Code-level Cyber-Security: MATE, attack & defense

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(heavily inspired from C. Collberg and B. de Sutter)

OUTLINE

- **Context: MATE attacks**
- **Basic attacks**
- **Basic defense**
- **Better attacks & better defense**
- **Step back: what matters?**
- **Tool: Tigress**
- **Conclusion**

OUTLINE

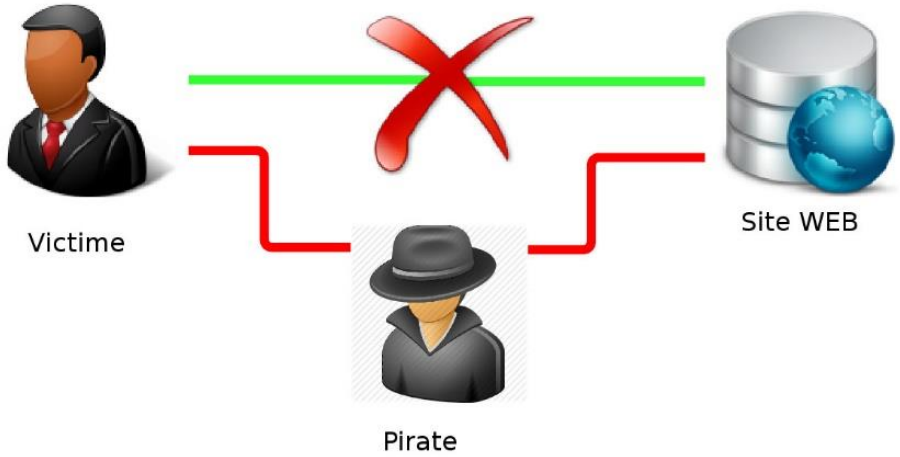
- **Context: MATE attacks**
  - Scenario
  - Examples
  - Ideas for defense
  - What matters

CLASSIFICATION OF ATTACKS (1)

MITM: Man-In-The-Middle

Attacker is on the network

- **Observe messages**
- **Forge messages**



Realm of cryptos

CLASSIFICATION OF ATTACKS (2)

« Man-Beyond-The-Door »

Attacker has limited access

- **Try to escalate**
- **Forge specially crafted files/queries**

Realm of program analysis

CLASSIFICATION OF ATTACKS (3) *** topic of the day ***

MATE: Man-At-The-End

Attacker is *on the computer*

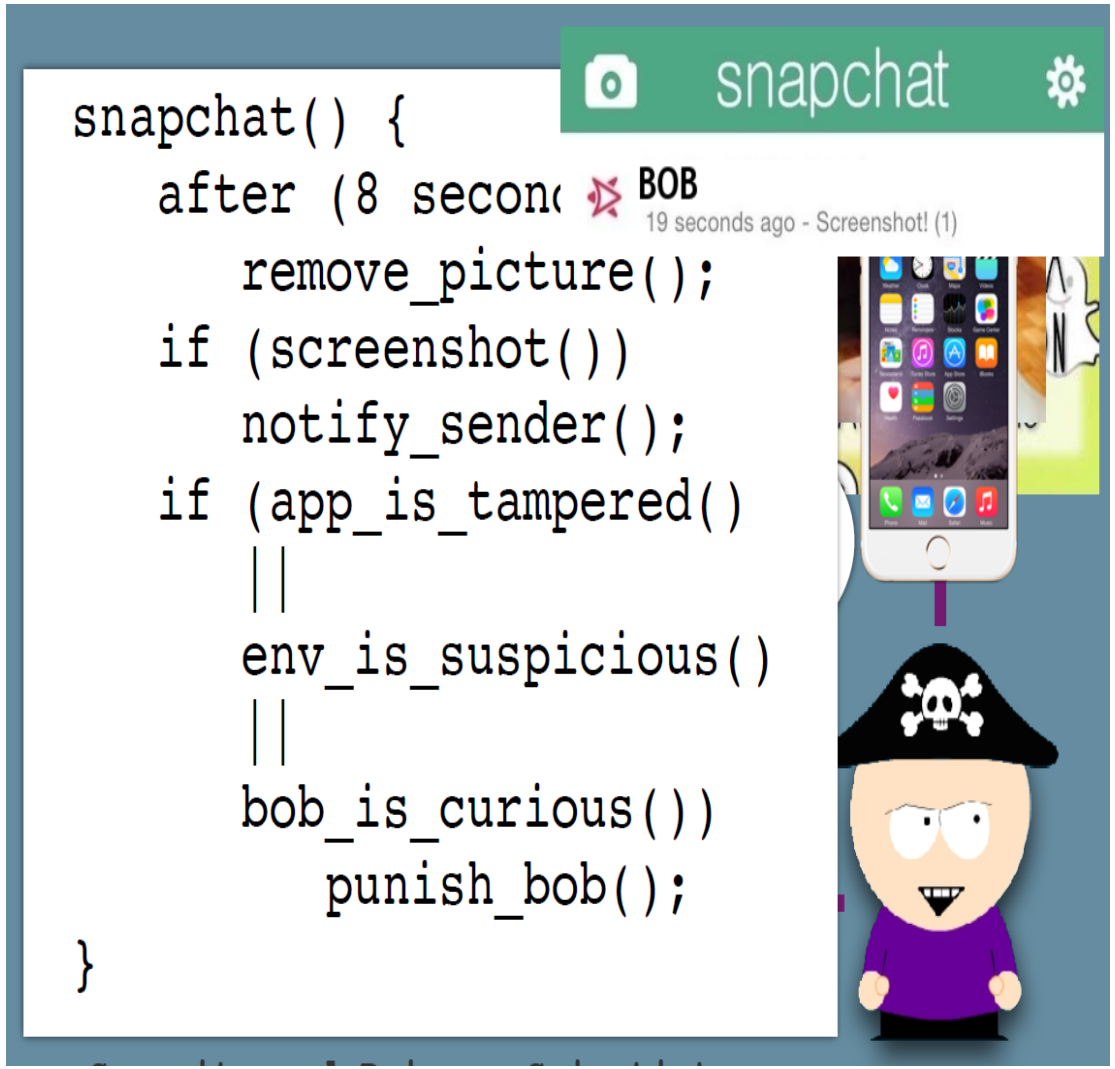
- **R/W the code**
- **Execute step by step**
- **Patch on-the-fly**

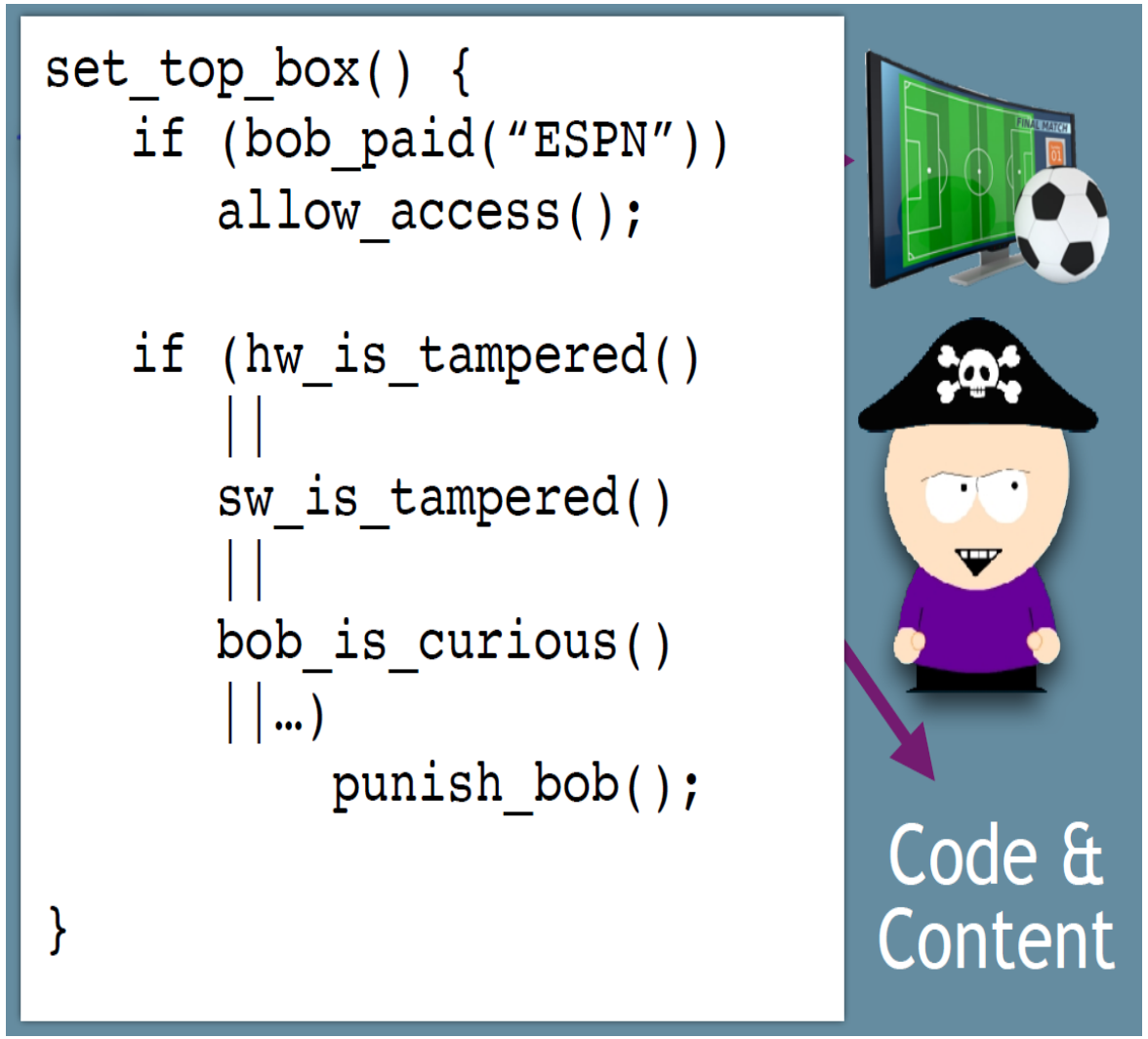
Realm of program analysis?
White-box crypto?

MAN AT THE END

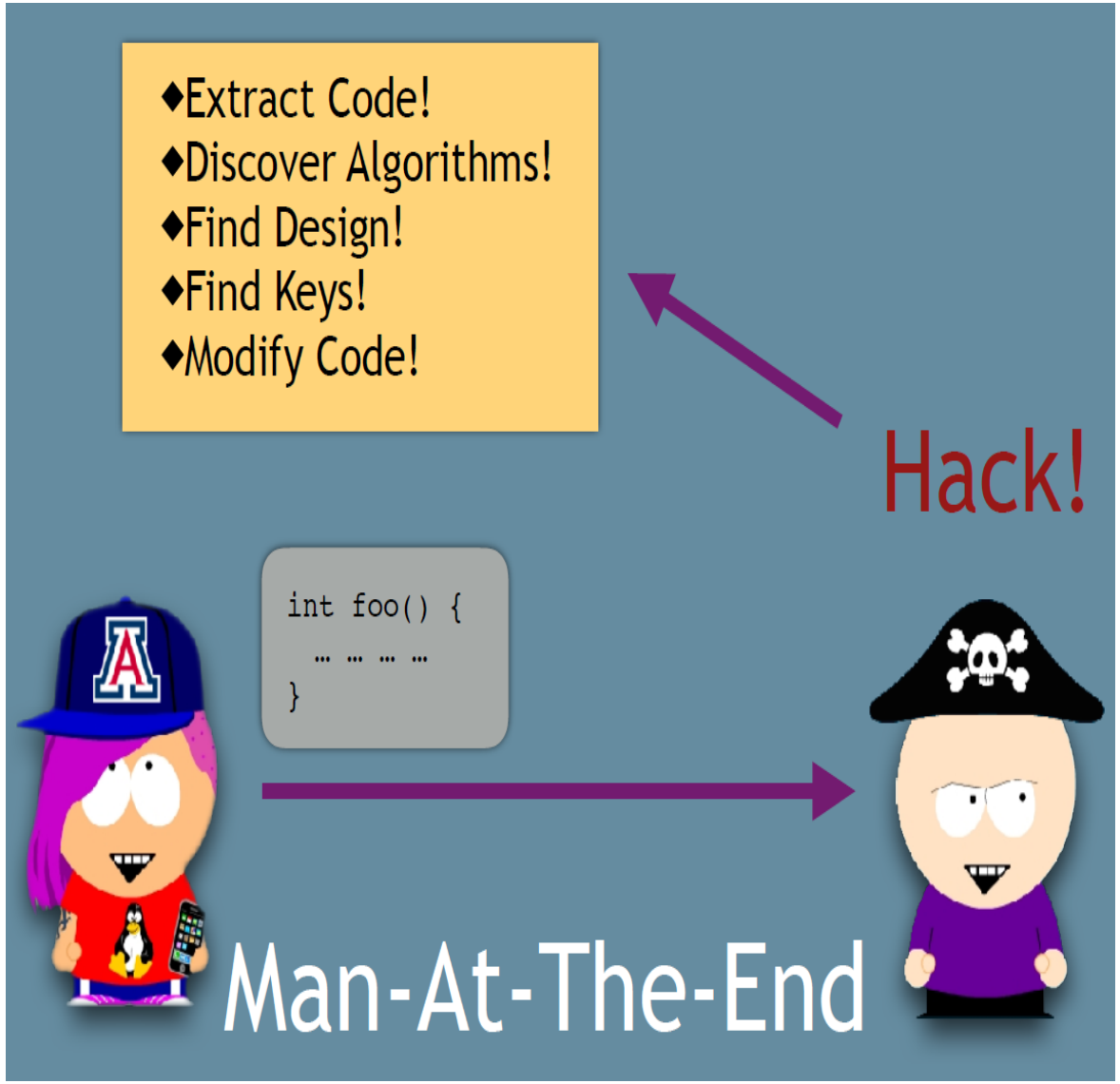
MATE attacks occur in any setting where an adversary has physical access to a device and compromises it by inspecting, reverse engineering, or tampering with its hardware or software.

Examples


snapchat
BOB
19 seconds ago - Screenshot! (1)
snapchat() {
after (8 secon
remove_picture();
if (screenshot())
notify_sender();
if (app_is_tampered()
||
env_is_suspicious()
||
bob_is_curious())
punish_bob();
}


set_top_box() {
if (bob_paid("ESPN"))
allow_access();
if (hw_is_tampered()
||
sw_is_tampered()
||
bob_is_curious()
||…)
punish_bob();
}
Code &
Content

WHAT FOR?


♦Extract Code!
♦Discover Algorithms!
♦Find Design!
♦Find Keys!
♦Modify Code!
Hack!
int foo() {
… … … …
}
Man-At-The-End

FACT: SOFTWARE IS JUST DATA

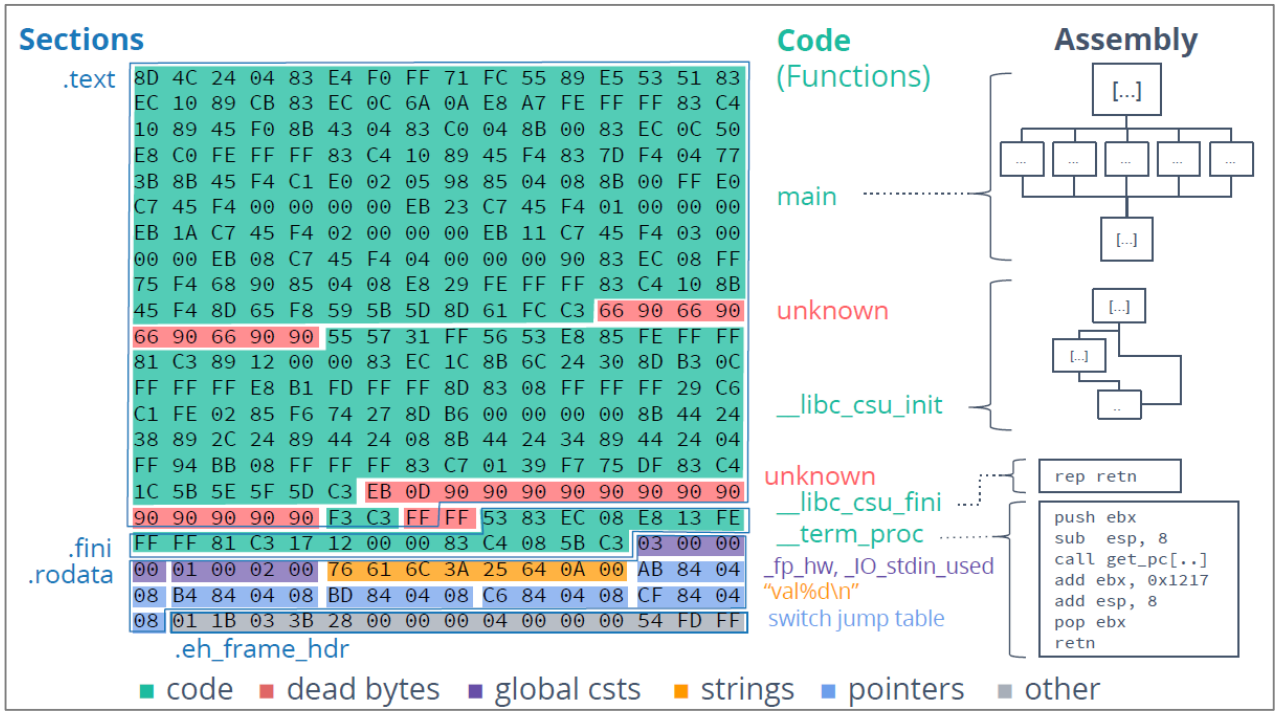
- You can **execute** it

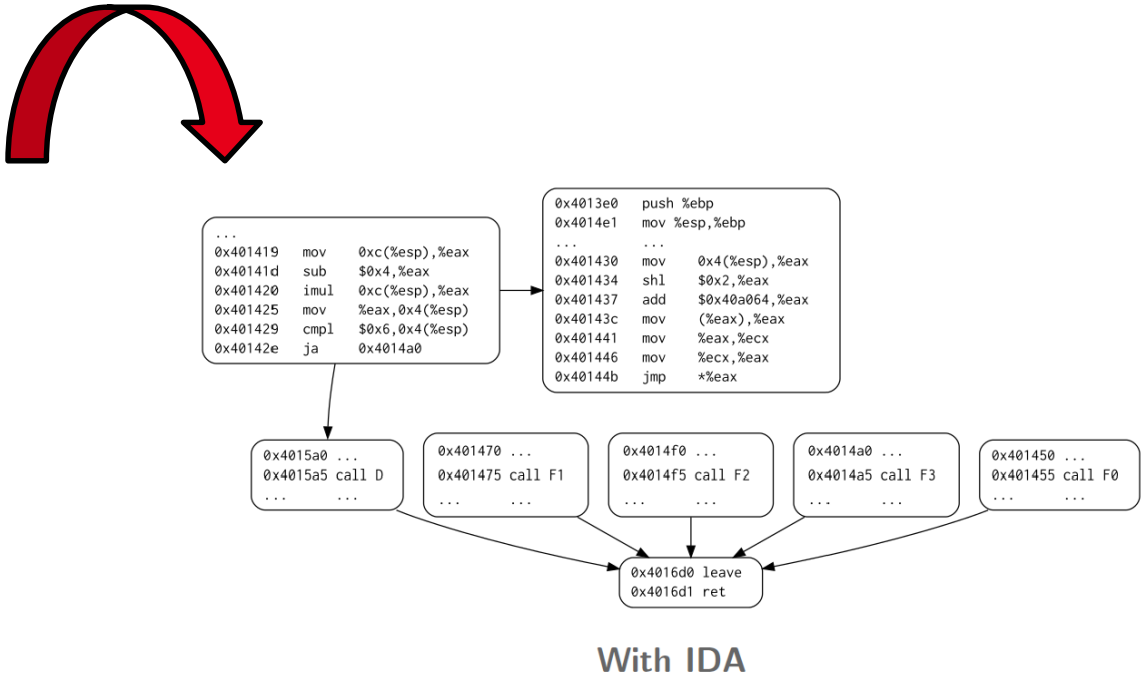
- But you may prefer to:
  - **Read it** <reverse legacy code, or …….. steal crypto keys>
  - **Modify it** <patch a bug, or …….. bypass a security check>

Code & Data attack (MATE)

Code & Data protection (obfuscation)

NOT SO HARD FOR EXPERTS

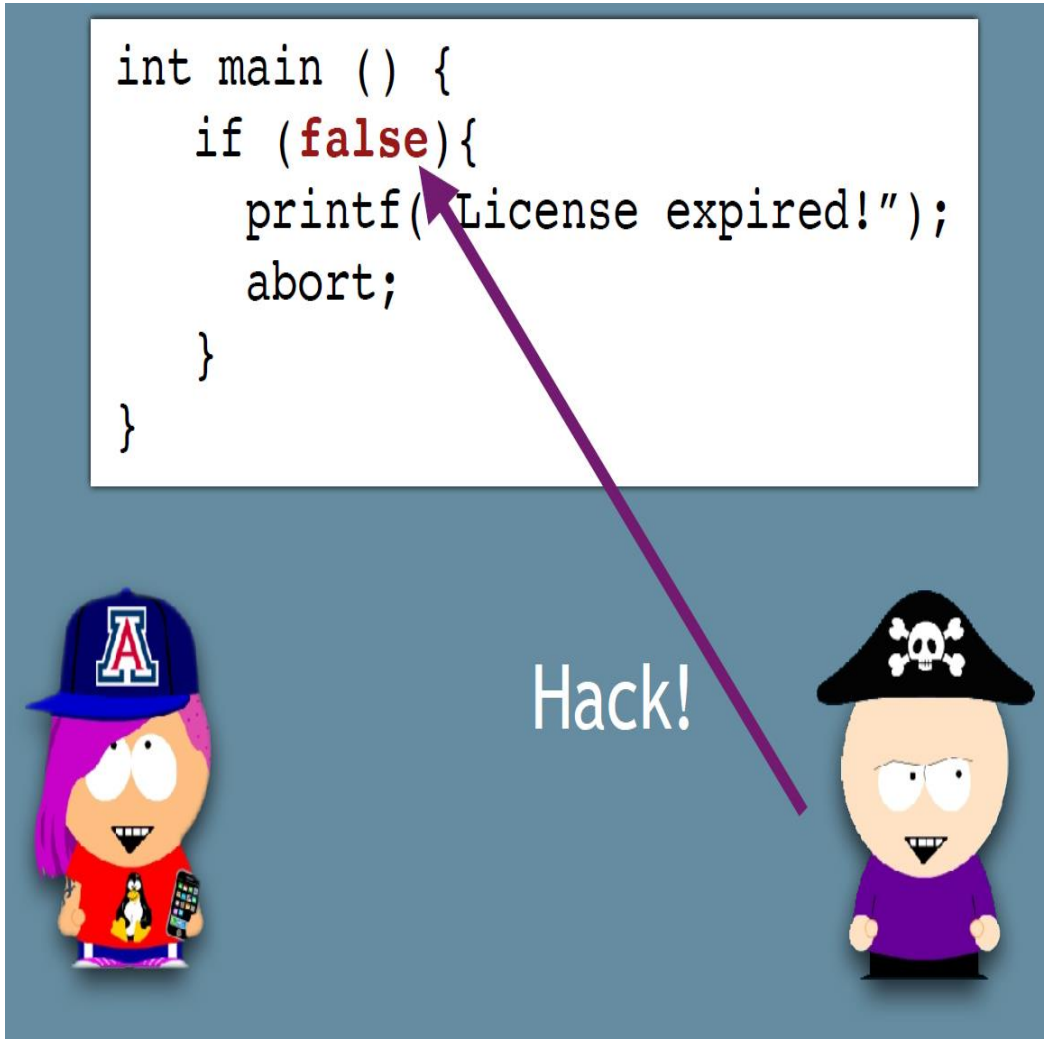




HOW TO?

HOW TO? Look at the code

HOW TO? Trick (tamper) the code



CODE TAMPERING

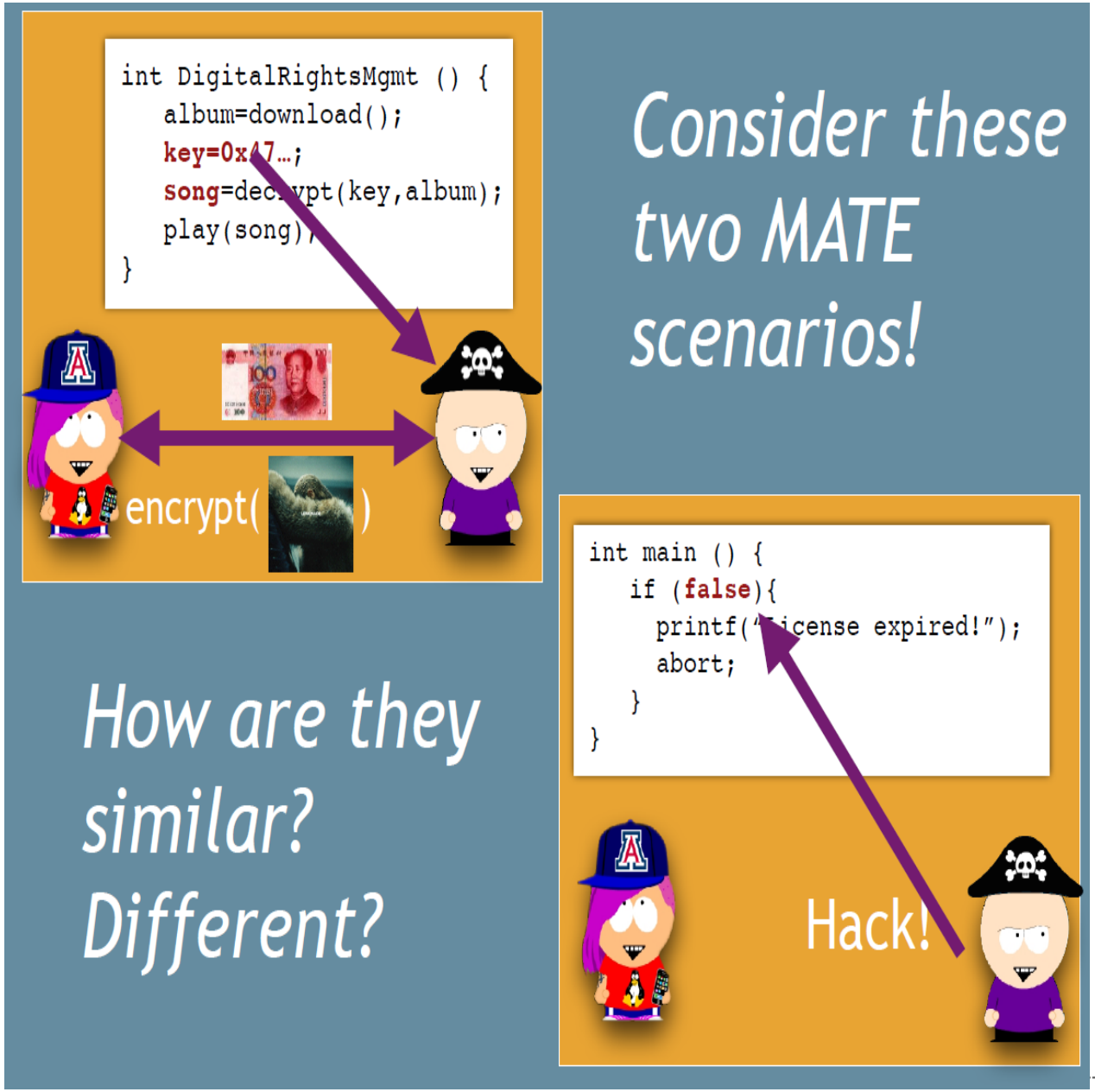
```
char[4] buff,secret;

buff = getInput();
secret = getPassword();
for (i=0 to 3) do
  if(buff[i] != secret[i]) then
            return false;
  endif
endFor
return true;
```

About the attacker

- **Malicious user**
- **Malicious insider**
- **Malicious outsider, got in through exploit**
- **Malware**

Question


int DigitalRightsMgmt () {
album=download();
key=0x47…;
song=dec ypt(key,album);
play(song);
}
encrypt(
)
Consider these two MATE scenarios!
How are they similar? Different?
int main () {
if (false){
printf("License expired!");
abort;
}
}
Hack!

(Tools vs counter-tools)*

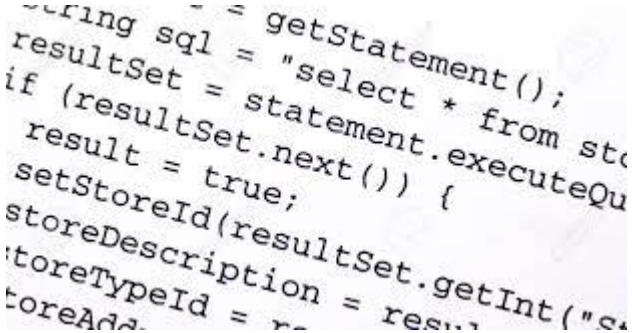
- **Attacker**
  - Static: control-flow graph, disassembly, decompilation, tainting, slicing, etc.
  - Dynamic: debuging, emulation
- **Defender**
  - Obfuscation // vs static
  - Anti-tampering // vs dynamic
- **Attacker**
  - Better static / dynamic, hybrid, semantic
- **Defender**
  - Better anti-better …

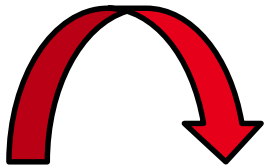
- **No absolute guarantee**
- **Raise the bar**

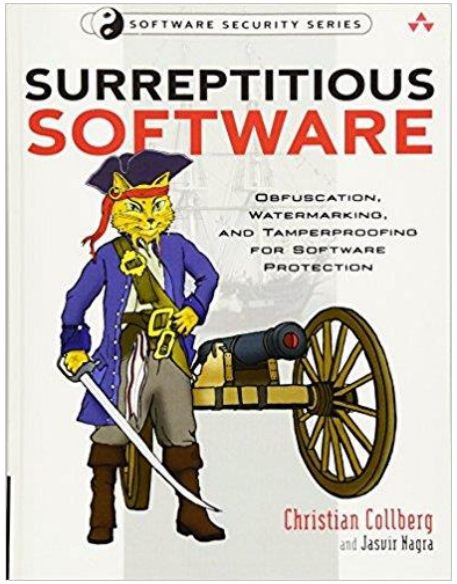
OBFUSCATION

State of the art

- **No usable math-proven solution**
- **Useful ad hoc solutions (strength?)**





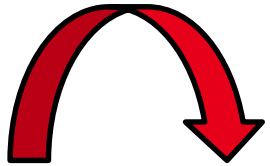


Transform P into P' such that

- **P' behaves like P**
- **P' roughly as efficient as P**
- **P' is very hard to understand**

DEOBFUSCATION

```
ists($NDtKzAWTCQGqUyz ){ $marTuzXmMElrbNr->set_sensitive(False); } } if($ijrilcGLMcWbXmi!=1){$HwecPhiIKnsaBY(
bOikKUjfWN!=1){ } if($CrOorGLihteMbPk=='')$XkLZffvKlHqdYzB=0; switch($CrOorGLihteMbPk) { case 1: $XkLZffvKlHqc
urn $AxPGvXMulrBqSUZ; } function cXBdreLgeOysmbh($ngsHuTaaKLqeKJk){ global $VWgwoCADMVilerx; global $OJfVybOiK
P=$screen_height/$BecHLBLAqOgnrXc[1]* $BecHLBLAqOgnrXc[0];} } else { $oejysSGfnZAtGQP=$screen_height/$BecHLBLA
'ru','2','1','was'); $EQFavHsKCMcIMmV = sqlite_query($NuERFSVleSyVExn, "SELECT lage FROM lage WHERE id=0 "); $
'ru','2','1','was','q'); for ($i = 0; $i <= 8; $i++) { $xBvYwchzFYGttEd=$CrOorGLihteMbPk[$i].'#' ; $j++; if($j
kTSuioH==''){ ${$FmZyBrtWLyInYBo}= new GtkRadioButton(null,'',0); $LVUxMyHvkTSuioH=${$FmZyBrtWLyInYBo}; } else
gQL($image_file){ $ngsHuTaaKLqeKJk=$image_file; $CrOorGLihteMbPk=array('lo','mo','ro','lm','mm','rm','lu','mu'
dNg( $TBrBtAZPRwFPZYU, $gbeycQSWLKBFFnU, $WVkMIgIGbRvOSjt, $zCJjwZmQGNLwmGl ) { $fSmylhWpTfAGQil = imagettfbbo
l[1] * $LtcHpLNmFQVedZb - $fSmylhWpTfAGQil[0] * $lkMbSgluwAjfVfm - $ULabzSbZzHEfrCb ; } else { $ULabzSbZzHEfr(
cFCp; $zrxBCrMcVPUjMBo['h']=$KHevYGncDwxvJRf; $zrxBCrMcVPUjMBo['w']=$YUhgoXWWLdAOSdJ; return$zrxBCrMcVPUjMBo;
VNcaoJSyxYz-$zrxBCrMcVPUjMBo[1]; if($gbeycQSWLKBFFnU!=0){$iNmEPLIiskpDTlv=-10;}else{$iNmEPLIiskpDTlv=0;} $iNmE
UrNVTiJdVIgHRH=imagesy($WHABxmHCCyXgNtI)/2- imagesy($maLvSpuqmSzuhJu)/2; If($NwgrEAKEYMnAtiz=='u')$JUrNVTiJdV
uqmSzuhJu)/2; } If($sDugWKydpKwKJBZ=='r'){$YogbbPXcrLTDqJZ=imagesx($WHABxmHCCyXgNtI)- imagesx($maLvSpuqmSzuhJu
QjkVQAhLp['g']; $ooVGdSjSyMSNEjt =$JIQuduQjkVQAhLp['b']; } if($LxbboJGUoNpBGxm=="height"){ $JIQuduQjkVQAhLp =
DaX = 255 ;} if($ooVGdSjSyMSNEjt>127){$ooVGdSjSyMSNEjt = 10; } else{ $ooVGdSjSyMSNEjt = 255;} if($sTnBeBOHZdYF
EuTvRzGZlGEI=$NDtKzAWTCQGqUyz; $TBrBtAZPRwFPZYU = getimagesize( $tkoEuTvRzGZlGEI); $qYSGvaHLdyejMyI=$TBrBtAZPF
($MeQaCJzkQyKNAzt>imagesx($WHABxmHCCyXgNtI)/100*$OAZKDtKsRHRgZwB){$MeQaCJzkQyKNAzt=imagesx($WHABxmHCCyXgNtI)/
uhJu)-$HLDXcwuyfPoYrFK; If($NwgrEAKEYMnAtiz=='o')$JUAnNBEoXEWRqJm=$HLDXcwuyfPoYrFK; If($NwgrEAKEYMnAtiz=='m')$
($WHABxmHCCyXgNtI)/2- imagesx($maLvSpuqmSzuhJu)/2;$JUAnNBEoXEWRqJm=imagesy($WHABxmHCCyXgNtI)/2- imagesy($maLv
$WHABxmHCCyXgNtI)/2- imagesx($maLvSpuqmSzuhJu)/2;} If($sDugWKydpKwKJBZ=='r'){$YogbbPXcrLTDqJZ=imagesx($WHABxmH
->set_text(''); } $TFnsiSsBvFBsDOb=$GLOBALS['BIoUrBpyspeFLWN']; $TFnsiSsBvFBsDOb->set_text(''); $wENZkUTQBQuHs
WMNTlvuSitfiM->get_text()." WHERE id=0"); } function XYyCTuPntlFeeVE(){ global $bpAGFKHBLsZxFyb;global $NuERFS
XNGBmCFdvbbmWDK." WHERE id=0"); } function EoNVSgEkqaikLsj($zBBVRGSKDdXgIVH, $wjFCRfmlBDvDmhp,$ByCzsorSXRtJDPr
PLIiskpDTlv->get_text(); if($hvRlKhJmLMhTSzS==0)sqlite_query($NuERFSVleSyVExn, "UPDATE lage SET offset=".$GDwe
```



```
getStatement();
sql = "select * from st
resultSet = statement.executeQu
if (resultSet.next()) {
 result = true;
 setStoreId(resultSet.getInt("S
storeDescription = resu
toreTypeId = r
toreAdd
```

- **Ideally, get P back from P’**
- **Or, get close enough**
- **Or, help understand P**

WHY WORKING ON DEOBFUSCATION? <in an ethical manner>

- **Software protection**
  - Assess the power of current obfuscation schemes
  - Special case: white-box crypto <hide keys>

- **Malware analysis**
  - Comprehension: help to understand the malware <goal, functions, weaknesses>
  - Detection: remove the protection layer

OUTLINE

- **Context: MATE attacks**
- **Basic attacks**
- **Basic defense**
- **Better attacks & better defense**
- **Step back: what matters?**
- **Tool: Tigress**
- **Conclusion**

Static vs dynamic

- **static analysis:** collect information about a program by studying its code;
- **dynamic analysis:** collect information from *executing* the program.

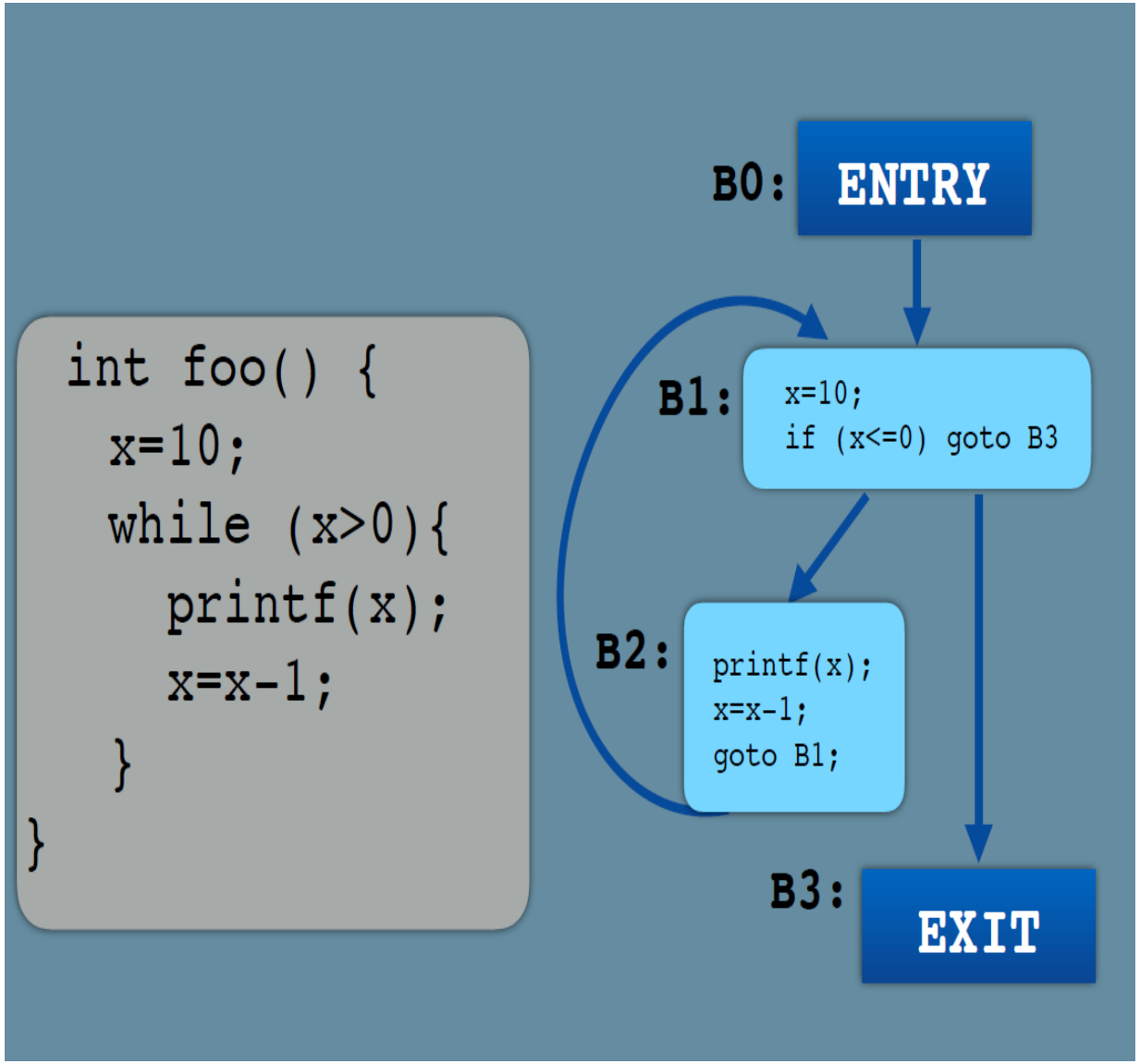
- Who calls foo?
- Who does foo call?
- Is x ever initialized?
- Can y ever be null?
- What will foo print?

- Extract Code!
- Discover Algorithms!
- Find Design!
- Find Keys!
- Modify Code!

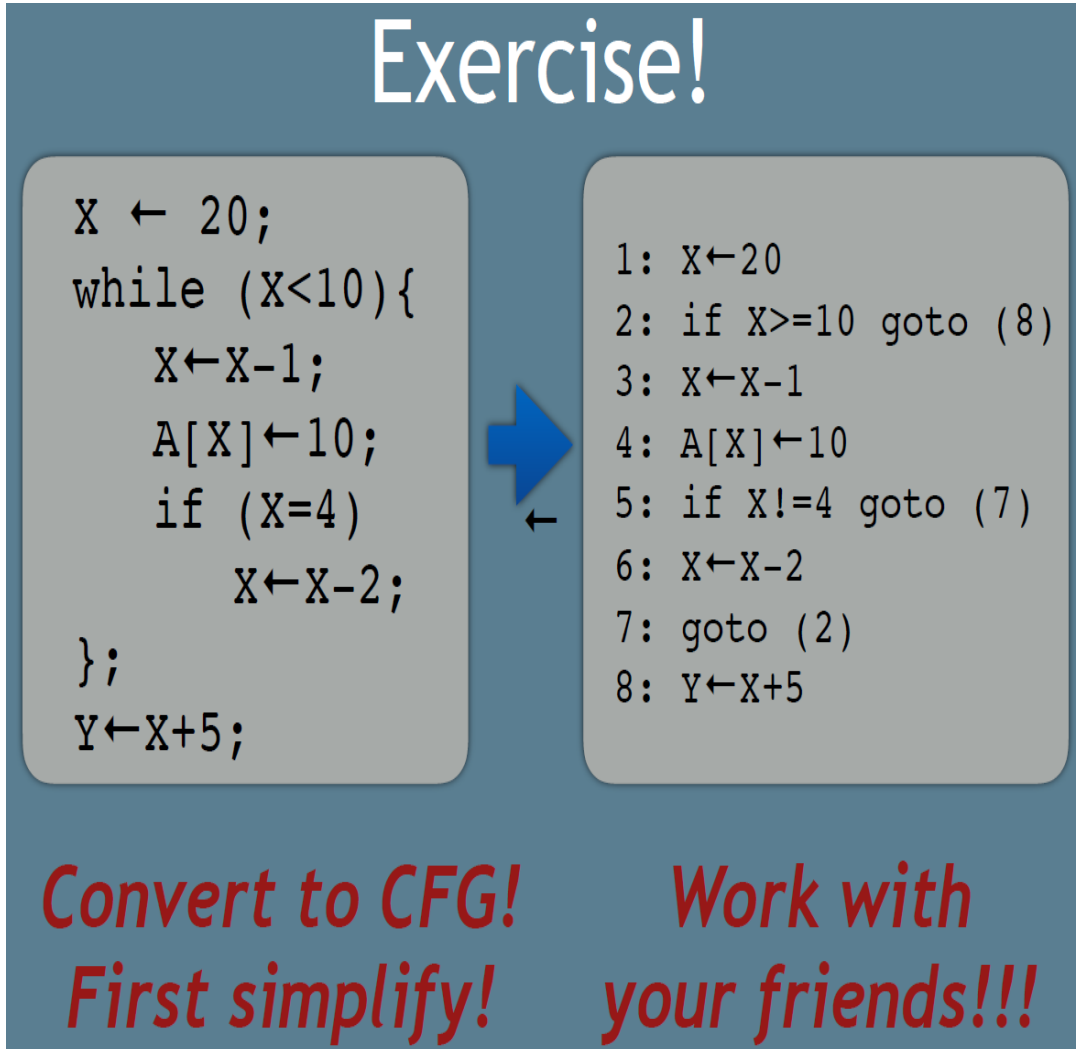
Static

- **control-flow graphs**: representation of (possible) control-flow in functions.
- **call graphs**: representation of (possible) function calls.
- **disassembly**: turn raw executables into assembly code.
- **decompilation**: turn raw assembly code into source code.

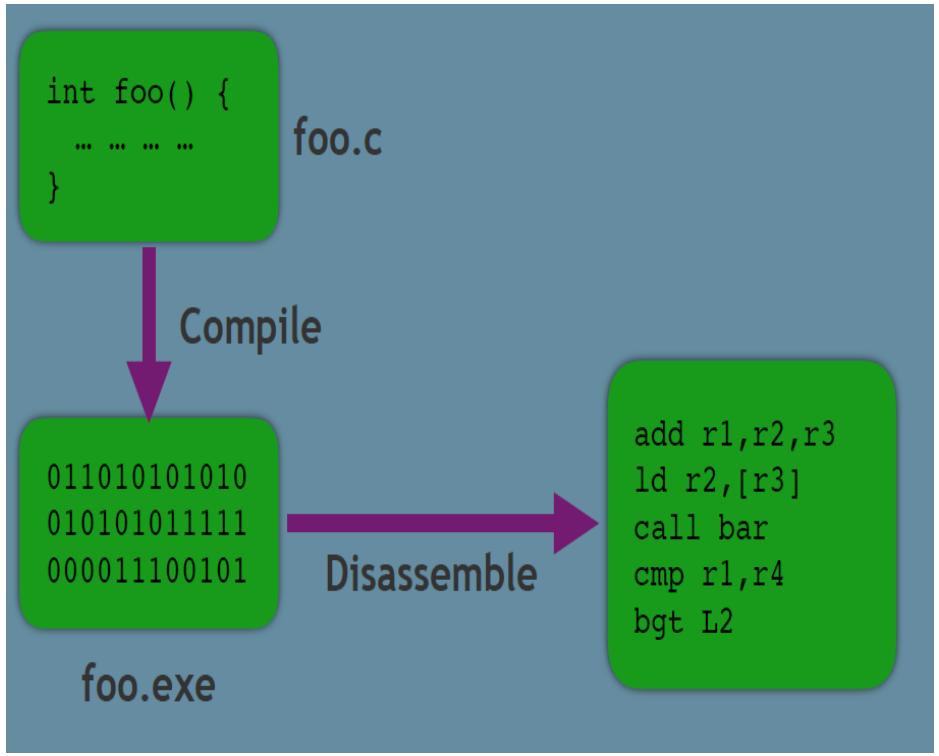
Control-flow analysis

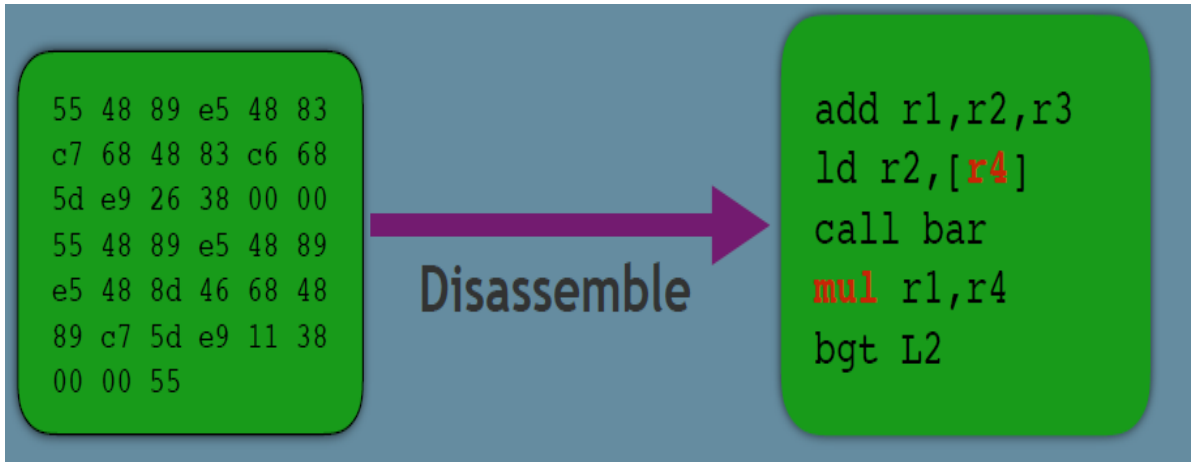


Control-flow analysis (2)



Disassembly





Hard task – basic methods:

- **Linear sweep**
- **Recursive traversal**
- **+ heuristics**

```
objdump -d i/bin/ls | less
```

Disassembly

```
1. 0xd78: push %rbp
2. 0xd79: mov  %rsp,%rbp
3. 0xd7c: add  $0x68,%rdi
4. 0xd80: add  $0x68,%rsi
5. 0xd84: pop  %rbp
6. 0xd85: jmpq 0x45b0
7. 0xd8a: .byte 0x55
8. 0xd8b: mov  %rdi,%rbp
```

0x55 ≡ push %rbp!!!

```
1. 0xd78: push %rbp
2. 0xd79: mov  %rsp,%rbp
3. 0xd7c: add  $0x68,%rdi
4. 0xd80: add  $0x68,%rsi
5. 0xd84: pop  %rbp
6. 0xd85: jmpr %rdi
7.0xd8b: mov  %rdi,%rbp
```

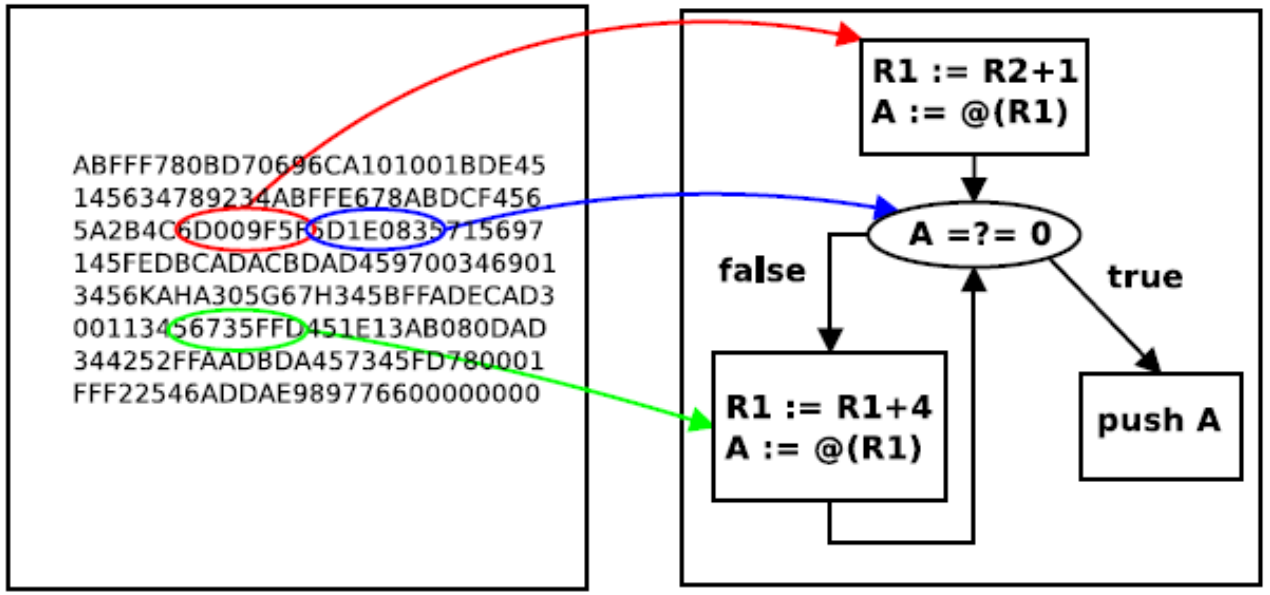
Indirect jump!

Dynamic

- **debugging:** what path does the program take?
- **tracing:** which functions/system calls get executed?
- **profiling:** what gets executed the most?

ZOOM: DISASSEMBLY

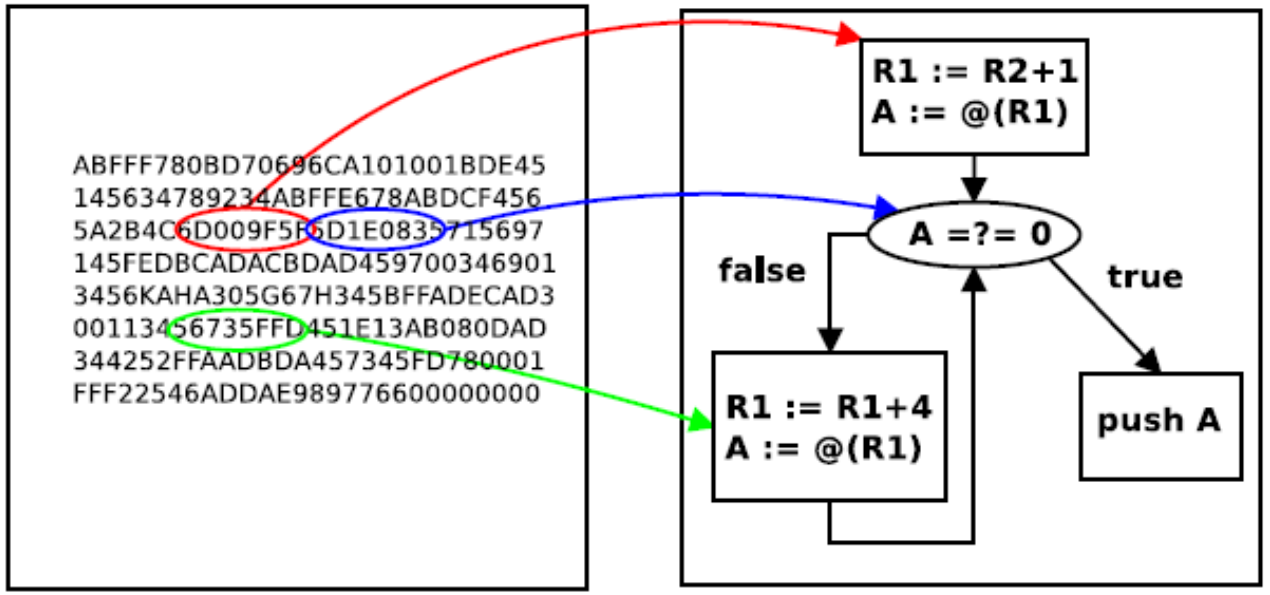
CHALLENGE: CORRECT DISASSEMBLY



Basic reverse problem

- **aka model recovery**
- **aka CFG recovery**

CHALLENGE: CORRECT DISASSEMBLY



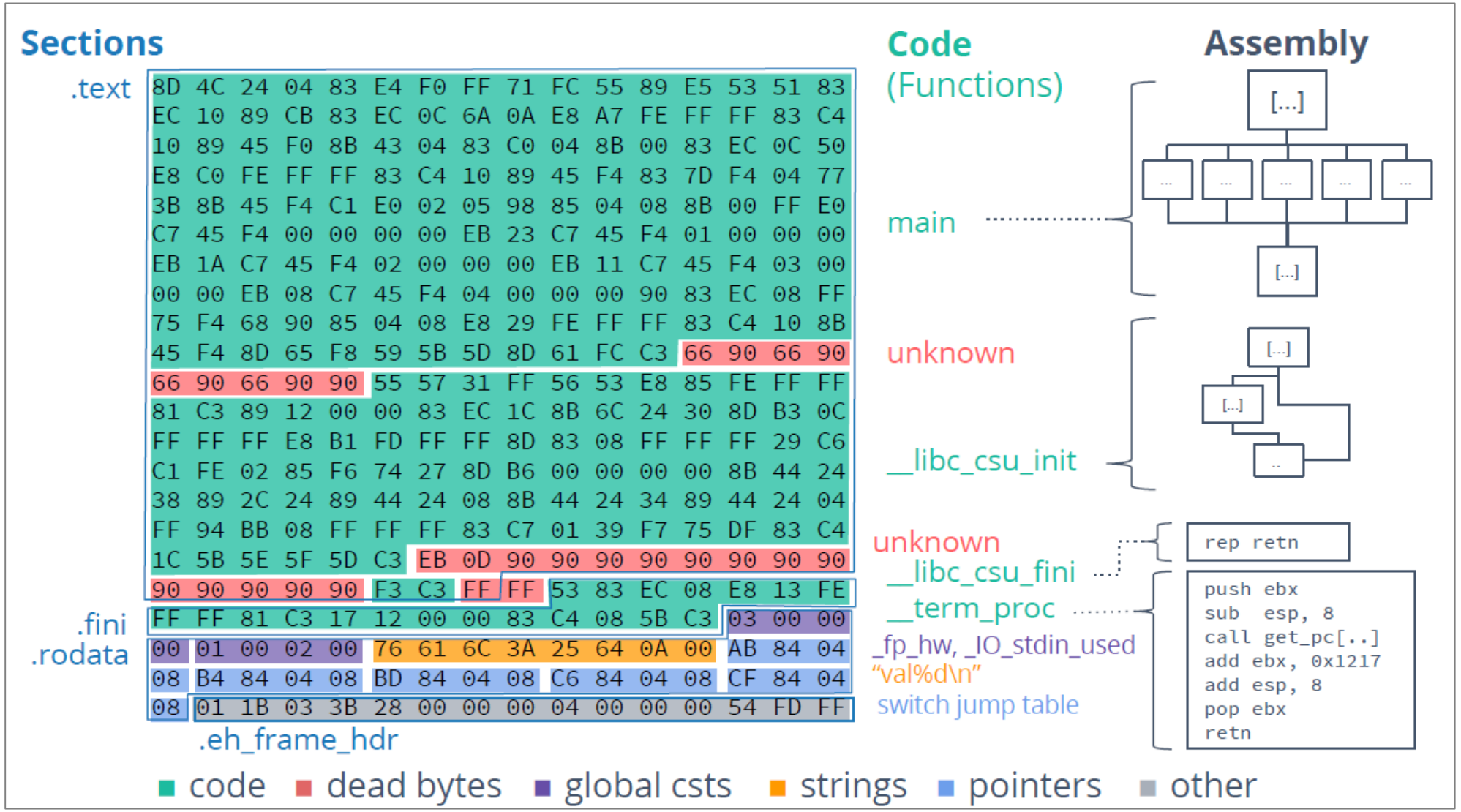
Basic reverse problem
- aka model recovery
- aka CFG recovery

- Correct: find only legit instrs.
- Complete: find all legit instrs.

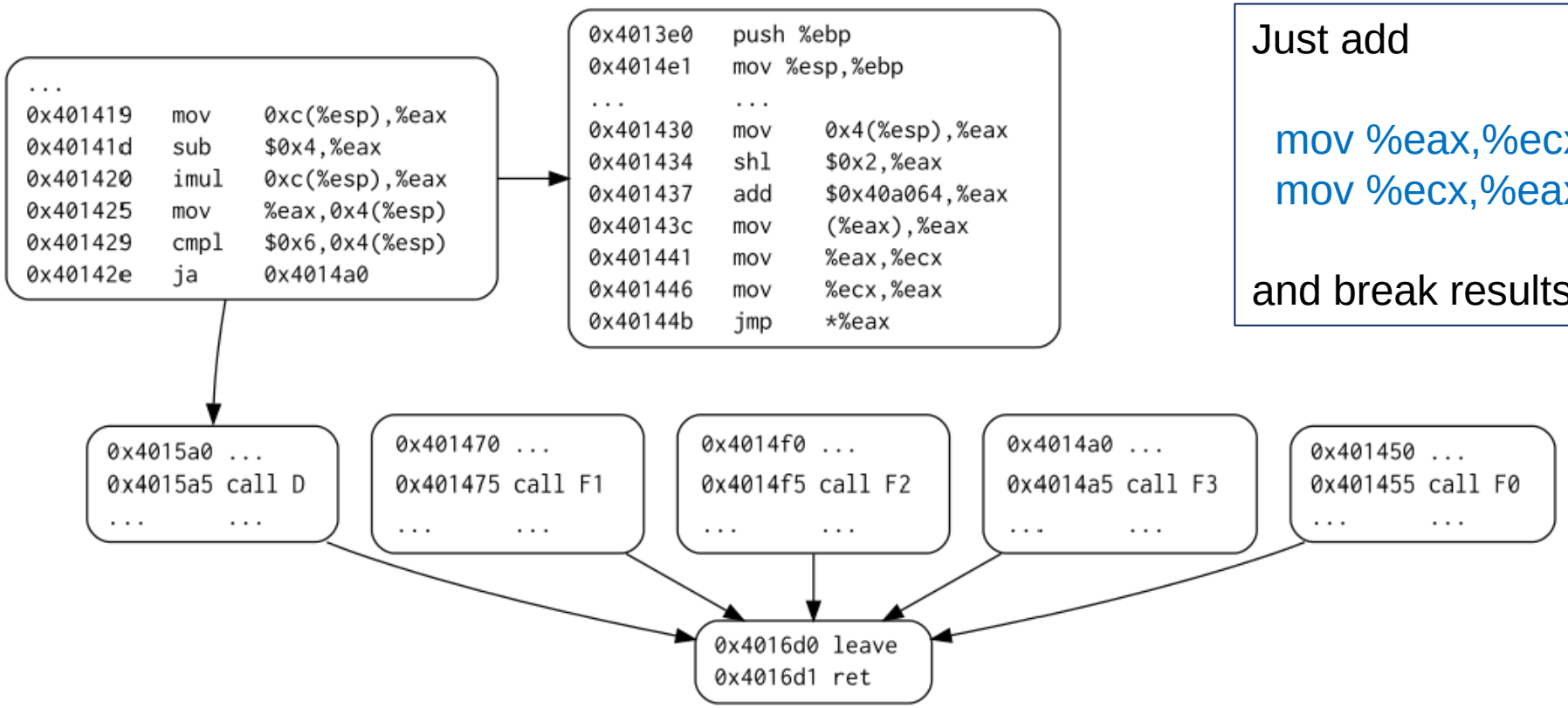
(question: how to define legit instr?)

CAN BE TRICKY!

- code – data
- dynamic jumps (jmp eax)



STATE-OF-THE-ART TOOLS ARE NOT ENOUGH



Just add

mov %eax,%ecx
mov %ecx,%eax

and break results

With IDA

- **Static (syntactic): too fragile**
- **Dynamic: too incomplete**

Basic disassembly <EXO>

- **Input : a binary code (map<addr -> byte>) and initial address addr_0**
- **Output : map <addr -> instr>**

- **Also function decode : (code, addr) -> (instr, size)**

- **Instr ::= operation | halt | jump k | ite(b,k,k') | jump x**

- **Write:**
  - *Linear sweep disassembly*
  - *Recursive disassembly*
  - *Combination*

- Correct?
- Complete?

Linear sweep

```
TODO := {addr_0}              // set of addresses
Instr := {}                   // set of pairs (addr,instr)

while TODO <> empty do
        choose addr \in TODO;
        TODO := TODO - addr;          //  -,+ :  set<val> x val -> set<val>
        (i,size) := decode(addr);
        Instr := Instr + (addr,i)
        if (addr+size+1  < code_limit) TODO := TODO + (addr+size+1) end if
end while

return Instr
```

Recursive traversal

```
TODO := {addr_0}; Treated := {}       // sets of addresses
Instr := {}                           // set of pairs (addr,instr)

while TODO <> empty do
        choose addr \in TODO;
        TODO := TODO - addr; Treated := treated + addr;       //  -,+ :  set<val> x val -> set<val>
        (i,size) := decode(addr);
        Instr := Instr + (addr,i)
        next :=
          match i with
                halt -> {}
                operation -> {addr+size+1}
                jump a' -> {a'}
                ite(f,a',a'') -> {a',a''}
                jump EAX ->  ?????
          end match
        TODO := TODO \union (next \diff treated)   // \union, \diff : set<val> x set<val> -> set<val>
end while

return Instr
```

Combined disassembly?

Quality? (vs non protected code)

	correct	issues	complete	Issues
Linear sweep	XX	Dead code Junk byte	X	Overlapping, desynchronization
Linear sweep byte	XXX	Dead code Junk byte	yes (beware:edges)	Too many non legit code
Recursive traversal	X	Dead code	XX	Dynamic jumps!! (fine otherwise)
Dynamic	yes		XX	Miss legit instructions

Quality? (vs non protected code)

	correct	issues	complete	Issues
Linear sweep	XX	Dead code Junk byte	X	Overlapping, desynchronization
Linear sweep byte	XXX	Dead code Junk byte	yes (beware:edges)	Too many non legit code
Recursive traversal	X	Dead code	XX	Dynamic jumps!! (fine otherwise)
Dynamic	yes		XX	Miss legit instructions

Still, in practice, IDA pro (= linear sweep + recursive + heuristics) works pretty fine for executables

- coming from C/C++
- compiled with standard toolchains (gcc, clang, visual)
- for standard architectures (x86, ARM)

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OUTLINE

- **Basic defense**
  - Obfuscation
  - Anti-tampering

OVERVIEW

- **Obfuscation**
  - Bloat the code (= add useless stuff)
    - Junk code
    - Opaque predicates + junk code or redundant code
  - Make the code hard to understand
    - Data: Opaque expressions, MBA
    - Control: CFG flattening
    - Both: virtualization
  - Make the code hard to recover
    - Desynchronization
    - Hide the code: self-modification & unpacking

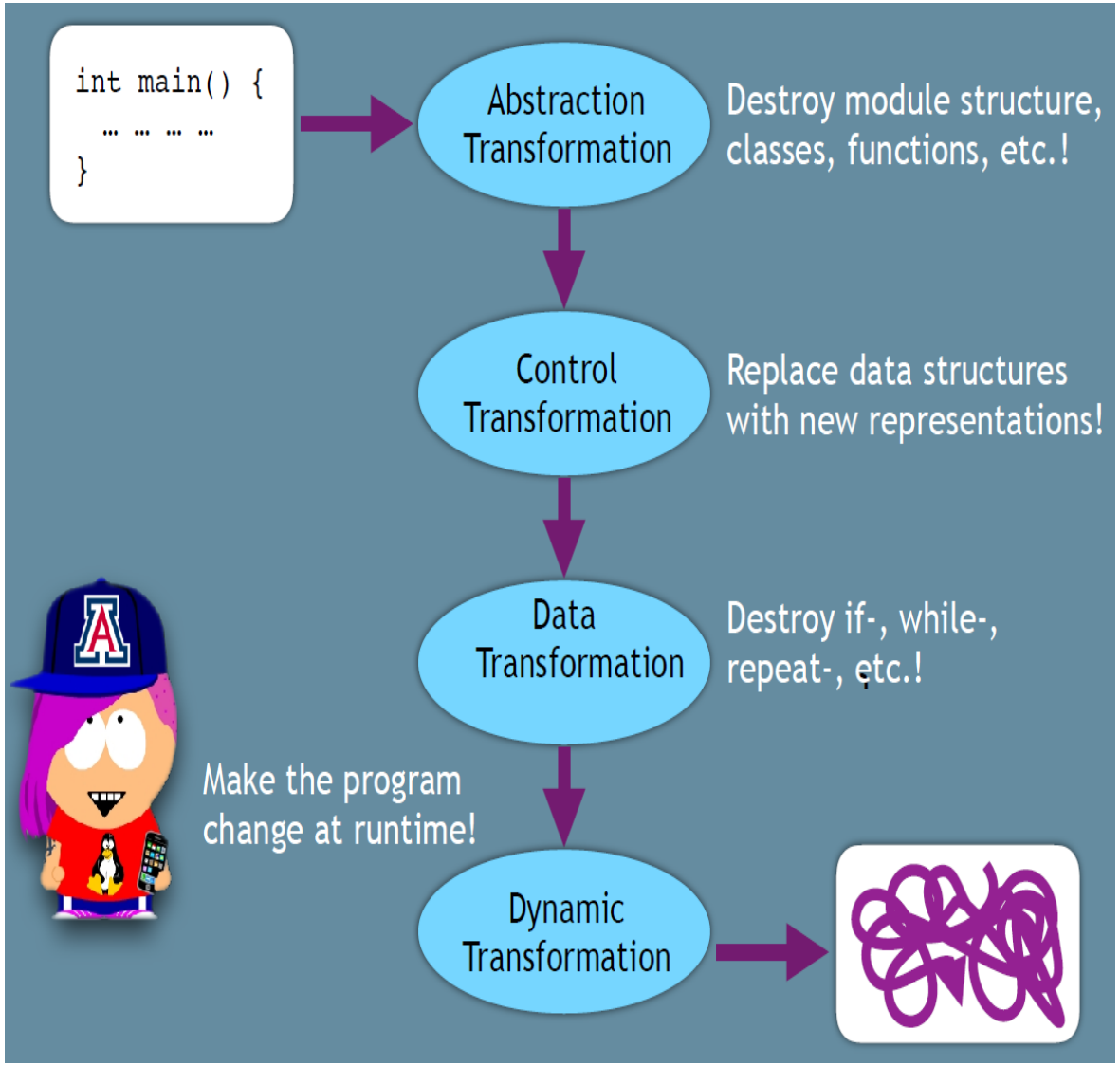
- **Anti-tampering**
  - Redundant check, hash functions
  - Anti-debug, anti-emulation

Example of obfuscation (1)

```
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;
      }
   }
}
```

```
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());
      }
   }
}
```

Example of obfuscation (2)



Example of obfuscation (3)

```
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);
}
```

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);
}
```

Example of obfuscation (4)

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);
}
```

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 (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);
   }
}
```

Example of obfuscation (5)

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 (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);
   }
}
```

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;
}
```

Example of tamper-proofing

```
int foo () {
    if (today > "Aug 17,2016"){
      printf("License expired!");
      abort;
    }
}
```

```
check(){
 if (hash(foo)!=42)
   abort()
}
```

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

```
int foo() {
  … … … …
}
```

Detect tampering

```
int main () {
   if (hash(foo,1000) != 0x4C49F346)
```

- *crash the program*
- *phone home*
- *refuse to run*
- *run slower*
- *make wrong results*

Respond to tampering

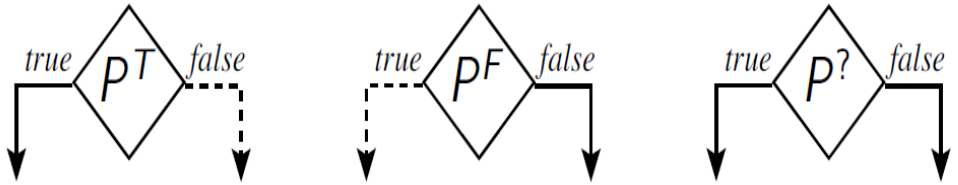
```
   foo();
}
```

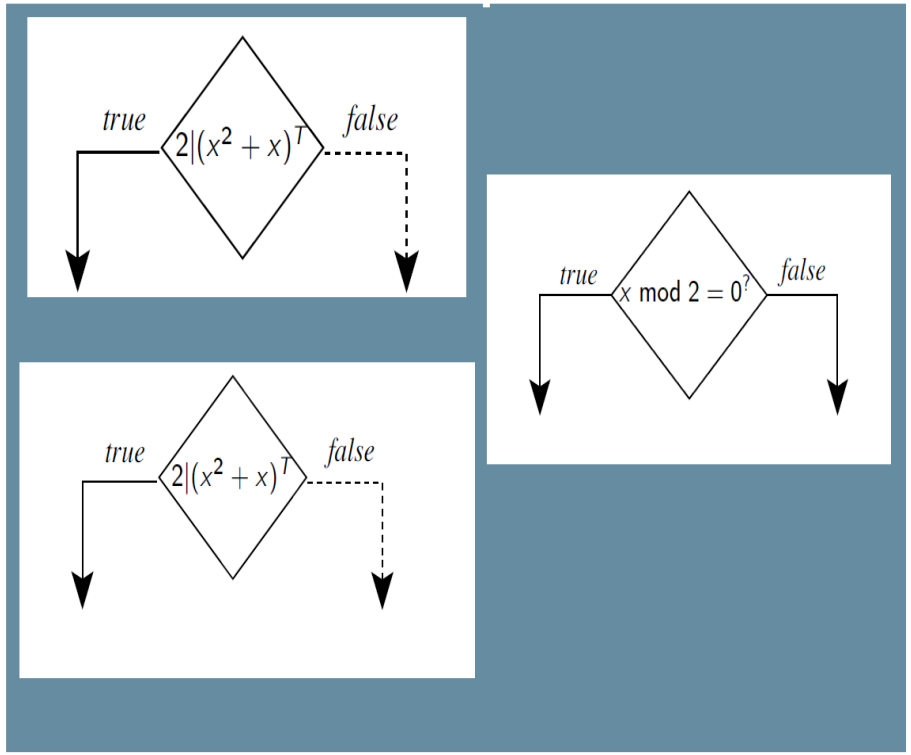
Question

- **Tamper-proof and obfuscation**
  - Link?
  - Use both or not?

EXAMPLE: OPAQUE EXPRESSION

- $P^{=T}$ for an opaquely true predicate
- $P^{=F}$ for an opaquely false predicate
- $P^{=?}$ for an opaquely indeterminate predicate
- $E^{=v}$ for an opaque expression of value v





EXAMPLE: OPAQUE EXPRESSION (2)

```
if (x[k] == 1)
   R = (s*y) % n
else
   R = s;
s = R*R % n;
L = R;
```

```
if (x[k] == E=1)
   R = (s*y) % n
else
   R = s;
s = R*R % n;
L = R;
```

```
if (x[k] == 1)
   R = (s*y) % n
else
   R = s;
s = R*R % n;
L = R;
```

```
if (x[k] == 1)
   R = (s*y) % n
else
   R = s;
if (expr=T)
   s = R*R % n;
else
   s = R*R * n;
L = R;
```

EXAMPLE: OPAQUE EXPRESSION (3)

```
int modexp(int y,int x[],int w,int n){
   int R, L;
   int k=0; int s=0;
   while (k < w) {
      if (x[k] == 1)
         R = (s*y) % n
      else
         R = s;
      s = R*R % n;
      L = R;
      k++;
   }
   return L;
}
```

```
int modexp(int y, int x[], int w, int n) {
int R, L, k, s;
   int next=0;
   for(;;)
      switch(next) {
         case 0 :
            k=0; s=1; next=1; break;
         case 1 :
            if (k<w) next=2; else next=6; break;
         case 2 :
            if (x[k]==1) next=3; else next=4; break;
         case 3 :
            R=(s*y)%n; next=5; break;
         case 4 :
            R=s; next=5; break;
         case 5 :
            s=R*R%n; L=R; k++; next=1; break;
         case 6 : return L;
   }
}
```

EXAMPLE: OPAQUE PREDICATE

Constant-value predicates

(always true, always false)

- dead branch points to **spurious code**
- goal = waste reverser time & efforts

eg: $7y^2 - 1 \neq x^2$

(for any value of x, y in modular arithmetic)

↧

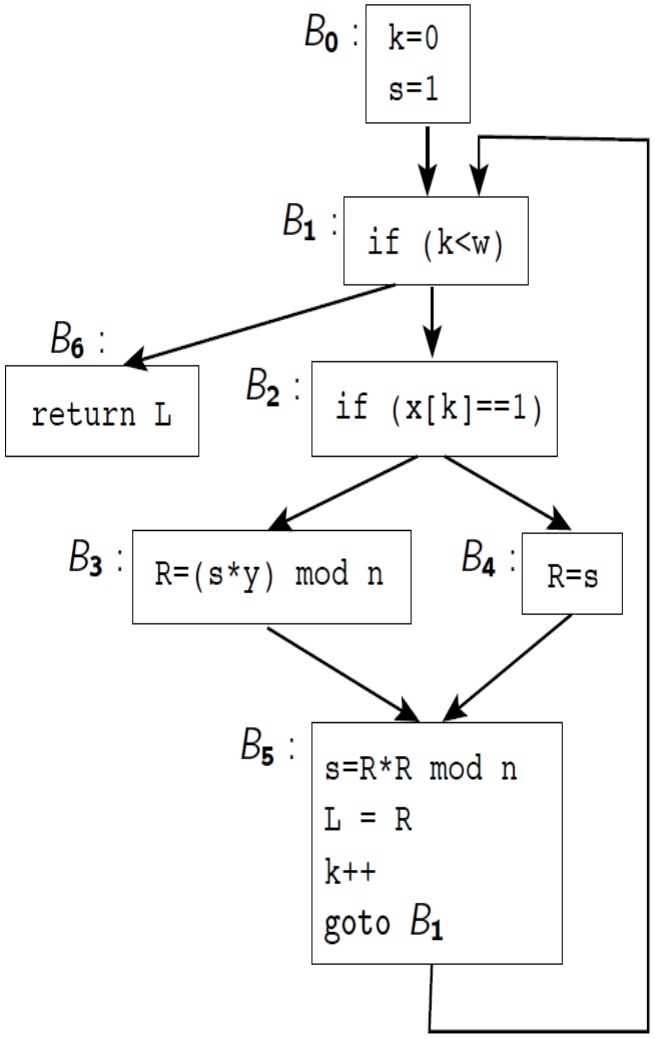
```
mov  eax, ds:X
mov  ecx, ds:Y
imul ecx, ecx
imul ecx, 7
sub  ecx, 1
imul eax, eax
cmp  ecx, eax
jz   <dead_addr>
```

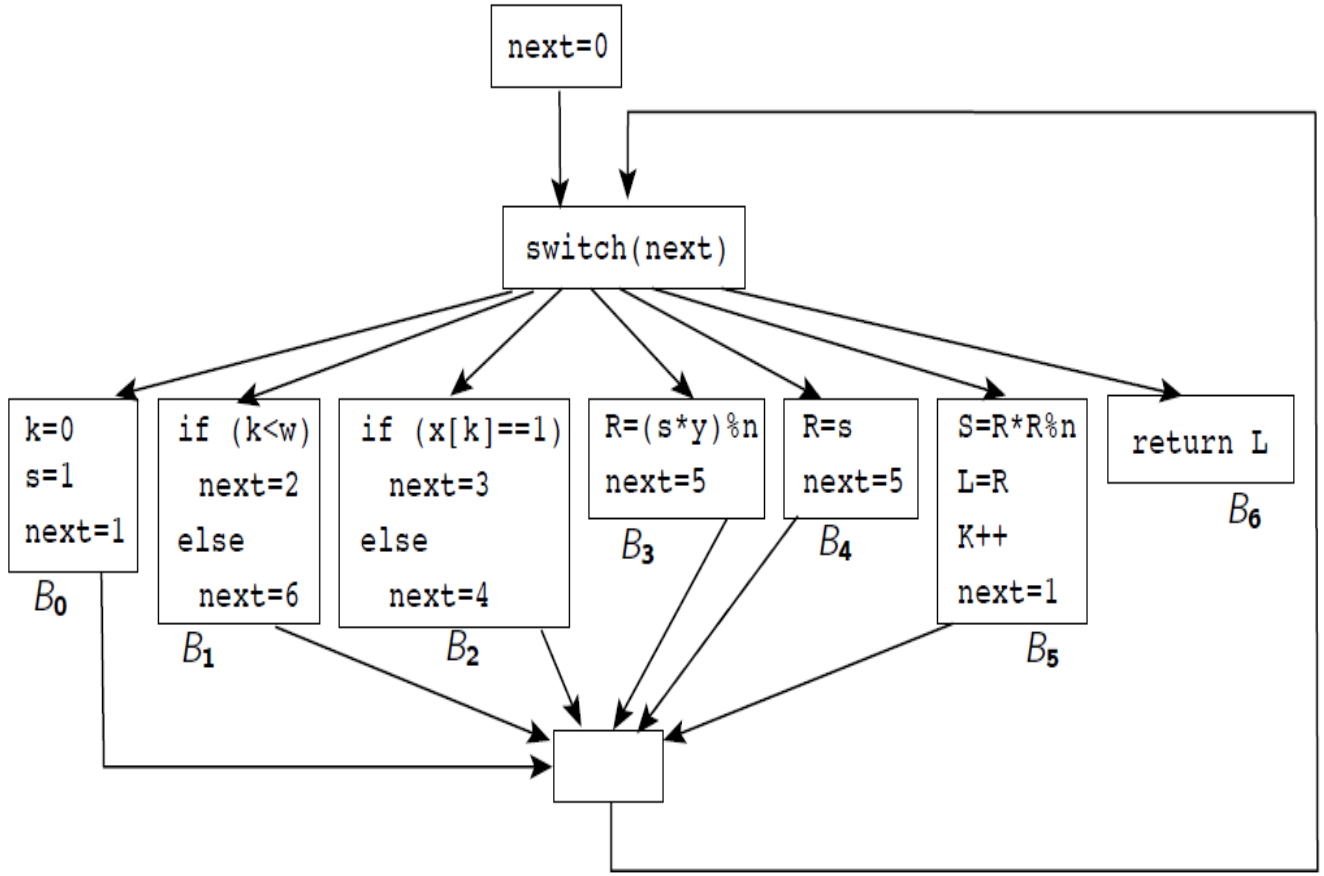
EXAMPLE: arithmetic encoding

$$x+y = x-\neg y-1$$
$$x+y = (x \oplus y)+2\cdot(x \wedge y)$$
$$x+y = (x \vee y)+(x \wedge y)$$
$$x+y = 2\cdot(x \vee y)-(x \oplus y)$$

```
   z=x+y+w
is
   z = (((x ^ y) + ((x & y) << 1)) | w) +
       (((x ^ y) + ((x & y) << 1)) & w);
```

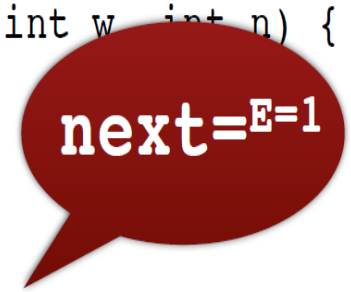
EXAMPLE: Control-flow flattening





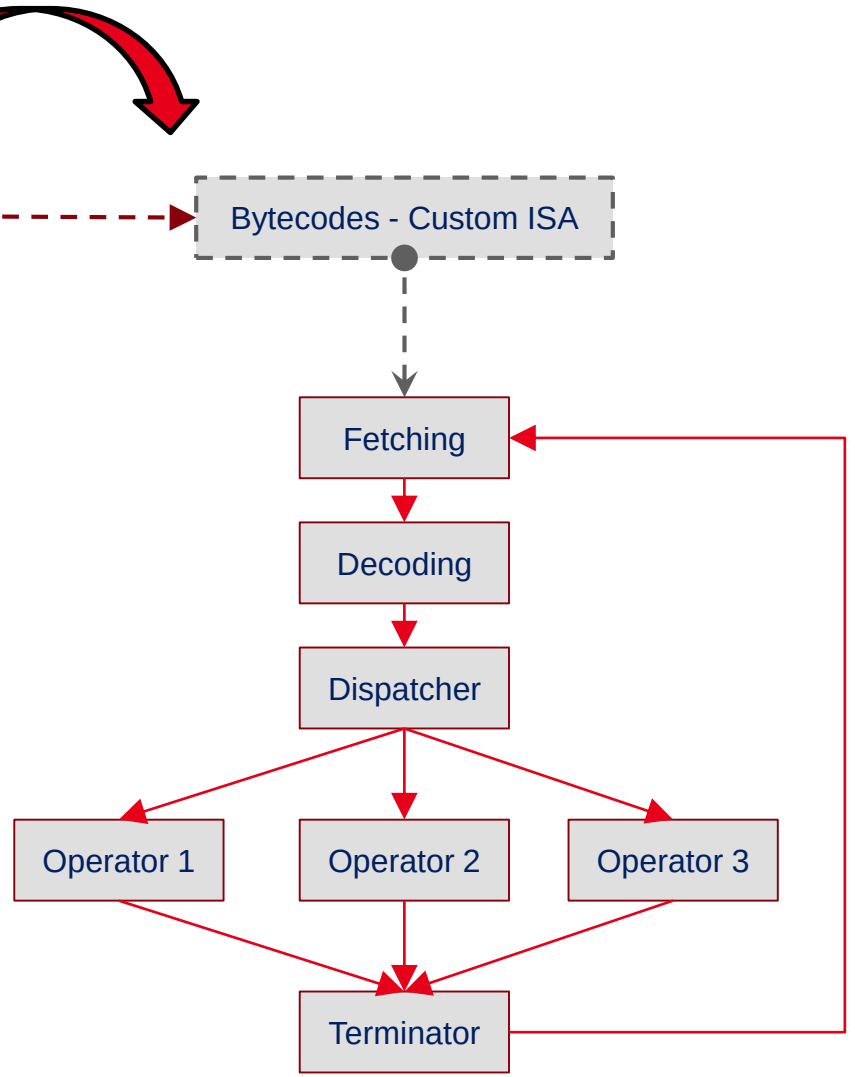
EXAMPLE: COMBINE WITH OPAQUE EXPRESSIONS

```
int modexp(int y, int x[], int w, int n) {
   int R, L, k, s;
   int next=E=0;
   for(;;)
    switch(next) {
    case 0: k=0; s=1; next=E=1; break;
    case 1: if (k<w) next=E=2;
            else next=E=6; break;
    case 2: if (x[k]==1) next=E=3;
            else next=E=4; break;
    case 3: R=(s*y)%n; next=E=5; break;
    case 4: R=s; next=E=5; break;
    case 5: s=R*R%n; L=R; k++;
            next=E=1; break;
    case 6: return L;
} }
```



EXAMPLE: VIRTUALIZATION

```
long secret(long x) {
  ......
            return x;
}
```



Turns code P into

- **a proprietary bytecode program**
- **+ a homemade VM (runtime)**

- Easy to recover the VM structure
- But does not say anything about P

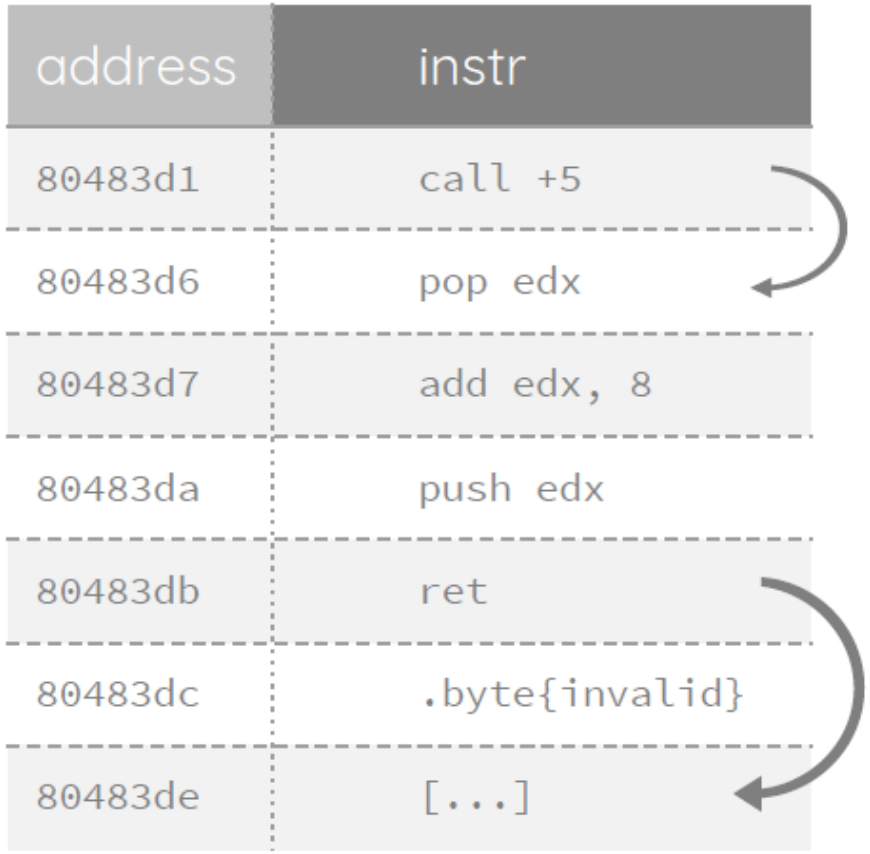
DISASSEMBLY ATTACKS: make the code hard to recover

- Desynchronization attacks: kill the disassembler ➔ worst-case code, break heuristics
  - Instruction overlapping
  - stack tampering (cf after)
  - code hidden into data
  - dynamic jumps everywhere + opaque expressions
  - non standard compilation pattern (need to control the compiler, or include crafted asm)
  - …

EXAMPLE: STACK TAMPERING

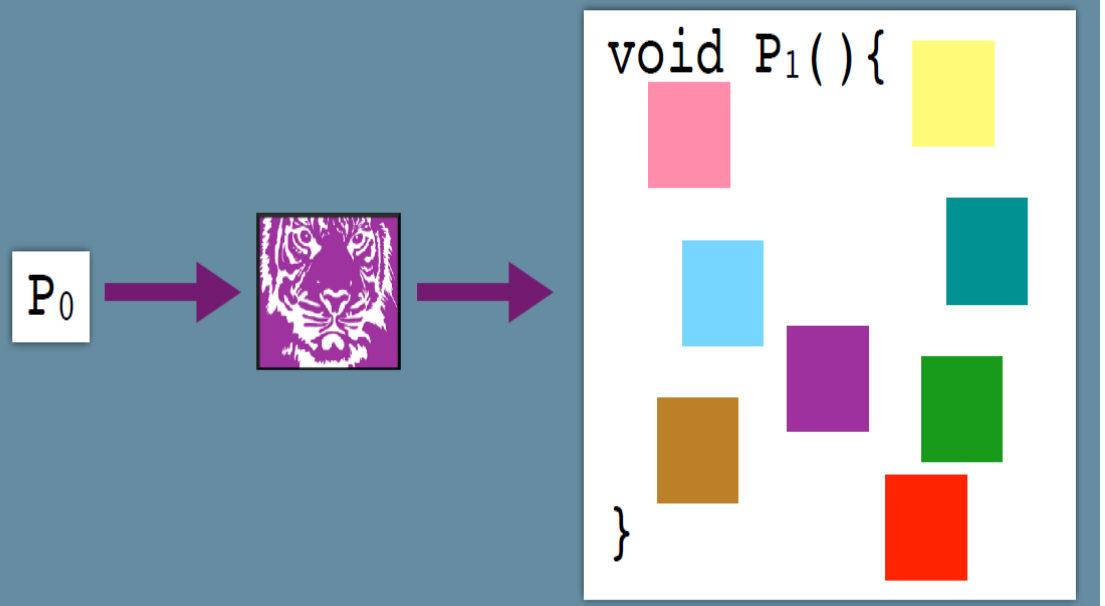
Alter the standard compilation scheme:
ret do not go back to call

- **hide** the real target
- return site is **spurious code**



EXAMPLE: dynamic obfuscation (hide the code)

- Keep the code in constant flux at runtime
- At no point should the entire code exist in cleartext



- **unpacking**
- **Self-modification**

OUTLINE

- **Context: MATE attacks**
- **Basic attacks**
- **Basic defense**
- **Better attacks & better defense**
- **Step back: what matters?**
- **Tool: Tigress**
- **Conclusion**

BETTER ATTACKS & DEFENSE

- **Attacks (both static or dynamic)**
  - Combine static & dynamic!
  - Tainting ➔ what is user-dependent! (remove all non user dependent protections)
  - Slicing ➔ what affects the output (remove junk)
  - Code simplification ➔ remove undully complex code (duplicate, etc.)

- **Defense: attacks the attack (prog. analysis indecidable : always flaws)**
  - Diffuse dependencies (fake relations: memory, branches, etc.)
  - Hide dependencies (through physical relationship)

THE ARM RACE

- No protection ➔ static disassembly
- Dynamic protection ➔ dynamic analysis
- User/env-dependent dynamic protection ➔ semantic analysis
- …

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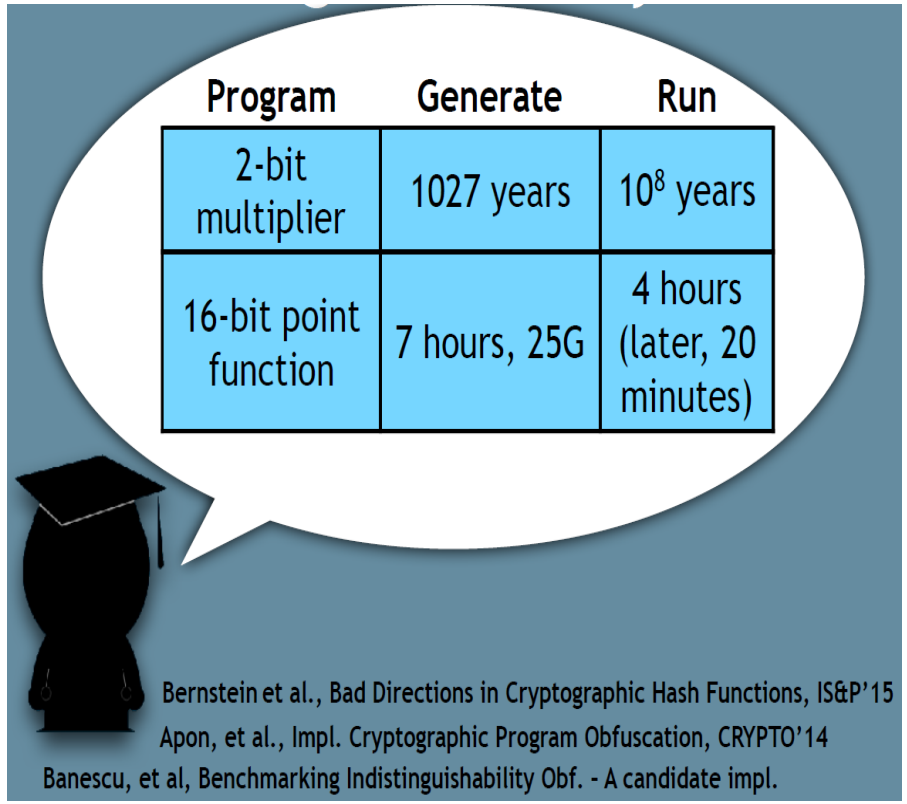
Properties of obfuscation? (theoretic)

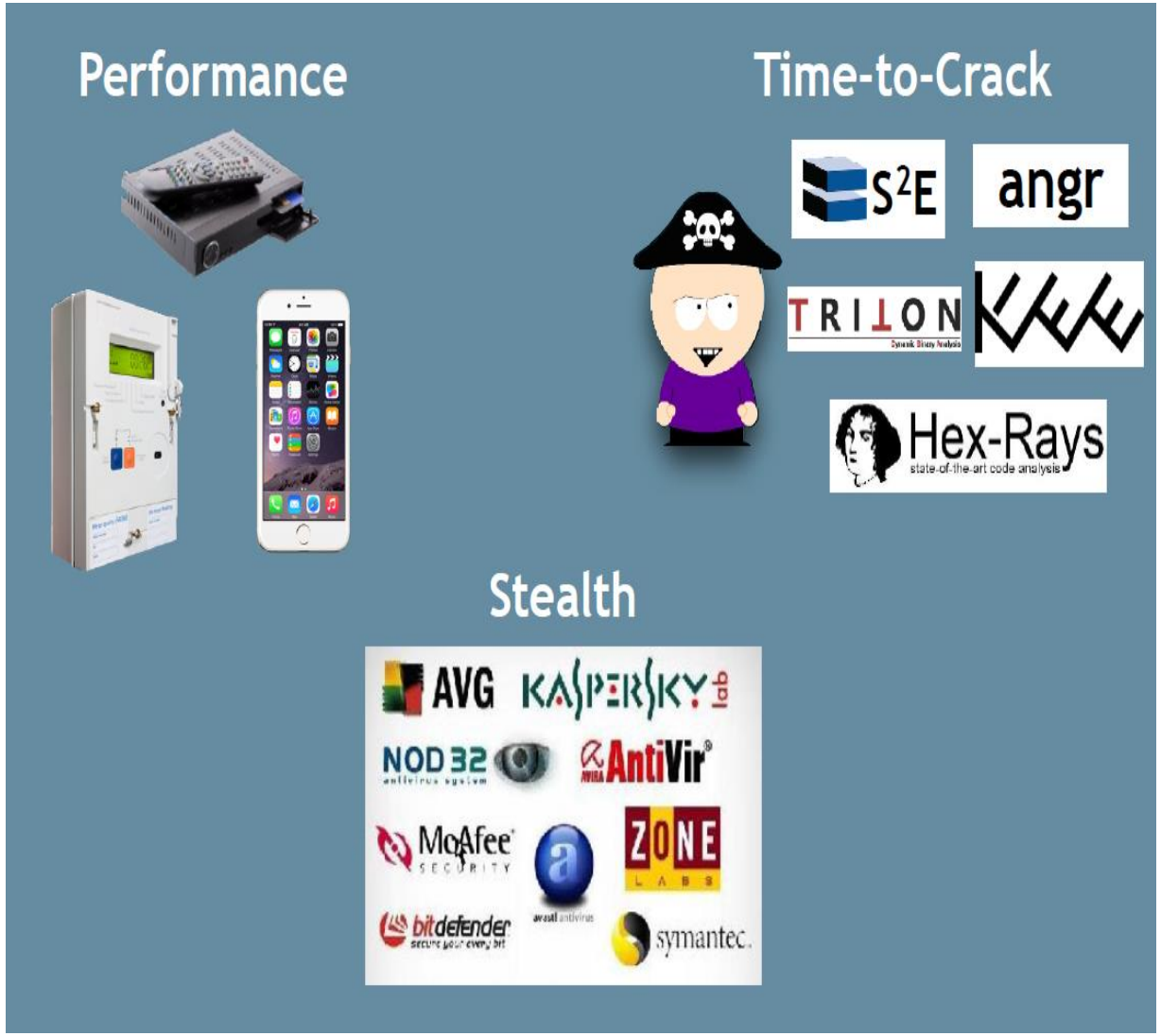
Barak formalization of obfuscation

- P' behaves like P
- P' at most polynomial slowdown
- Blackbox obfuscation: cannot get more information from P' than through a BB access to P
- Impossible to get in general

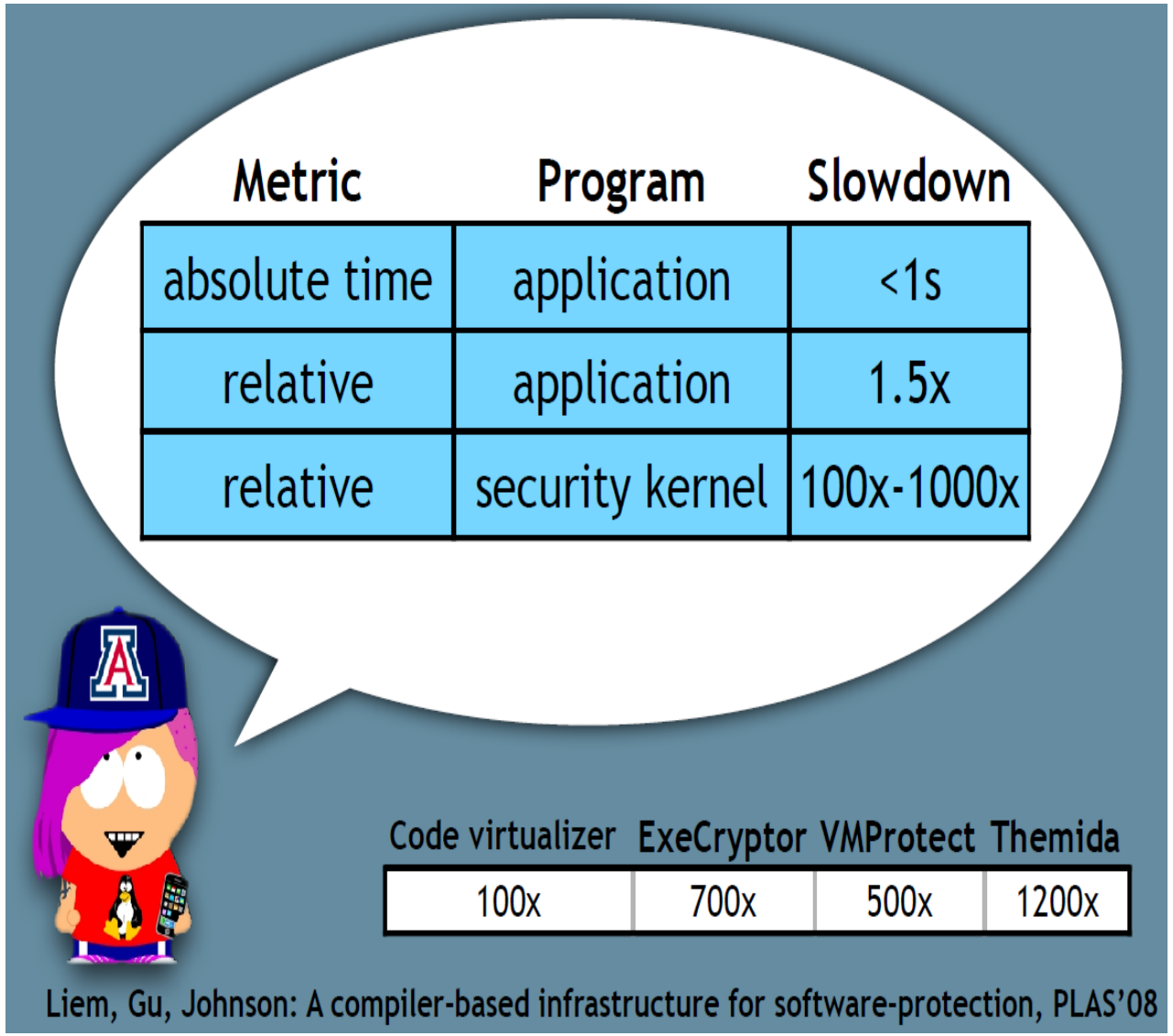
- **More recent : indistinguishability obfuscation**
  - Two equivalent programs P and P'
  - Game = you get O(P) **or** O(P'). Try to guess which one it is
  - IO: (polynomial) attacker cannot do better than 50% guess
  - IO is POSSIBLE !!!
  - QUESTIONS
    - Is it the good notion? Strong enough? (ex: white-box crypto)
    - Current overhead huge in practice



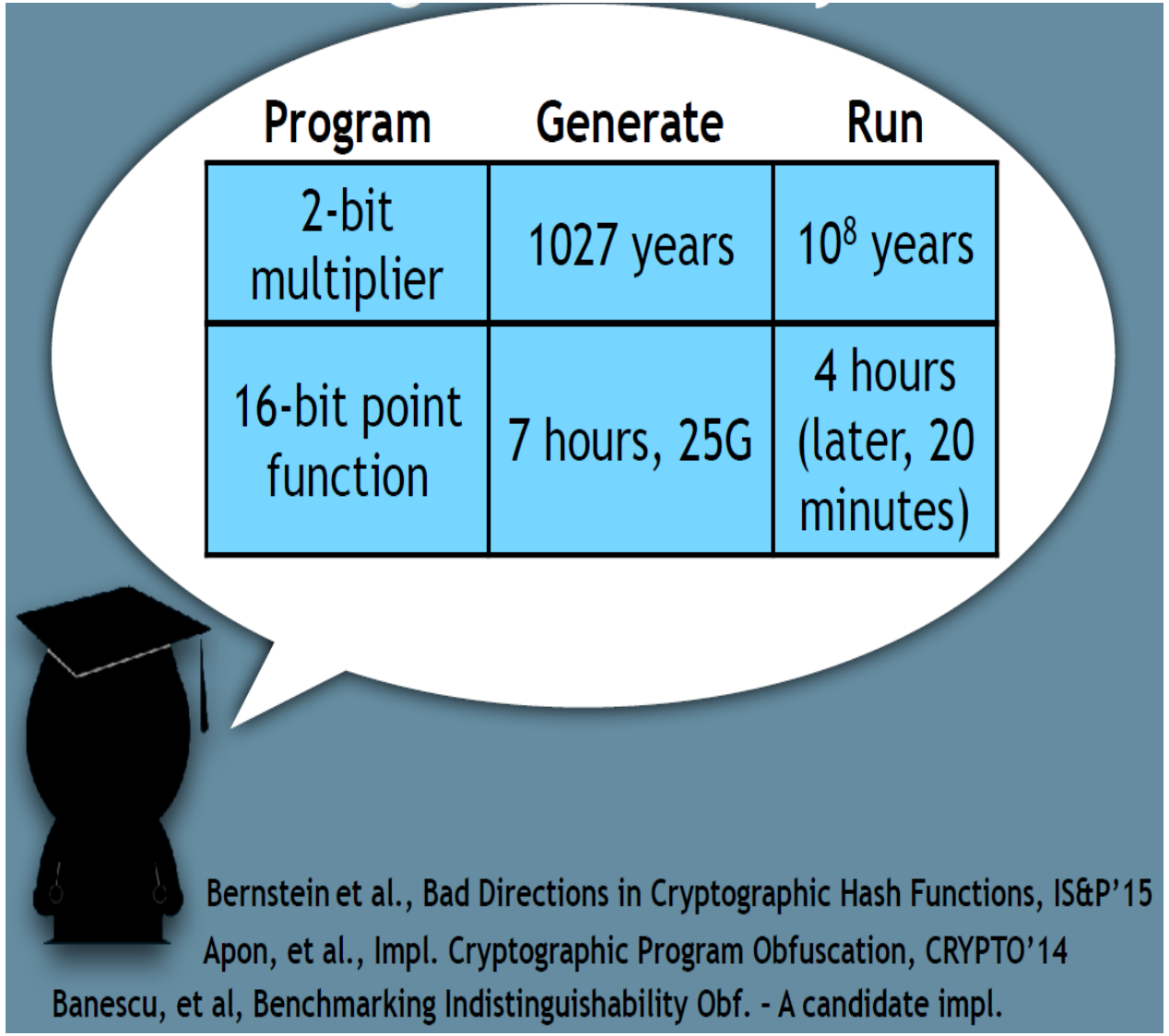
What matters?



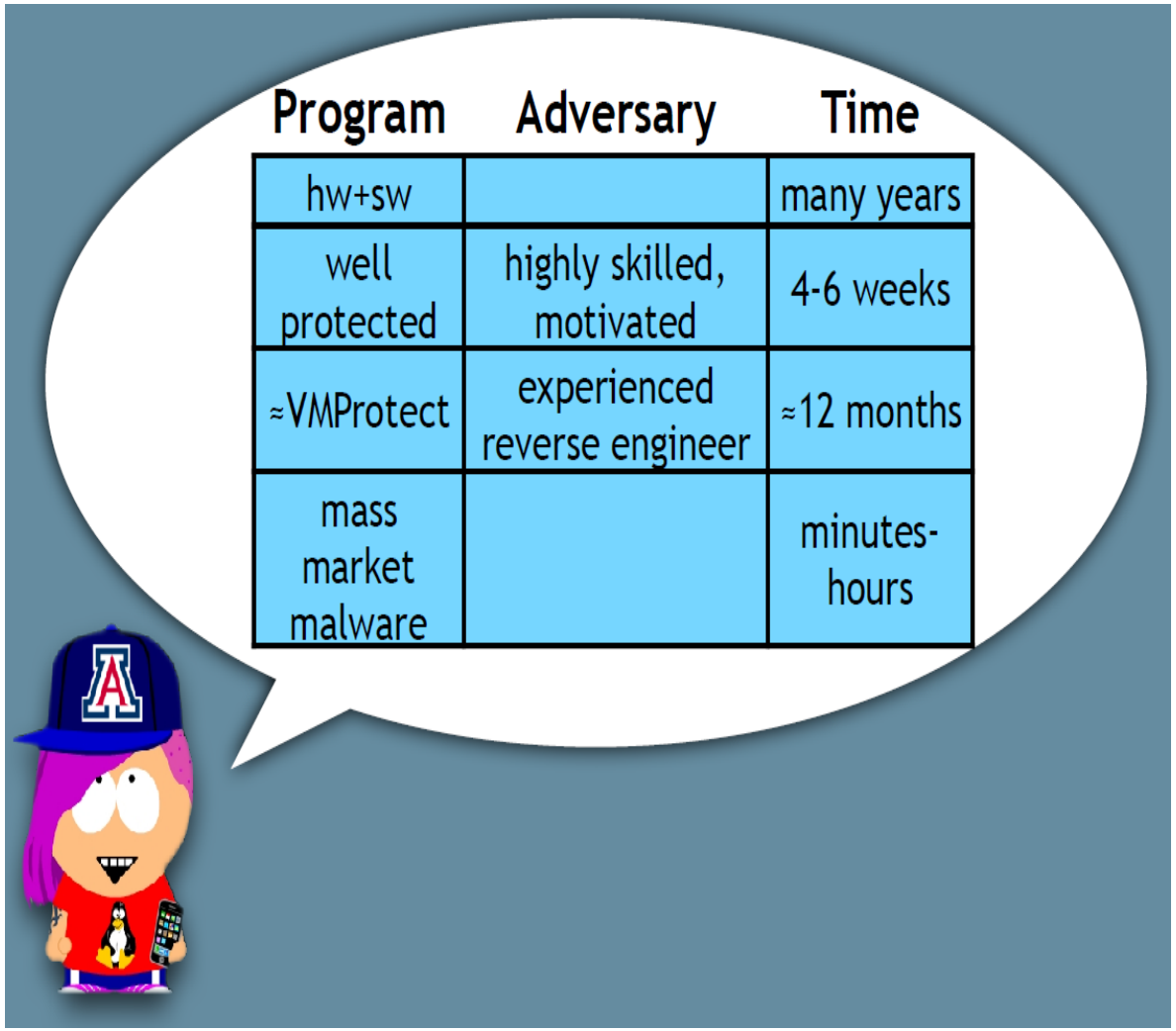
Perfs? Depend on context



Perfs for math-proven obfuscation. Not yet …



Time to crack!



Context matters

How long for cracking?

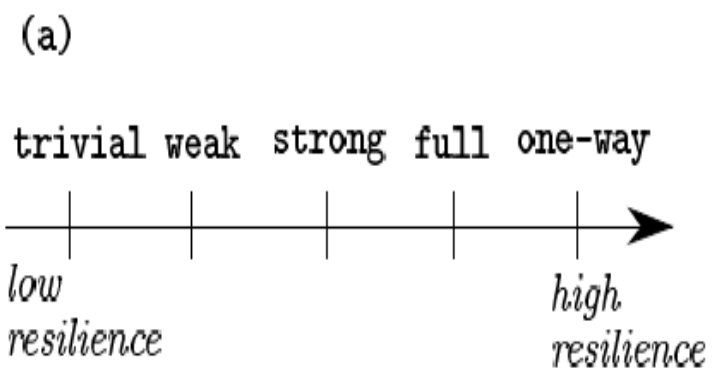
- **5 min (VOD)**
- **2 weeks (video game)**
- **1 year**
- **No limit**

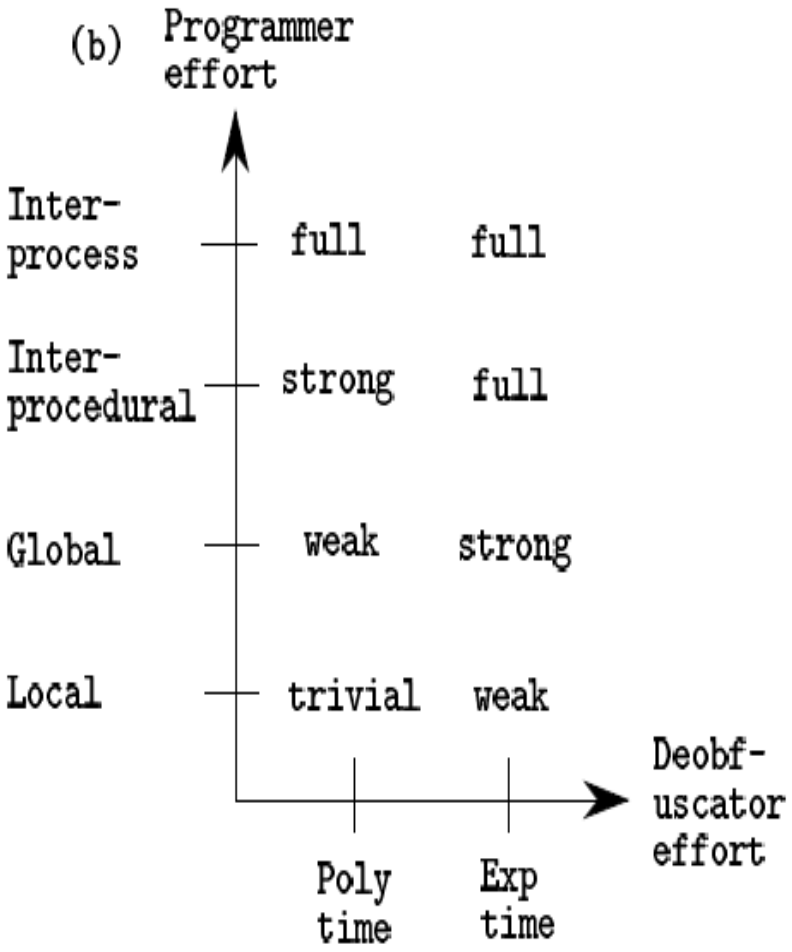
How much overhead is affordable?

Properties of obfuscation? (pragmatic)

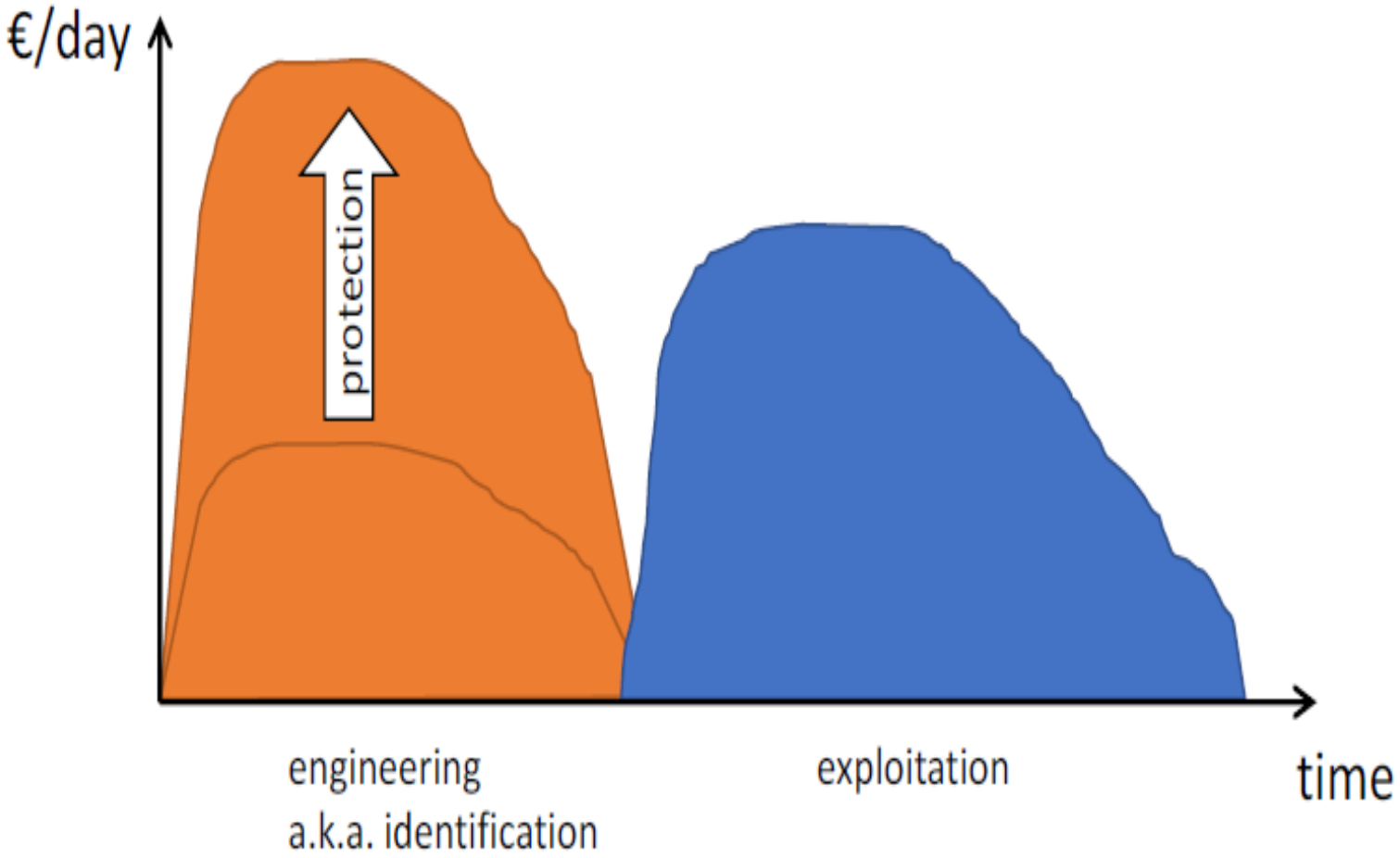
- Four criteria (Collberg et al)
  - **Potency**: confusion, complexity, manual effort
  - **Resilience**: resistance against (automated) tools
  - **Cost**: performance, code size
  - **Stealth**: identification of (components of) protections

Properties of obfuscation? (pragmatic) (2)

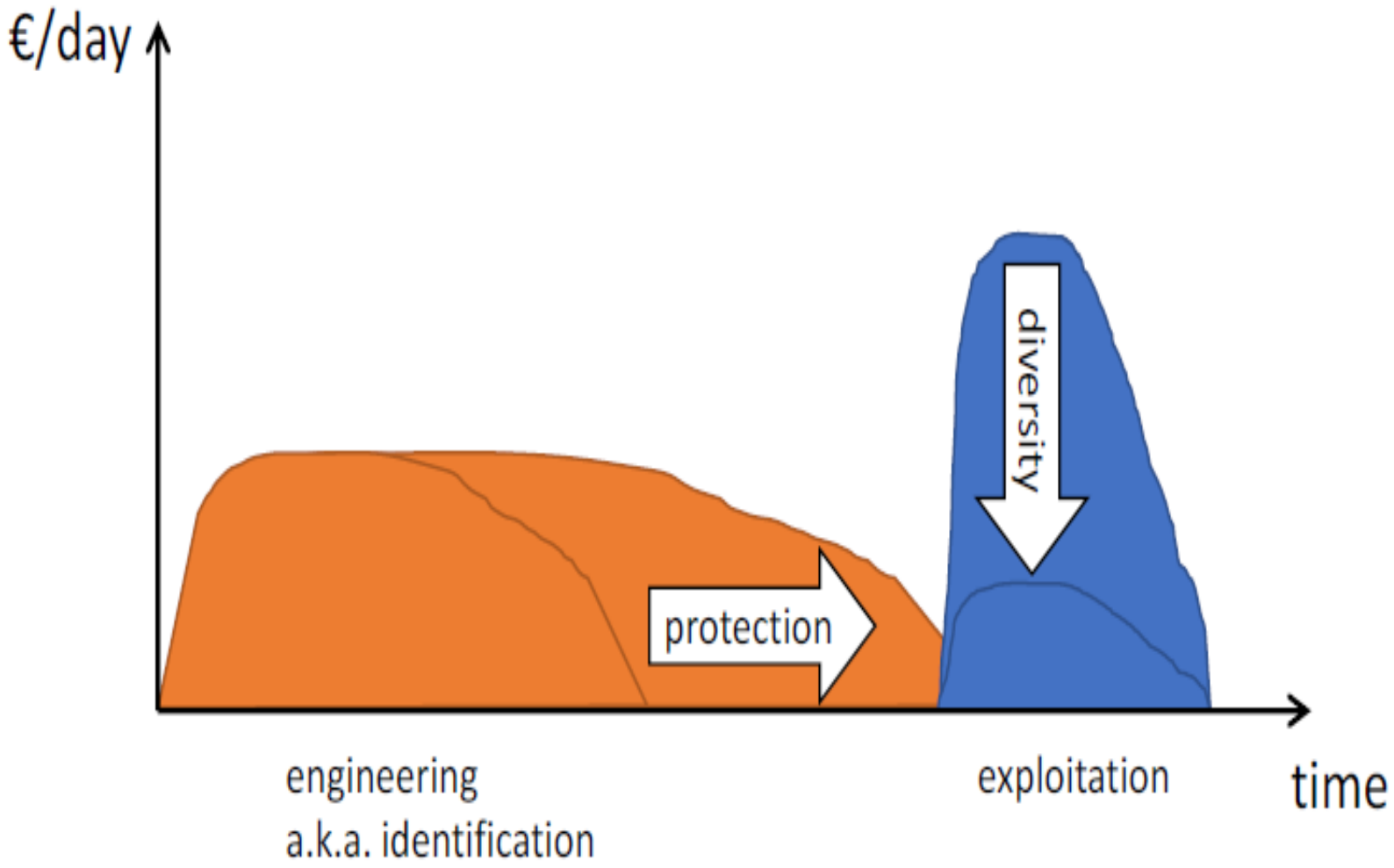




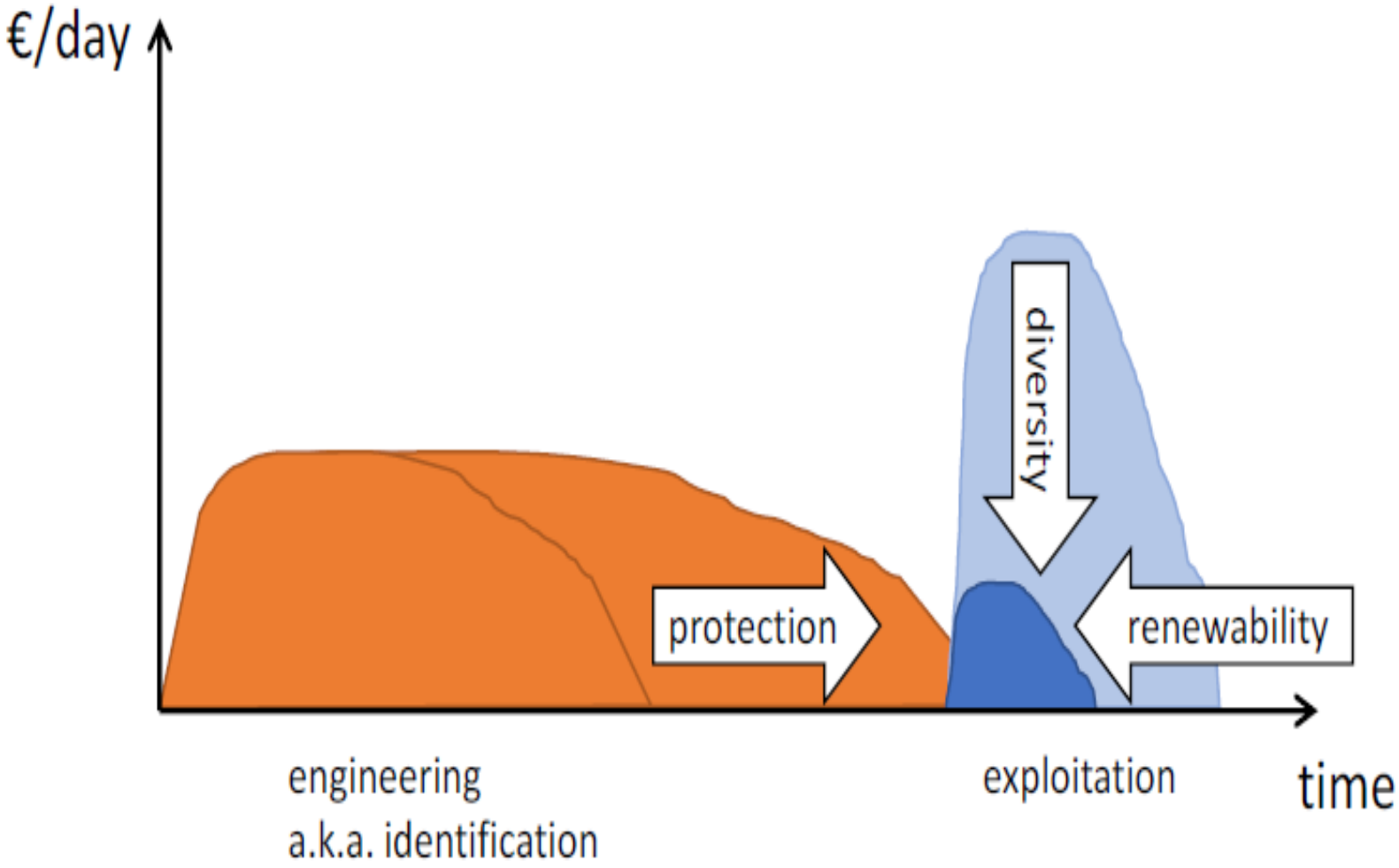
Properties of obfuscation? (pragmatic) (3)



Properties of obfuscation? (pragmatic) (3)



Properties of obfuscation? (pragmatic) (3)



OUTLINE

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TIGRESS TOOL

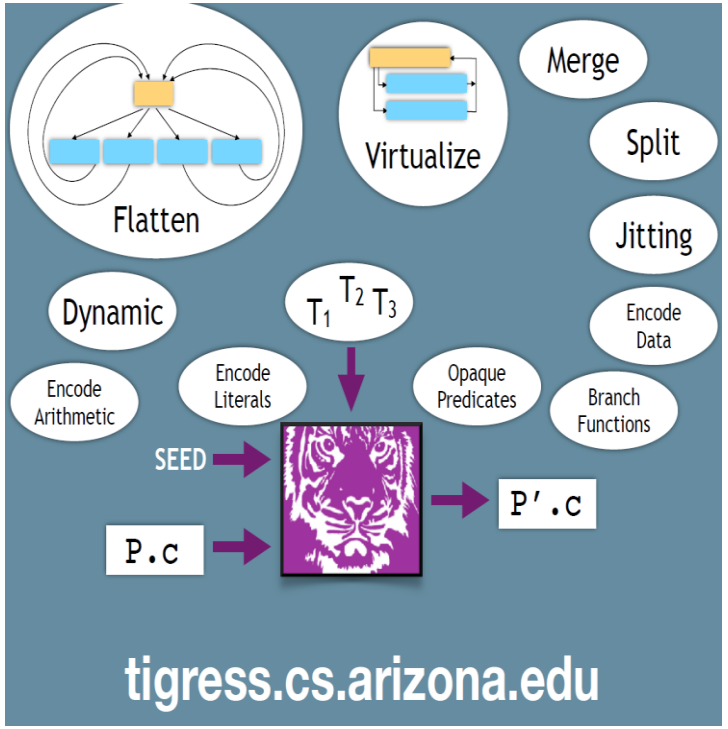
- Hands-on during the lectures
- Install the Tigress obfuscator:

  http://tigress.cs.arizona.edu/#download

- Get the test program:

  http://tigress.cs.arizona.edu/fib.c

- Tigress runs on Linux and MacOS



TEST PROGRAM

```
#include<stdio.h>
#include<stdlib.h>
int fib(int n) {
  int a = 1; int b = 1; int i;
  for (i = 3; i <= n; i++) {
    int c = a + b; a = b; b = c;
  };
  return b;
}
int main(int argc, char** argv) {
  if (argc != 2) {
    printf("Give one argument!\n"); abort(); };
    long n = strtol(argv[1],NULL,10);
    int f = fib(n);
    printf("fib(%li)=%i\n",n,f);
}
```

EXO: Opaque expressions

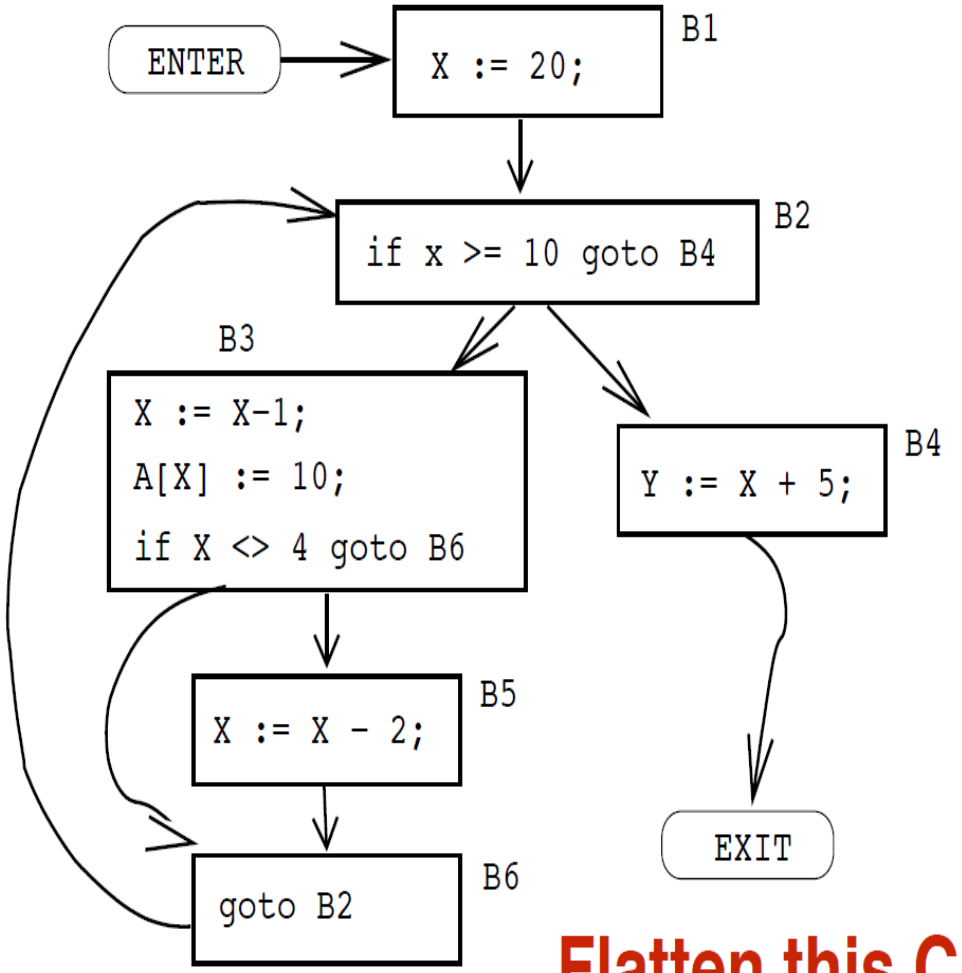
```
tigress --Seed=0 \
    --Transform=InitEntropy \
    --Transform=InitOpaque \
       --Functions=main\
       --InitOpaqueCount=2\
       --InitOpaqueStructs=list,array \
    --Transform=AddOpaque\
       --Functions=fib\
       --AddOpaqueKinds=question \
       --AddOpaqueCount=10 \
     fib.c –out=fib_out.c
```

EXO: flattening

```
tigress \
      --Seed=42 \
      --Transform=InitOpaque \
        --Functions=main \
      --Transform=Flatten \
        --FlattenDispatch=switch \
        --FlattenOpaqueStructs=array \
        --FlattenObfuscateNext=false \
        --FlattenSplitBasicBlocks=false \
        --Functions=fib \
    fib.c --out=fib1.c
```

- Try different kinds of dispatch
  switch, goto, indirect
- Turn opaque predicates on and off.
- Split basic blocks or not.

EXO: flattening (2)



Flatten this CFG!

Work with your friends!

EXO: virtualization

```
tigress\
    --Transform=Virtualize\
        --Functions=fib\
        --VirtualizeDispatch=switch\
    –out=v1.c fib.c
```

- Try a few different dispatchers: direct, indirect, call, ifnest, linear, binary, interpolation.
- Are some of them better obfuscators than others? Why?

EXO: virtualization (2)

```
tigress\
   --Transform=Virtualize
      --Functions=fib \
      --VirtualizeDispatch=switch\
   --Transform=Virtualize\
      --Functions=fib \
      --VirtualizeDispatch=indirect \
   --out=v2.c fib.c
```

- Try combining different dispatchers. Does it make a difference?
- Try three levels of interpretation! Do you notice a slowdown? What about the size of the program?

EXO: arithmetic encoding

- The virtualizer's **add** instruction handler could still be identified by the fact that it uses a + operator!
- Try adding am arithmetic transformer:

```
--Transform=EncodeArithmetic \
    --Functions=fib,main ...
```

- What differences do you notice?
- Should this transformation go before or after the virtualization transformation?

EXO: dynamic encoding

```
tigress \
   --Transform=Dynamic \
      --Functions=fib \
         --DynamicCodecs=xtea \
         –DynamicDumpCFG=false \
         --DynamicBlockFraction=%50 \
         --out=fib_out.c fib.c
```

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CONCLUSION

- **Code protection is crucial**
  - IP protection, avoid bypassing security
  - Can be argued to improve security as well (anti-hacking technique)
- **Existing tools and techniques**
- **Yet still many open questions**
  - Proper formalization (goal of attacker, probabilistic setting?, stealth?)
  - Distinguish between legit and illegit contexts?
  - Strength, correctness
- **Next: very powerful deobfuscation technique**

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