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- Hard to pin down exactly what obfuscation is
- Hard to devise practically useful algorithms
- Hard to evaluate the quality of these algorithms.

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  - tries to thwart static analysis
  - attacked by dynamic techniques (debugging, emulation, tracing).

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- static obfuscation $\Rightarrow$ obfuscated programs that remain fixed at runtime.
  - tries to thwart static analysis
  - attacked by dynamic techniques (debugging, emulation, tracing).
- dynamic obfuscators $\Rightarrow$ transform programs continuously at runtime, keeping them in constant flux.
  - tries to thwart dynamic analysis

Code obfuscation — Overview

1. Simple obfuscating transformations.

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Algorithm OBFTP: Identifier renaming

- Java released 1996:
  - decompilation is easy!
  - compiled code ⇔ source!

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  3. RIP

Algorithm OBFTP: Identifier renaming

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  1. released Crema a Java obfuscator.
  2. released Mocha Java decompiler.
  3. RIP
- It's an obfuscator/decompiler war!
  1. HoseMocha kills Mocha (add an instruction after `return`);
  2. Rename identifiers using characters that are legal in the JVM, but not in Java source.

Renaming Example

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

```c
int f1(
       int x1,int x2[],
        int x3,int x4) {
    int x5, x6;
    int x7 = 0;
    int x8 = 1;
    while (x7 < x3) {
        if (x2[x7] == 1)
            x5 = (x8*x1)%x4;
        else
            x5 = x8;
        x8 = x5*x5%x4;
        x6 = x5;
        x7++;
    }
    return x6;
}
```

Identifier renaming

- Historical interest.

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Identifier renaming

- Historical interest.
- Decompiler can't recover information which has been removed!
- Identifier renaming $\Rightarrow$ no performance overhead!

Algorithm OBFTP

- In an object-oriented language:
  - Use overloading!
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- In an object-oriented language:
  - Use overloading!
  - Give as many declarations as possible the same name!
- Algorithm by Paul Tyma:

  - Used in PreEmptive Solutions' Dash0 Java obfuscator.
  - Licensed by Microsoft for Visual Studio

Algorithm OBFTP

- Java naming rules:
  1. Class names should be globally unique,
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Algorithm OBFTP

- Java naming rules:
  1. Class names should be globally unique,
  2. Field names should be unique within classes
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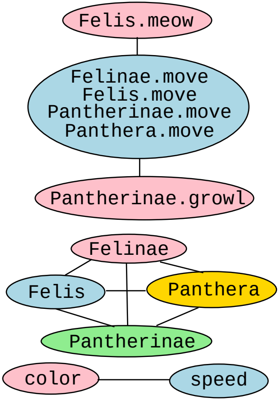
- Algorithm
  1. Build a graph:
     - nodes are declarations
     - edges between nodes that cannot have the same name
  2. Merge methods that must have the same name (because they override each other) into super-nodes.
  3. Color the graph with the smallest number of colors (=names)!

Algorithm OBFTP: Original program

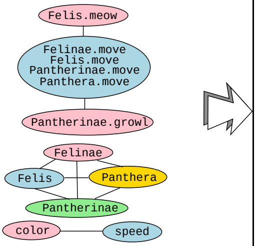
```
class Felinae {
   int color;
   int speed;
   public void move(int x,int y){}
}
class Felis extends Felinae {
   public void move(int x,int y){}
   public void meow(int tone,int length){}
}
class Pantherinae extends Felinae {
   public void move(int x,int y){}
   public void growl(int tone,int length){}
}
class Panthera extends Pantherinae {
   public void move(int x,int y){}
}
```

Algorithm OBFTP: Interference graph

```
class Felinae {
   int color;
   int speed;
   void move(int x,int y)
}
class Felis extends Felinae {
   void move(int x,int y){}
   void meow(int tone,int len)
}
class Pantherinae extends Felinae{
   void move(int x,int y){}
   void growl(int tone,int len)
}
class Panthera extends Pantherinae{
   void move(int x,int y)
}
```



Algorithm OBFTP: Renamed program




```
class Pink {
   int Pink;
   int Blue;
   public void Blue(int x,int y){}
}
class Blue extends Pink {
   public void Blue(int x,int y){}
   public void Pink(int tone,int len){}
}
class Green extends Pink {
   public void Blue(int x,int y){}
   public void Pink(int tone,int len){}
}
class Yellow extends Green {
   public void Blue(int x,int y){}
}
```

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- Transformations that make it difficult for an adversary to analyze the flow-of-control:
    1. insert bogus control-flow,

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Complicating control flow

- Transformations that make it difficult for an adversary to analyze the flow-of-control:
  1. insert bogus control-flow,
  2. flatten the program
  3. hide the targets of branches to make it difficult for the adversary to build control-flow graphs
- None of these transformations are immune to attacks,

Opaque Expressions

- Simply put:

  an expression whose value is known to you as the defender (at obfuscation time) but which is difficult for an attacker to figure out

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- Simply put:

  > *an expression whose value is known to you as the defender (at obfuscation time) but which is difficult for an attacker to figure out*

- Notation:
  - 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

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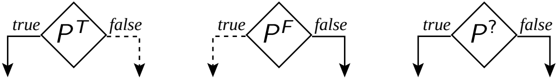
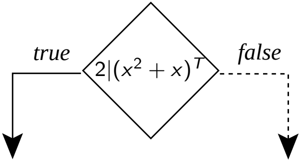
- Graphical notation:



- Building blocks for many obfuscations.

Opaque Expressions

- An opaquely true predicate:



Opaque Expressions

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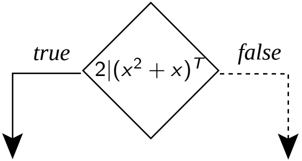
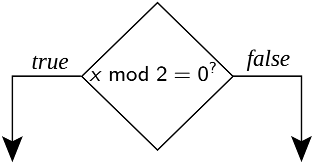


- An opaquely indeterminate predicate:



Simple Opaque Predicates

- Look in number theory text books, in the *problems* sections:

  "Show that $\forall x, y \in \mathbb{Z} : p(x, y)$"

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Simple Opaque Predicates

- Look in number theory text books, in the *problems* sections:

  $$\text{“Show that } \forall x, y \in \mathbb{Z} : p(x, y)\text{”}$$

- $\forall x, y \in \mathbb{Z} : x^2 - 34y^2 \neq 1$
- $\forall x \in \mathbb{Z} : 2 | x^2 + x$
- ...

Algorithm $\text{OBFCTJ}_{\text{bogus}}$: Inserting bogus control-flow

- Insert *bogus* control-flow into a function:
  1. dead branches which will never be taken

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  3. branches which will sometimes be taken and sometimes not, but where this doesn't matter

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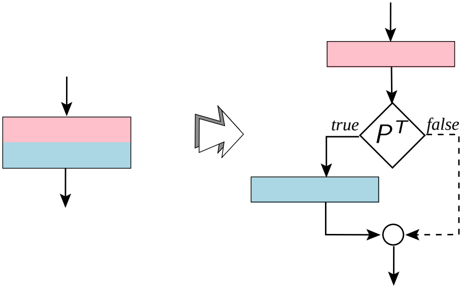
  1. dead branches which will never be taken
  2. superfluous branches which will *always* be taken
  3. branches which will sometimes be taken and sometimes not, but where this doesn't matter
- The resilience reduces to the resilience of the opaque predicates.

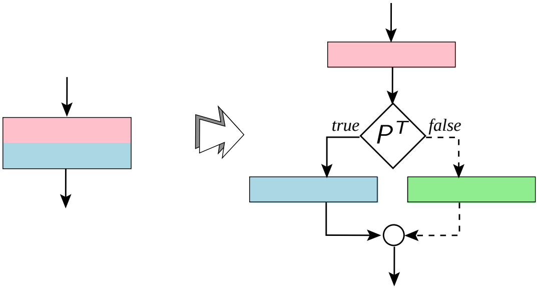
Algorithm OBFCTJ$_{\text{bogus}}$: Inserting bogus control-flow

- It seems that the blue block is only sometimes executed:



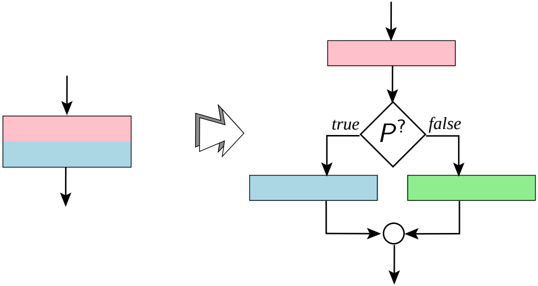
Algorithm $\textsc{obf}\mathrm{CTJ}_{\mathrm{bogus}}$: Inserting bogus control-flow

- A bogus block (green) appears as it might be executed while, in fact, it never will:



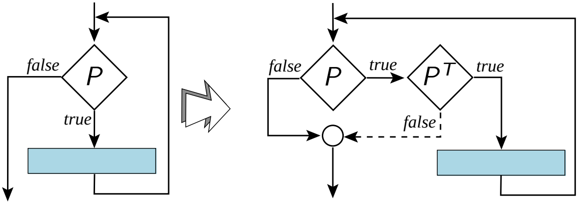
Algorithm $\textsc{obf}\mathrm{CTJ}_{\mathrm{bogus}}$: Inserting bogus control-flow

- Sometimes execute the blue block, sometimes the green block.
- The green and blue blocks should be semantically equivalent.



Algorithm OBFCTJ$_{\text{bogus}}$: Inserting bogus control-flow

- Extend a loop condition P by conjoining it with an opaquely true predicate P^T:



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- Removes the control-flow *structure* of functions.
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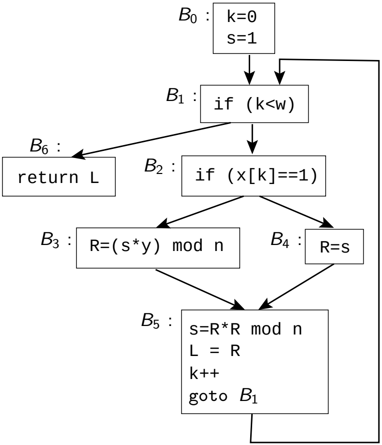
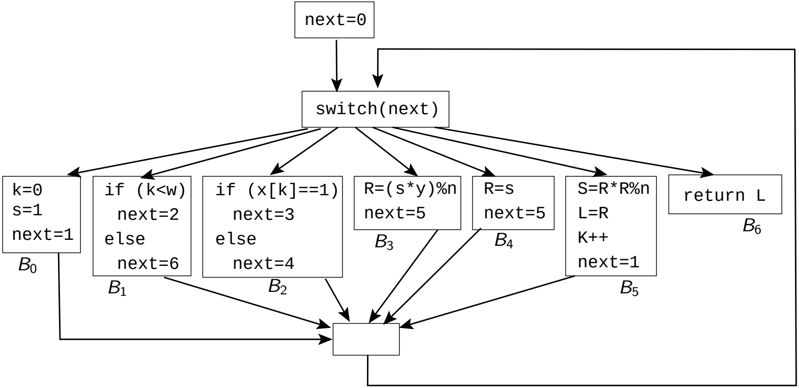
- Known as *chenxify*, *chenxification*, after Chenxi Wang:

```
int modexp(int y,int x[],
           int w,int n) {
   int R, L;
   int k = 0;
   int s = 1;
   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;
      }
}
```


next=0
switch(next)
k=0
s=1
next=1
B_0
if (k<w)
next=2
else
next=6
B_1
if (x[k]==1)
next=3
else
next=4
B_2
R=(s*y)%n
next=5
B_3
R=s
next=5
B_4
S=R*R%n
L=R
K++
next=1
B_5
return L
B_6

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- Replacing 50% of the branches in three SPEC programs slows them down by a factor of 4 and increases their size by a factor of 2.

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  1. The for loop incurs one jump,
  2. the switch incurs a bounds check the `next` variable,
  3. the switch incurs an indirect jump through a jump table.
- Optimize?
  1. Keep tight loops as one switch entry.
  2. Use `gcc`'s labels-as-values ⇒ a jump table lets you jump directly to the next basic block.

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- Attack against Chenxification:
  1. Work out what the next block of every block is.

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- Attack against Chenxification:
  1. Work out what the next block of every block is.
  2. Rebuild the original CFG!
- How does an attacker do this?
  1. use-def data-flow analysis
  2. constant-propagation data-flow analysis

Compute next as an opaque predicate!

```
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;
      }
}
```

```
int modexp(int y, int x[], int w, int n) {
   int R, L, k, s;
   int next=0;
   int g[] = {10,9,2,5,3};
   for(;;)
      switch(next) {
         case 0 : k=0; s=1; next=g[0]%g[1] =1 ;break;
         case 1 : if (k<w) next=g[g[2]] =2 ;
                  else next=g[0]-2*g[2] =6 ;break;
         case 2 : if (x[k]==1) next=g[3]-g[2] =3 ;
                  else next=2*g[2] =4 ; break;
         case 3 : R=(s*y)%n; next=g[4]+g[2] =5 ;break;
         case 4 : R=s; next=g[0]-g[3] =5 ; break;
         case 5 : s=R*R%n; L=R; k++; next=g[g[4]]%g[2] =1 ;
                  break;
         case 6 : return L;
      }
}
```

Modify the array at runtime!

A function that rotates an array one step right:

```
void permute(int g[], int n, int* m) {
    int i;
    int tmp=g[n-1];
    for(i=n-2; i>=0; i--) g[i+1] = g[i];
    g[0]=tmp;
    *m = ((*m)+1)%n;
}
```

- Make static array aliasing analysis harder for the attacker!
- Modify the array at runtime!

```
int modexp(int y, int x[], int w, int n) {
   int R, L, k, s;
   int next=0;
   int m=0;
   int g[] = {10,9,2,5,3};
   for(;;) {
      switch(next) {
      case 0 : k=0; s=1; next=g[(0+m)%5]%g[(1+m)%5]; break;
      case 1 : if (k<w) next=g[(g[(2+m)%5]+m)%5];
               else next=g[(0+m)%5]-2*g[(2+m)%5]; break;
      case 2 : if (x[k]==1) next=g[(3+m)%5]-g[(2+m)%5];
               else next=2*g[(2+m)%5]; break;
      case 3 : R=(s*y)%n; next=g[(4+m)%5]+g[(2+m)%5]; break;
      case 4 : R=s; next=g[(0+m)%5]-g[(3+m)%5]; break;
      case 5 : s=R*R%n; L=R; k++;
               next=g[(g[(4+m)%5]+m)%5]%g[(2+m)%5]; break;
      case 6 : return L;
      }
      permute(g,5,&m);
   }
}
```

Make the array global!

```
int g[20]; int m;
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=g[m+0]%g[m+1]; break;
      case 1 : if (k<w) next=g[m+g[m+2]];
               else next=g[m+0]-2*g[m+2]; break;
      case 2 : if (x[k]==1) next=g[m+3]-g[m+2];
               else next=2*g[m+2]; break;
      case 3 : R = (s*y)%n; next=g[m+4]+g[m+2]; break;
      case 4 : R=s; next=g[m+0]-g[m+3]; break;
      case 5 : s = R*R%n; L=R; k++;
               next=g[m+g[m+4]]%g[m+2]; break;
      case 6 : return L;
    }
}
```

With the array global you can initialize it differently at different call sites:

```
g[0]=10; g[1]=9; g[2]=2; g[3]=5; g[4]=3; m=0;
modexp(y, x, w, n);
...
g[5]=10; g[6]=9; g[7]=2; g[8]=5; g[9]=3; m=5;
modexp(y, x, w, n);
```

Sprinkle pointer variables (pink), pointer manipulations (blue), dead code (green) over the program:

```
int modexp(int y, int x[], int w, int n) {
   int R, L, k, s; int next=0;
   int g[] = {10,9,2,5,3,42}; int* g2; int* gr;
   for(;;)
      switch(next) {
      case 0 : k=0;  g2=&g[2]; s=1; next=g[0]%g[1];
               gr=&g[5]; break;
      case 1 : if (k<w)  next=g[*g2];
               else next=g[0]-2*g[2]; break;
      case 2 : if (x[k]==1) next=g[3]-*g2;
               else next=2**g2; break;
      case 3 : R=(s*y)%n; next=g[4]+*g2; break;
      case 4 : R=s; next=g[0]-g[3]; break;
      case 5 : s=R*R%n;L=R;k++; next=g[g[4]]%*g2;break;
      case 6 : return L;
      case 7 : *g2=666; next=*gr%2; gr=&g[*g2]; break;
      }
}
```

Algorithm $\textsc{obf}\mathrm{WHKD}_{\mathrm{alias}}$

- Hopefully, because of the obfuscated manipulations the attacker's static analysis will conclude that nothing can be deduced about `next`.

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- Not knowing `next`, he can't rebuild the CFG.
- Symbolic execution? We know next starts at 0...

$\textsc{obf}\text{WHKD}_{\text{opaque}}$: Opaque values from array aliasing

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1
36	58	1	46	23	5	16	65	2	41	2	7	1	37	0	11	16	2	2

Invariants:

1. every third cell (in pink), starting will cell 0, is $\equiv 1 \bmod 5$;
2. cells 2 and 5 (green) hold the values 1 and 5, respectively;
3. every third cell (in blue), starting will cell 1, is $\equiv 2 \bmod 7$;
4. cells 8 and 11 (yellow) hold the values 2 and 7, respectively.

You can update a pink element as often as you want, with any value you want, as long as you ensure that the value is always $\equiv 1 \bmod 5$!

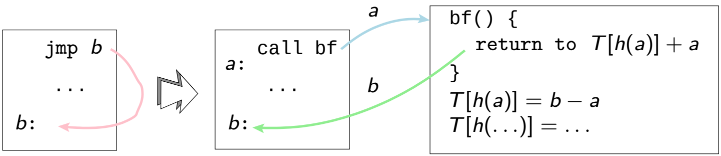
```c
int g[] = {36,58,1,46,23,5,16,65,2,41,
           2,7,1,37,0,11,16,2,21,16};

if ((g[3] % g[5])==g[2])
   printf("true!\n");

g[5] = (g[1]*g[4])%g[11] + g[6]%g[5];
g[14] = rand();
g[4] = rand()*g[11]+g[8];

int six = (g[4] + g[7] + g[10])%g[11];
int seven = six + g[3]%g[5];
int fortytwo = six * seven;
```

- pink: opaquely true predicate.
- blue: g is constantly changing at runtime.
- green: an opaque value 42.

Initialize g at runtime!

OBFLDK: Jumps through branch functions

- Replace unconditional jumps with a call to a branch function.
- Calls normally return to where they came from... But, a branch function returns to the target of the jump!



obfLDK: Make branches explicit

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

OBFLDK: Jumps through branch functions

- A table T stores
$$T[h(a_i)] = b_i - a_i.$$
- Code in pink updated the return address!
- The branch function:

```
char* T[2];
void bf() {
   char* old;
   asm volatile("movl 4(%%ebp),%0\n\t" : "=r" (old));
   char* new = (char*)((int)T[h(old)] + (int)old);
   asm volatile("movl %0,4(%%ebp)\n\t" : : "r" (new));
}
```

```
int modexp(int y, int x[], int w, int n) {
  int R, L; int k = 0; int s = 1;
  T[h(&&retaddr1)]=(char*)(&&endif-&&retaddr1);
  T[h(&&retaddr2)]=(char*)(&&beginloop-&&retaddr2);
  beginloop:
    if (k >= w) goto endloop;
    if (x[k] != 1) goto elsepart;
      R = (s*y) % n;
      bf();       // goto endif;
      retaddr1:
      asm volatile(".ascii \"bogus\"\n\t");
    elsepart:
      R = s;
    endif:
    s = R*R % n;
    L = R;
    k++;
    bf();        // goto beginloop;
    retaddr2:
  endloop:
  return L;
}
```

OBFLDK: Jumps through branch functions

- Designed to confuse disassembly.
- 39% of instructions are incorrectly assembled using a linear sweep disassembly.
- 25% for recursive disassembly.
- Execution penalty: 13%
- Increase in text segment size: 15%.

Outline

Constructing opaque predicates

- Construct them based on
  - number theoretic results
    - $\forall x, y \in \mathbb{Z} : x^2 - 34y^2 \neq 1$
    - $\forall x \in \mathbb{Z} : 2 | x^2 + x$
  - the hardness of alias analysis
  - the hardness of concurrency analysis

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- Protect them by
  - making them hard to find
  - making them hard to break
- If your obfuscator keeps a table of predicates, your adversary will too!

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- Create an obfuscating transformation from a known computationally hard static analysis problem.

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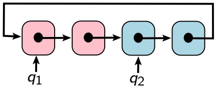
- Of course, these assumptions may be false!

Algorithm OBFCTJ$_{\text{alias}}$

- Construct one or more heap-based graphs, keep pointers into those graphs, create opaque predicates by checking properties you know to be true.



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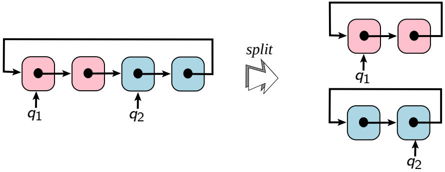

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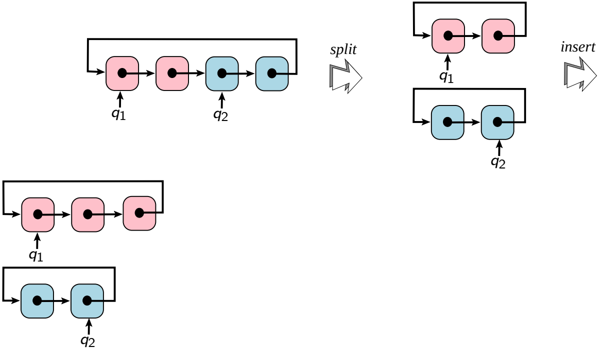

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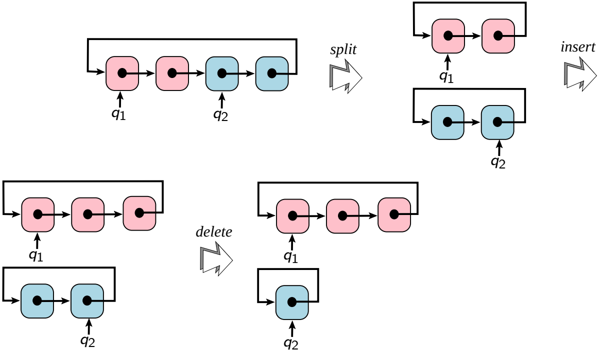

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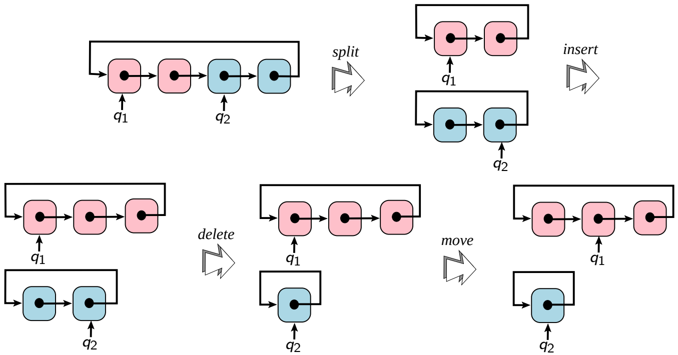

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- Two invariants:
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- Perform enough operations to confuse even the most precise alias analysis algorithm,
- Insert opaque queries such as $(q_1 \neq q_2)^T$ into the code.

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- Concurrent programs are difficult to analyze statically: n statements in a parallel region can execute in $n!$ different orders.

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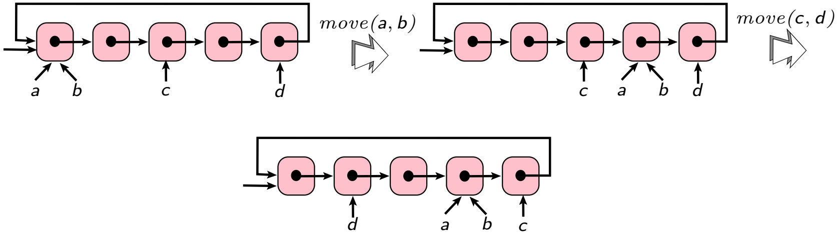
- Concurrent programs are difficult to analyze statically: n statements in a parallel region can execute in $n!$ different orders.
- Construct opaque predicates based on the difficulty of analyzing the threading behavior of programs!
- Keep a global data structure G with a certain set of invariants I, to concurrently update G while maintaining I, and use I to construct opaque predicates over G

Opaque predicates from concurrency



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- Thread T_1 updates a and b, such that each time a is updated to point to its next node in the cycle, b is also updated to point to its next node in the cycle.

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Opaque predicates from concurrency

- Thread T_1 updates a and b, such that each time a is updated to point to its next node in the cycle, b is also updated to point to its next node in the cycle.
- Thread T_2 updates c and d.
- Opaquely true predicate $(a = b)^T$ is statically indistinguishable from an opaquely false predicate $(c = d)^F$!

Outline

Encoding literal data

- Literal data often carries much semantic information:
  - `"Please enter your password:"`
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- Print each character one at a time?

Convert literals to code — Mealy machine

- Encode the strings `"MIMI"` and `"MILA"` in a finite state transducer (a *Mealy machine*)

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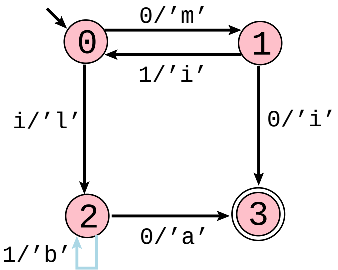
- Encode the strings `"MIMI"` and `"MILA"` in a finite state transducer (a *Mealy machine*)
- The machine takes a bitstring and a state transition table as input and and generates a string as output.
- `Mealy(`10_2`)` produces `"MIMI"`.
- `Mealy(`110_2`)` produces `"MILA"`.

Convert literals to code — Mealy machine




```
int next[][2] =
      {{1,2},
       {3,0},
       {3,2}};
char out[][2] =
      {{'m','l'},
       {'i','i'},
       {'a','b'}};
```

- $s_0 \xrightarrow{i/o} s_1$ means in state s_0 on input i transfer to state s_1 and produce an o.
- next[*state*][*input*]=*next state*
- out[*state*][*input*]=*output*

Mealy machine — table driven

```
char* mealy(int v) {
   char* str=(char*)malloc(10);
   int state=0,len=0;
   while (state!=3) {
      int input = 1&v; v >>= 1;
      str[len++]=out[state][input];
      state = next[state][input];
   }
   str[len]='\0';
   return str;
}
```

Mealy machine — hardcoded

```
char* mealy(int v) {
   char* str=(char*)malloc(10);
   int state=0,len=0;
   while (1) {
      int input = 1&v; v >>= 1;
      switch (state) {
          case 0: state=(input==0)?1:2;
                  str[len++]=(input==0)?'m':'l'; break;
          case 1: state=(input==0)?3:0;
                  str[len++]='i'; break;
          case 2: state=(input==0)?3:2;
                  str[len++]=(input==0)?'a':'b'; break;
          case 3: str[len]='\0'; return str;
      }
   }
}
```

Outline

Static vs. Dynamic obfuscation

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Static vs. Dynamic obfuscation

- Statically obfuscated code: the attacker sees *the same* mess every time.
- Dynamic obfuscated code: the execution path changes as the program runs.
- Some algorithms are "semi-dynamic" — they perform a small, constant number of transformations (often one) at runtime
- Some algorithms are *continuous*: the code is in constant flux.

Dynamic Obfuscation: Definitions

- A dynamic obfuscator runs in two phases:
  1. At compile-time transform the program to an initial configuration and add a runtime code-transformer.
  2. At runtime, intersperse the execution of the program with calls to the transformer.

Dynamic Obfuscation: Definitions

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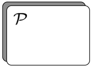
  1. At compile-time transform the program to an initial configuration and add a runtime code-transformer.
  2. At runtime, intersperse the execution of the program with calls to the transformer.
- A dynamic obfuscator turns a “normal” program into a self-modifying one.

Modeling dynamic obfuscation — compile-time



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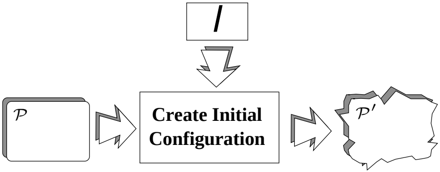

- Transformer I creates $\mathcal{P}$'s initial configuration.

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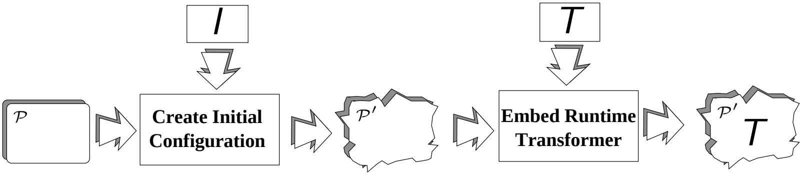
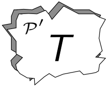


- Transformer I creates $\mathcal{P}$'s initial configuration.
- T is the runtime obfuscator, embedded in $\mathcal{P}'$.

Modeling dynamic obfuscation — runtime



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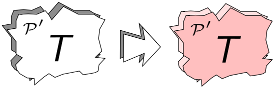

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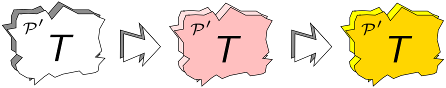

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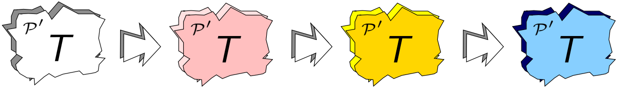

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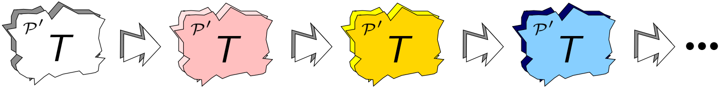

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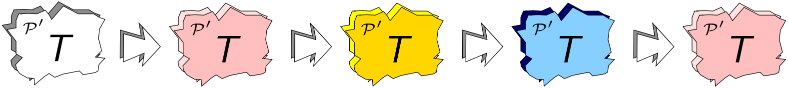
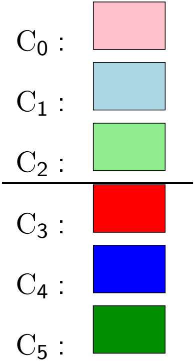


- Transformer T continuously modifies $\mathcal{P}'$ at runtime.
- We'd like an infinite, non-repeating series of configurations.
- In practice, the configurations repeat.

Dynamic obfuscation: Aucsmith's algorithm



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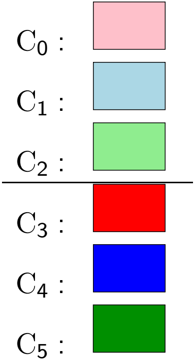
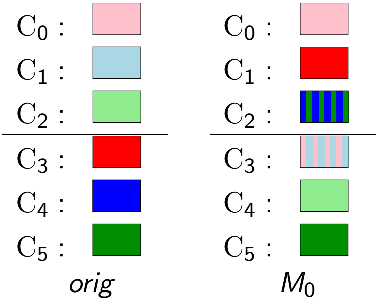
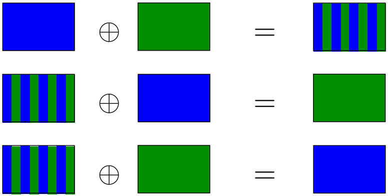


- A function is split into cells.
- The cells are divided into two regions in memory, upper and lower.

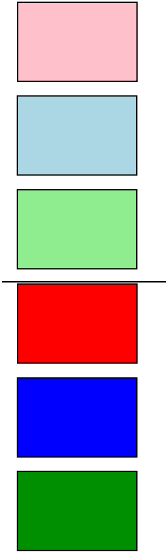
One step



XOR!



The Dynamic Primitive — Aucsmith



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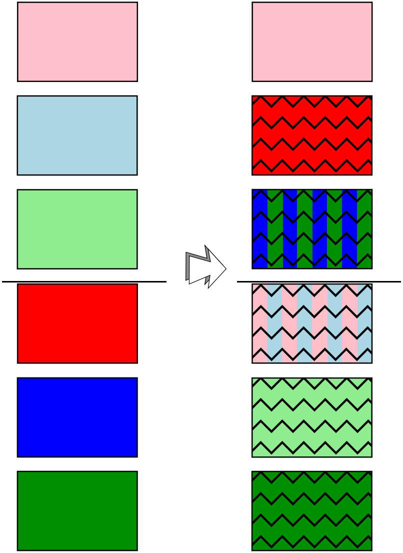

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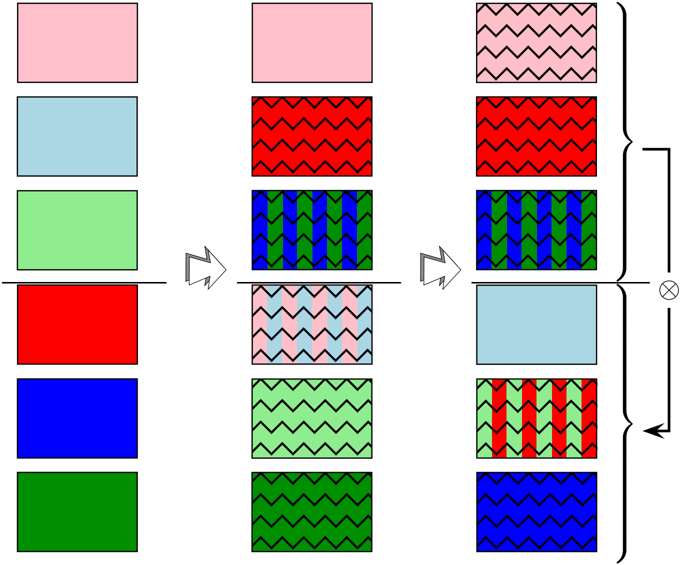

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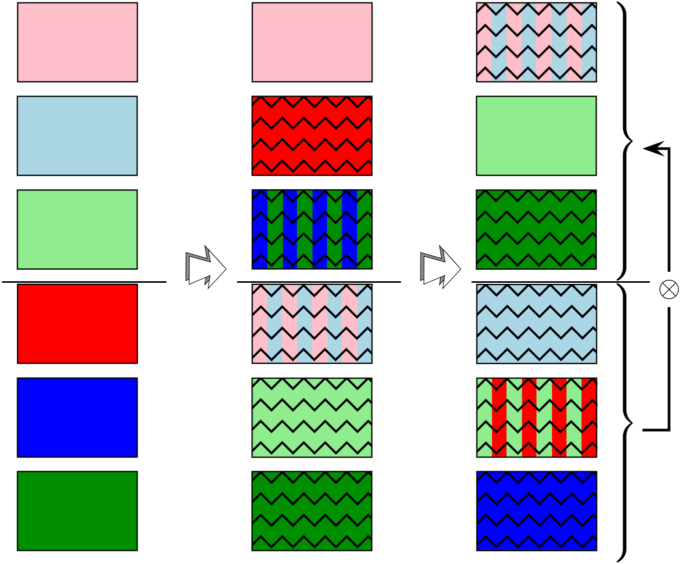

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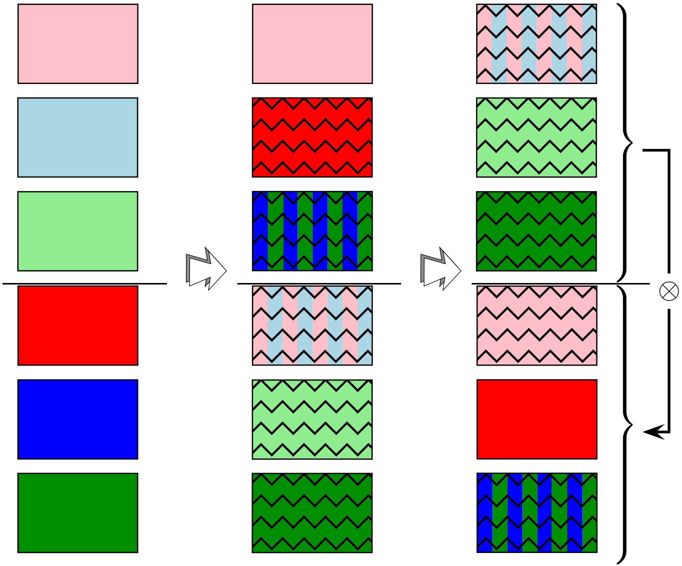

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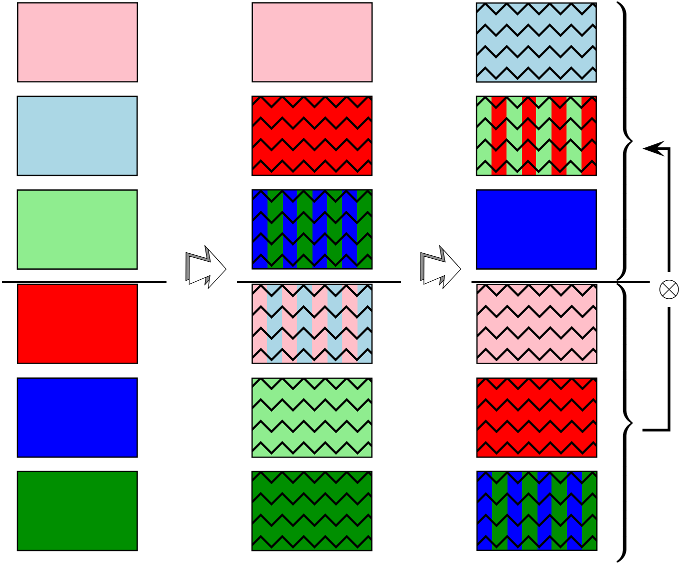

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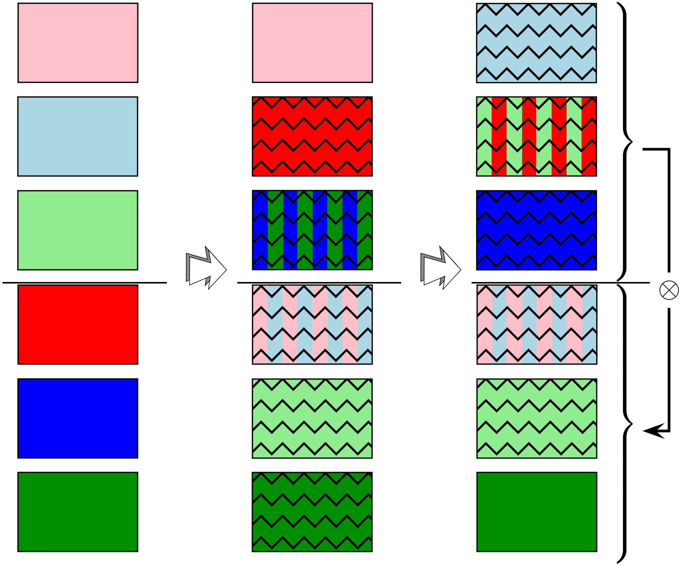

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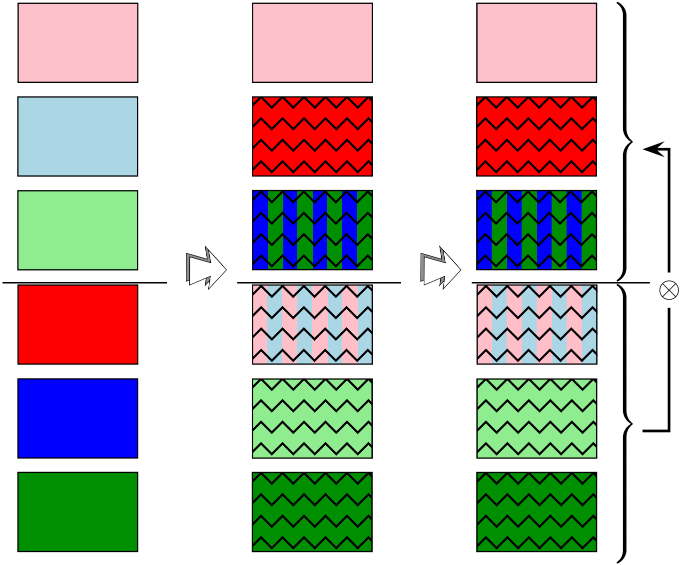

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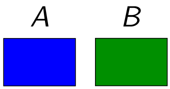

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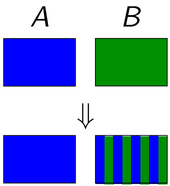

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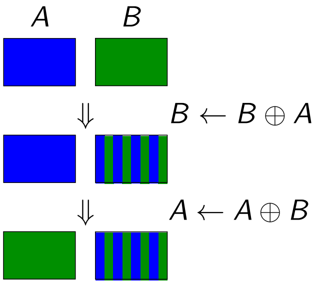

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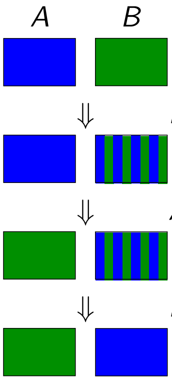

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OBFCKSP: Code as key material

- Encrypt the code to keep as little code as possible in the clear at any point in time during execution.

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- Extremes:
  1. Decrypt the next instruction, execute it, re-encrypt it, ... ⇒ only one instruction is ever in the clear!
  2. Decrypt the entire program once, prior to execution, and leave it in cleartext. ⇒ easy for the adversary to capture the code.

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- On entry, a function first encrypts its caller.
- Before returning, a function decrypts its caller.
- $\Rightarrow$ At most two functions are ever in the clear!

obfCKSP: Code as key material

- What do we use as key? The code itself!

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- What do we use as key? The code itself!
- What cipher do we use? Something simple!

obfCKSP: Code as key material

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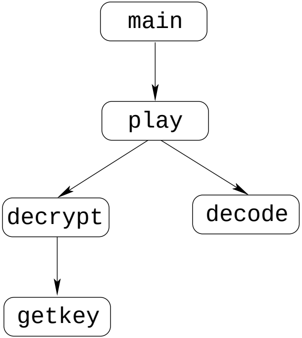

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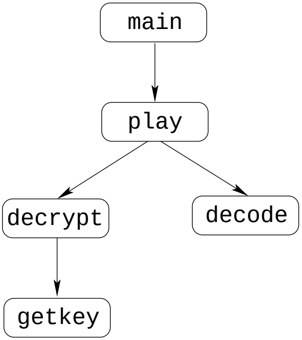

- Before and after every procedure cally you insert calls to a guard function that decrypts/re-encrypts the callee, using a hash of the cleartext of the caller as key.

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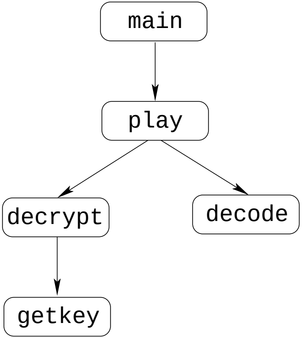

- Before and after every procedure cally you insert calls to a guard function that decrypts/re-encrypts the callee, using a hash of the cleartext of the caller as key.
- On entrance and exit of the callee you encrypt/decrypt the caller using a hash of the cleartext of the callee as key.

```
int player_main (int argc, char *argv[]) {
   int user_key = 0xca7ca115;
   int digital_media[] = {10,102};
   guard(play,playSIZE,player_main,player_mainSIZE);
   play(user_key,digital_media,2);
   guard(play,playSIZE,player_main,player_mainSIZE);
}
int getkey(int user_key) {
   guard(decrypt,decryptSIZE,getkey,getkeySIZE);
   int player_key = 0xbabeca75;
   int v = user_key ^ player_key;
   guard(decrypt,decryptSIZE,getkey,getkeySIZE);
   return v;
}
int decrypt(int user_key, int media) {
   guard(play,playSIZE,decrypt,decryptSIZE);
   guard(getkey,getkeySIZE,decrypt,decryptSIZE);
   int key = getkey(user_key);
   guard(getkey,getkeySIZE,decrypt,decryptSIZE);
   int v = media ^ key;
   guard(play,playSIZE,decrypt,decryptSIZE);
   return v;
}
```

```
float decode (int digital) {
   guard(play,playSIZE,decode,decodeSIZE);
   float v = (float)digital;
   guard(play,playSIZE,decode,decodeSIZE);
   return v;
}
void play(int user_key, int digital_media[], int len) {
   int i;
   guard(player_main,player_mainSIZE,play,playSIZE);
   for(i=0;i<len;i++) {
      guard(decrypt,decryptSIZE,play,playSIZE);
      int digital = decrypt(user_key,digital_media[i]);
      guard(decrypt,decryptSIZE,play,playSIZE);

      guard(decode,decodeSIZE,play,playSIZE);
      printf("%f\n",decode(digital));
      guard(decode,decodeSIZE,play,playSIZE);
   }
   guard(player_main,player_mainSIZE,play,playSIZE);
}
```

```
void crypto (waddr_t proc,uint32 key,int words) {
    int i;
    for(i=1; i<words; i++) {
        *proc ^= key;
        proc++;
    }
}

void guard (waddr_t proc,int proc_words,
            waddr_t key_proc,int key_words) {
    uint32 key = hash1(key_proc,key_words);
    crypto(proc,key,proc_words);
}
```

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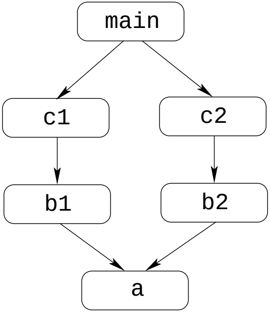
- So, what if the call-graph is shaped like a DAG, like this:



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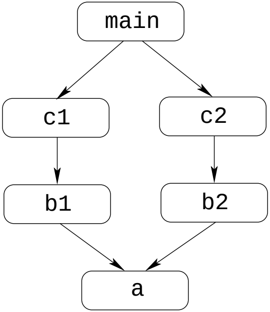

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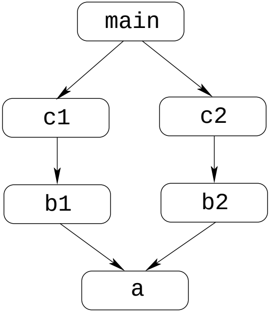

  What key to use to decrypt `a`?
- We can't use the cleartext of the caller as key, because now there are two callers!
- Let the callers' callers(`c1` and `c2`) do the decryption using a combination of the *ciphertexts* of `b1` and `b2`.

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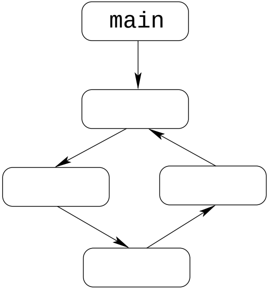
- What if the program is recursive?



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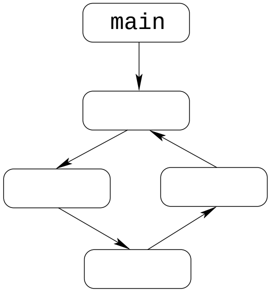

- Keep the entire cycle in cleartext. . . .

Outline

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- Integrity — make programs hard to understand to make them hard to change

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- Apply these basic operations to
  - Control structures
  - Data structures
  - Abstractions

Static VS. Dynamic Obfuscation

- Static obfuscations confuse static analysis.
- Dynamic obfuscations confuse static and dynamic analysis.
  - the code segment is treated as code *and* data
- Dynamic algorithms generate self-modifying code. Bad for performance:
  1. flush instruction pipeline
  2. write data caches to memory
  3. invalidate instruction caches