: Versatile Software Obfuscation from a Lightweight Secure Element

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French ANR SWITECH project (ANR-AAPG2019)
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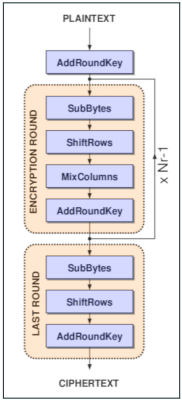
anr agence nationale de la recherche
AU SERVICE DE LA SCIENCE

Luxembourg National Research Fund

Plan

(Cryptographic) Code obfuscation

White-box cryptography



```
#include <stdio.h>
#include <math.h>
#define E return
#define S for
char*J="LJFFF%7544x^H^XXHZZ
I%KBPBEP%CBPEaIqBAI%CAaIqBq
AaIqB%AAaIqBEH%AAPBaIqB%PCD
%C@qJBH%AAaIqBAI%C@cJ%"    "
3P%H@ABhIaBBI%P@S@PC@",
typedef struct{x c,a,t;
;y G(x t,x a,x c){K.c=t    ;
nt)=putchar,X=40,z=5,o,   a
+c*b.a,b.t*c+a.t);}x H=   .
b.t+b.c*a.c+a.a*b.a;}x Q(){
a,pow(O(a,a),-H));}x D(y p)
++b],b<=r;Q())M=p.t?q -M PI
o+a,w=q*(w>t+H*a?o:    w>t?
1):A(M,p,U(O(A(P,M,T)    ,p
/8+8; M=Q      ()?o&1
int main(    int    L,char
++e)S(o=a    =0,j    =J+9;(c=
32,b++[B]    =G(q    +=*j/8&3
T:1), (c&    7)+    1e-4,o>2
?0:m(c),a          );*++j)==(
F<110;)S(L=-301;p=Z,++L<300
=G(-4,4.6,29),d=V(A(A(A(Z,V
(30.75,-6,-75),20)),g=R=255
A(h,d,i)));R=1<.01);S(N=V(A
U(i/3-D(A(h,N,i/3)))/pow(
M=V(G(T,1,2)),d,T))))
O(N,M))*H*Y+Y,g*=
q,q,1); P=A(p,s
);d=A(d,N,-2*O
```

Credits: Matt Zucker. IOCCC obfuscation contest 2011.

(Cryptographic) Code obfuscation

Generic code obfuscation

```c
#include <stdio.h>

int main(void)
{
  for(int i=1; i<=100; ++i)
  {
    if (i % 3 == 0)
      printf("Fizz");
    if (i % 5 == 0)
      printf("Buzz");
    if (i % 3 && i % 5)
      printf("%d", i);
    printf("\n");
  }

  return 0;
}
```

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%C@qJBH%AAaIqBAI%C@cJ%"   "
JP%H@ABhIaBBI%P@S@PC#",
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nt)=putchar,X=40,z=5,o,   a
+c*b.a,b.t*c+a.t);}x H=   .
b.t+b.c*a.c+a.a*b.a;}x Q(){
a,pow(O(a,a),-H));}x D(y p)
++b],b<=r;Q())M=p.t?q =M_PI
o+a,w=q*(w>t+H*a?o:   w>t?
1):A(M,p,U(O(A(P,M,T)   ,p
/8+8; M=Q         ()?o&1
int main(   int    L,char
++e)S(o=a   =0,j   =J+9;(c=
32,b++[B]   =G(q   +=*j/8&3
T:1), (c&   7)+    1e-4,o>2
70:m(c),a       ):*++j>=(
F<110;)S(L=-301;p=Z,++L<300
=G(-4,4.6,29),d=V(A(A(A(Z,V
(30.75,-6,-75),20)),g=R=255
A(h,d,i)));R=i<.01);S(N=V(A
U(i/3-D(A(h,N,i/3)))/pow(
M=V(G(T,1,2)),d,T))))
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Obfuscation: State-of-the-Art

White-box Cryptography:

- Practical & Fast

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Theoretical Obfuscation (iO):

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Besides iO and White-box

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Hardware security:

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Trusted
Execution
Environment (TEE)
(SGX, TrustZone, ...)

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Increased functionality & complexity

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Larger attack surface

Obfuscating with Hardware

- "Founding Cryptography on Tamper-Proof Hardware Tokens"
  Goyal, Ishai, Sahai, Venkatesan, and Wadia 2010 TCC
- Program *obfuscation* using *stateless* secure HW tokens

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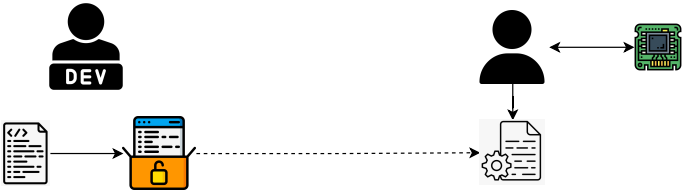

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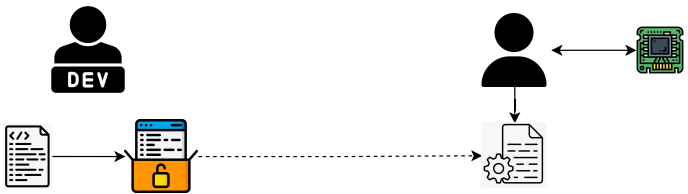

This work: exploring the design space, generalization

Focus: performance and user-friendliness (and security)

Our work - Overview

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OBFUSCURO (NDSS'19) IRON (CCS'17)

SGX

Larger attack surface

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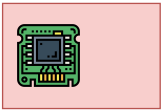
PHANTOM (CCS'13) | GhostRider (ASPLOS'15) | HOP (NDSS'17) | OBFUSCURO (NDSS'19) | IRON (CCS'17)

CPU + ORAM | SGX

Larger attack surface

Plan

Obfuscation with Secure Element



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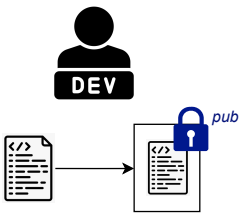

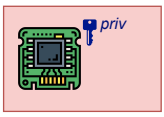

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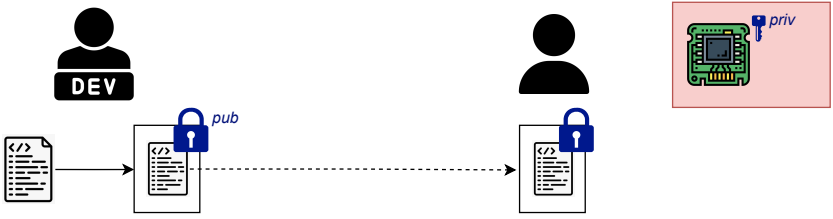

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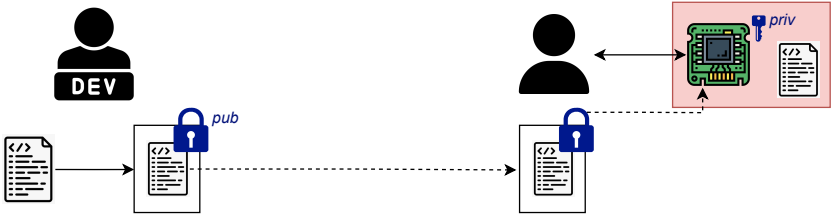

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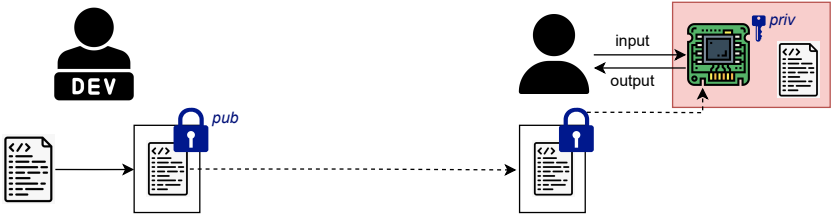

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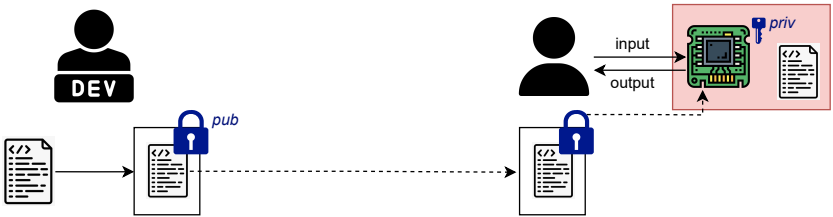
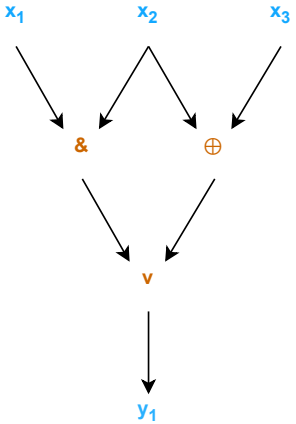


Problem: too complex secure element!

Scheme from TCC'10 (1/2)



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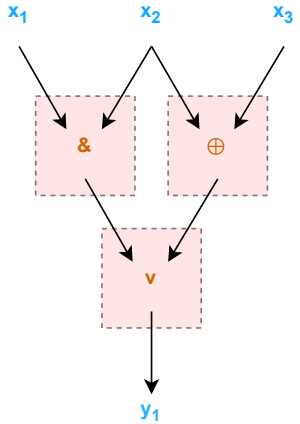

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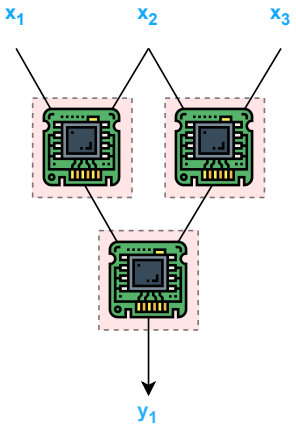

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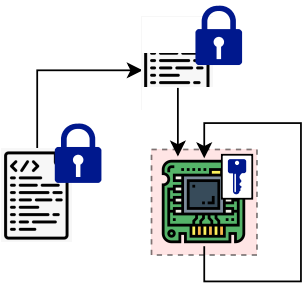

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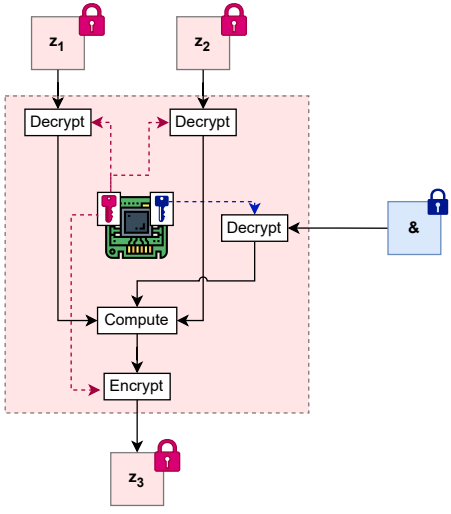

Scheme from TCC'10 (2/2)

Prevent mix-and-match attacks:

- Authenticate node labels

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- Decrypt symmetric key for instructions once, *reencrypt* using internal symm. key

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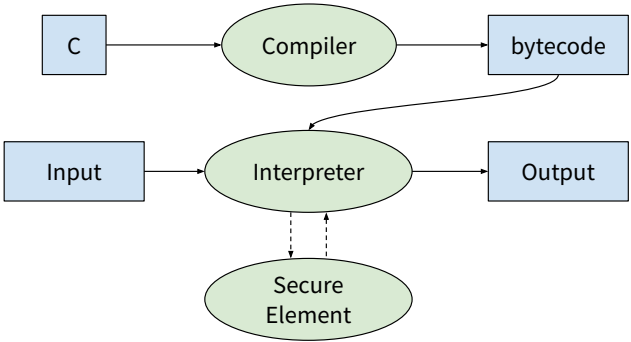
More details omitted, 4-5 different query types needed...

Plan

High-level overview



Example C code

```
unsigned int sum_naive(const unsigned int *array)
{
  // fix the size of array
  unsigned int n = 1000;
  unsigned int i;
  unsigned int s = 0;
  for (i=0; i<n; i++){
    s += array[i];
  }
  return s;
}
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```
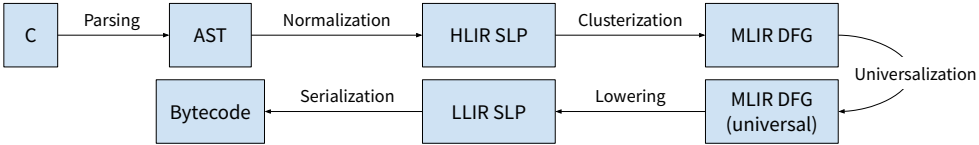
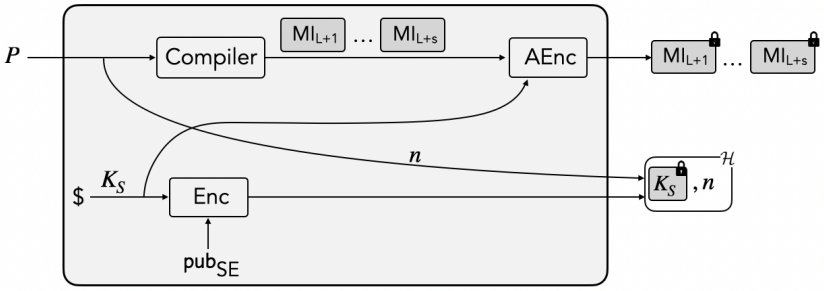

Subset of C language:

- only `uint32` (incl. pointers) supported
- constant-length loops (to be unrolled)
- no data-dependent control flow
- ternary operator allowed:
  `condition ? expr1 : expr2`

Compilation chain



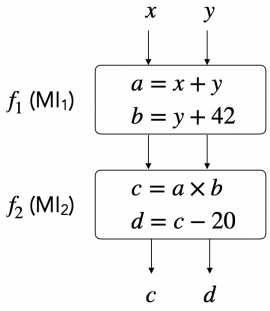
Obfuscation process



Multi-instructions

Inputs: x, y
Outputs: c, d
Body:
$a = x + y$
$b = y + 42$
$c = a \times b$
$d = c - 20$

Straightline Program



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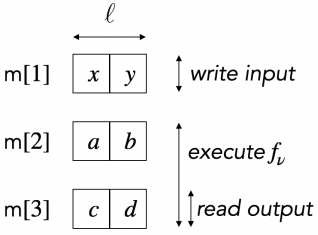
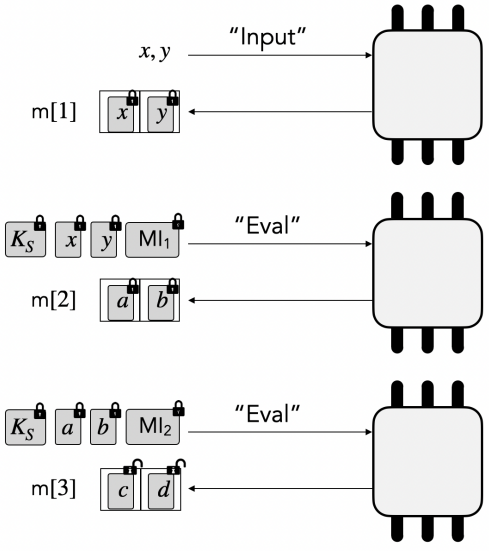


Memory

SE queries



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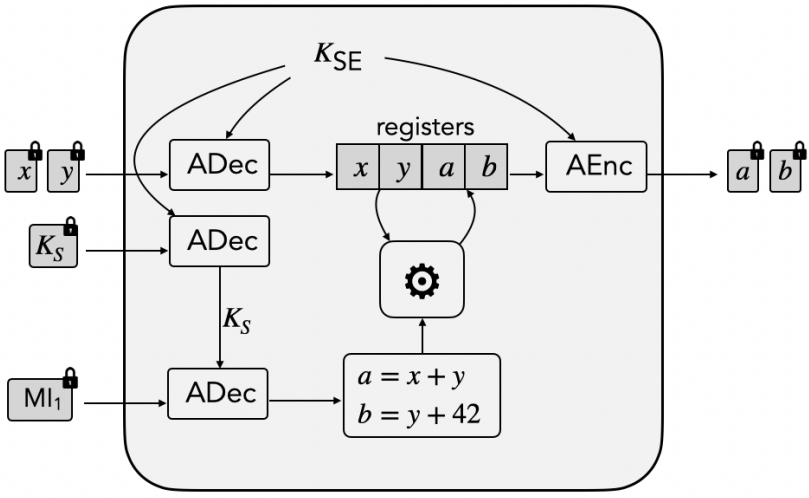
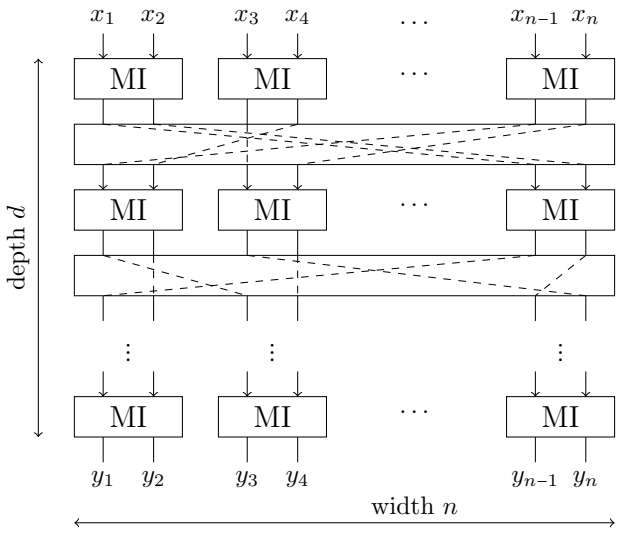

K_{SE}
registers
x
y
ADec
x y a b
AEnc
a
b
K_S
ADec
K_S
MI$_1$
ADec
$a = x + y$
$b = y + 42$

Universalization



Plan

SE parameters

SE name	#MI inputs &outputs	#MI instr.	Estimated performance on ARM Cortex-M3 (120 MHz)
small	8	32	600 MIs/sec
medium	16	64	300 MIs/sec
large	32	128	150 MIs/sec
extra-large	64	256	75 MIs/sec

Benchmarks - White-box mode

Source	Secure Element	#instr.	#MIs (final)	Compil. time	Exec. time (est.)
AES	small	5.3k	290	3.2 sec	0.5 sec
	medium		120	3.1 sec	0.4 sec
	large		59	3.1 sec	0.4 sec
	xlarge		29	3.2 sec	0.4 sec
Traceable AES	small	11k	580	4.8 sec	1.0 sec
	medium		240	4.4 sec	0.8 sec
	large		120	4.8 sec	0.8 sec
	xlarge		59	4.7 sec	0.8 sec
Neural Net	small	230k	22k	220 min	36.7 sec
	medium		11k	58 min	36.7 sec
	large		5.5k	21 min	36.7 sec
	xlarge		2.6k	520 sec	36.7 sec

White-box obfuscation mode. Time estimated on ARM Cortex-M3 120 MHz.

Benchmarks - Full obfuscation

Source	Secure Element	#instr.	Depth	Width	#MIs (final)	Exec. time (est)
AES	small	5.3k	190	7	12k	20 sec
	medium		110	3	3.4k	11 sec
	large		58	2	1.0k	7 sec
	xlarge		29	1	0.1k	2 sec
sum(tree)	small	1000	6	1.2k	28k	47 sec
	medium		3	63	3.1k	11 sec
	large		4	56	3.8k	26 sec
	xlarge		3	46	2.0k	27 sec
findmax(tree)	small	2k	5	190	24k	40 sec
	medium		3	63	3k	11 sec
	large		3	57	3k	20 sec
	xlarge		3	47	2k	27 sec

Full obfuscation mode.

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- *Obfuscation* framework with provable reduction to HW security
  - Compilation from C programs
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github.com/CryptoExperts/OBSCURE

tches.iacr.org/index.php/TCHES/article/view/11440