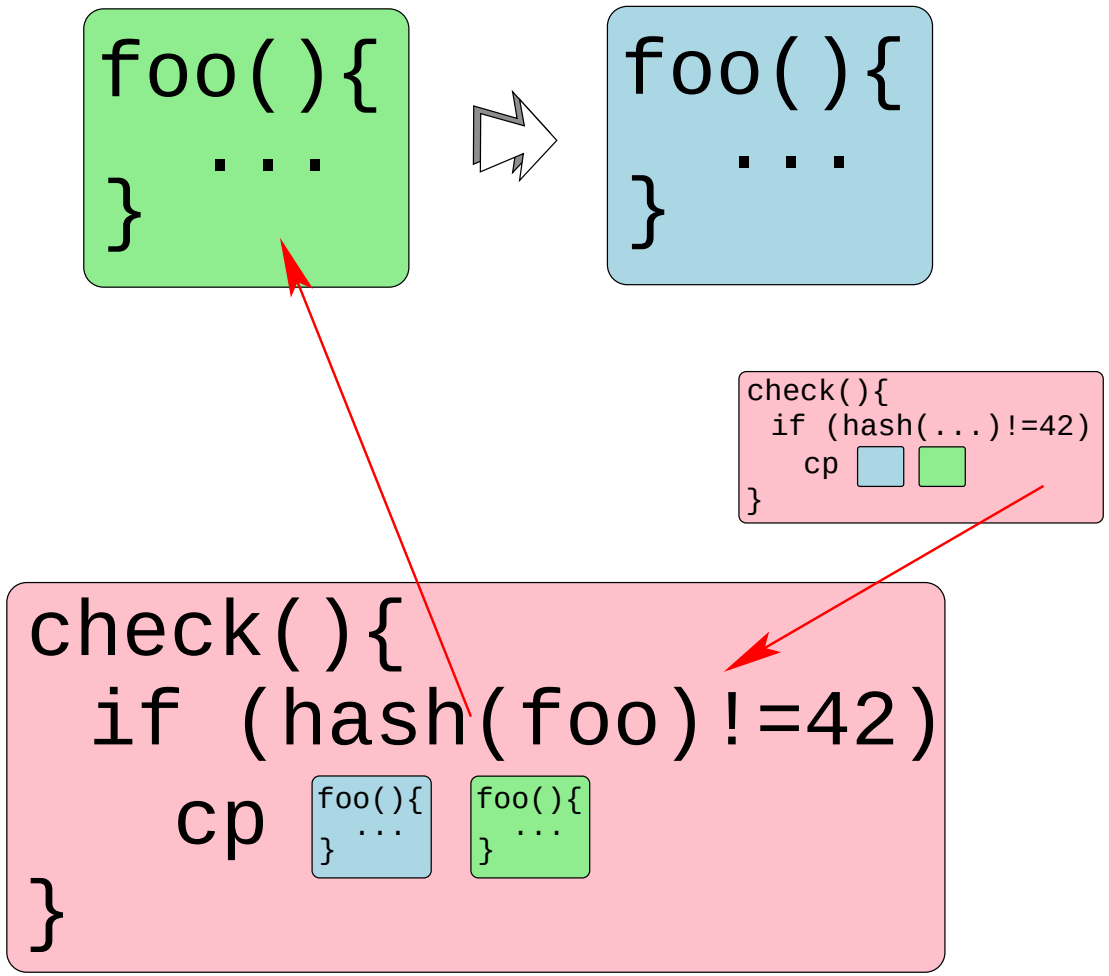


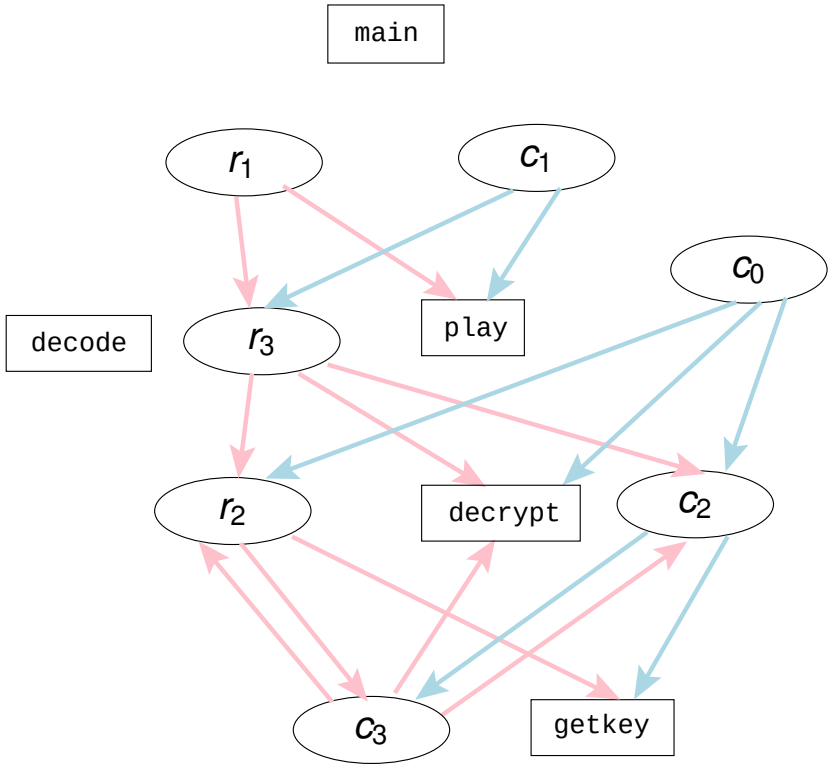
Repairing Hacked Functions

```
void copy_of_important_function () {
   ...
}

void important_function () {
   ...
}

int main () {
   int v = hash (important_function,1000);
   if (v != 0x4C49F346) {
      memcpy(important_function,
             copy_of_important_function,
             1000)
   }
   important_function(...)
}
```

Checker network



- code — code blocks
- c_i — checkers
- r_i — repairers

Skype's hash function

```
uint32 hash7() {
   addr_t addr=(addr_t)((uint32)addr^(uint32)addr);
   addr = (addr_t)((uint32)addr + 0x688E5C);
   uint32 hash = 0x320E83 ^ 0x1C4C4;
   int bound = hash + 0xFFCC5AFD;
   do {
      uint32 data=*((addr_t)((uint32)addr + 0x10));
      goto b1; asm volatile(".byte 0x19"); b1:
      hash = hash ⊕ data; addr -= 1; bound--;
   } while (bound!=0);
   goto b2; asm volatile(".byte 0x73"); b2:
   goto b3; asm volatile(".word 0xC8528417,..."); b3:
   hash-=0x4C49F346; return hash;
}
```