Compiler-assisted security enhancement

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Summary

- Information leakage
- LADA & SECURE
- Bit-slicing
- The *'bit-slicer'*
- A few considerations

Information leakage

Information leakage

Small electronic encrypting devices

Information leakage

Intrinsic features

- Power consumption
- Timing behaviour
- Electromagnetic leaks
- Sound emission

Information leakage

$$\boxed{\text{intrinsic features} \quad \propto \quad \text{sensitive data}}$$

$$\downarrow$$

SIDE CHANNEL

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Information leakage

Side channel attacks

An attacker may use a side channel in order to gain sensitive information without the need of a flaw of the software or a brute force attack

Side channel examples:

flow control

The pointer p points to sensitive data (the padding). According to the length of the padding the function returns. The execution flow depends on the length of the padding then

Security issue: CVE-2013-0169

```
p = buf;

switch( ctx->padding )
{
    case RSA_PKCS_V15:
        if( p++ != 0 )
            return( POLARSSL_ERR_RSA_INVALID_PADDING);
        bt = *p++;
        if( ( bt != RSA_CRYPT && mode == RSA_PRIVATE )
         || ( bt != RSA_SIGN && mode == RSA_PUBLIC ) )
        {
            return( POLARSSL_ERR_RSA_INVALID_PADDING);
        }
}
```

Side channel examples:

cache access

The variable y contains sensitive data from buf and is then used to access the array R. An attacker might gain some information about the content of y by monitoring the cache events.

Security issue: CVE-2016-7440

```
y=(int)(buf >> (DIGIT_BIT-1))&1;
buf<<=(fp_digit)1;

/*do ops*/
fp_mul(&R[0], &R[1], &R[y^1]);
fp_montgomery_reduce(&R[y^1], P, mp);

fp_sqr(&R[y], &R[y]);
fp_montgomery_reduce(&R[y], P, mp);
```

LADA & SECURE

LADA & SECURE

The LADA project

Leakage Aware Design Automation

Development of tools that help the programmer design secure code and test it against leakage-related attacks

LADA & SECURE

The LADA project

Leakage Aware Design Automation

Development of tools that help the programmer design secure code and test it against leakage-related attacks

Partnership with Embecosm → SECURE project

LADA & SECURE

The SECURE project

Security Enhancing Compilation for use in Real Environments

Development and integration to the mainstream of LLVM and GCC of compiler tools that help the programmer write secure code

LADA & SECURE

The SECURE project: aims

- Automatic selective bit-slicing
- Stack erasing
- Security warnings

Bit-slicing

Bit-slicing

Historically

Used in order to increase the word length of the processor before the advent of the microprocessor.

Bit-slicing: Historically

Construction of a processor from modules of smaller bit width, such as an n-bit processor with n 1-bit processors

Software needed to be properly designed

Bit-slicing

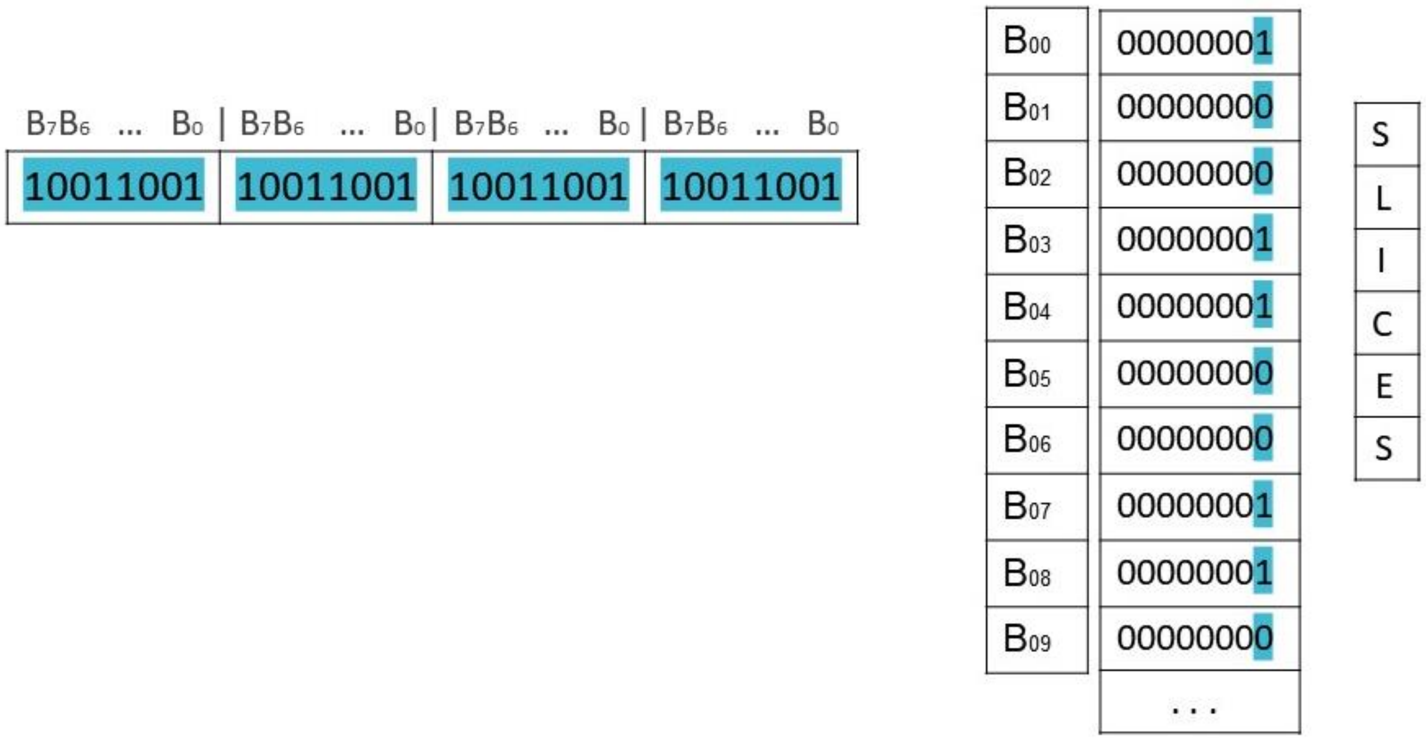
In software

Software simulation of a parallel machine on a general purpose CPU

data slicing + instructions slicing

Bit-slicing:
data slicing

Let's suppose that we need to bit-slice the array on the left, a new virtual register (that may be an element in a new array) is allocated to each of the bits of the original array



Bit-slicing: instruction slicing

The algorithm used on bit-sliced data needs to be 'bit-sliced' as well: it must be turned into an equivalent algorithm made of atomic boolean operations, each addressing the proper slice of data.

```
for ( i=0; i<n; i++ ){
    array3[i] = array1[i] ^ array2[i];

}
```

```
for ( i=0; i<n; i++ ){
    for ( j=0; j<8; j++ ){
        array3_slices[i] = array1_slices[i] ^ array2_slices[i];
    }

}
```

Bit-slicing

What for?

Bit-slicing

What for?

Only some algorithms can be bit-sliced

Bit-slicing

What for?

Only some algorithms can be bit-sliced

And only some of these benefit from that (e.g. SIMD)

Bit-slicing:
What for?

Given a SIMD system

B_7B_6 … B_0	B_7B_6 … B_0	B_7B_6 … B_0	B_7B_6 … B_0
10011001	10011001	10011001	10011001
01001001	00100010	00100100	00101011
00010110	10100010	00000001	10011000
11110000	11000100	00010010	00000110
01001001	00001001	00000000	10010010
00100100	00010010	00001001	10010011
10010010	11111111	00011101	10000010
10001110	01001010	11111110	00111101

B_{00}	10100011
B_{01}	01111010
B_{02}	10001000
B_{03}	10000111
B_{04}	10110101
B_{05}	10000010
B_{06}	00000000
B_{07}	01110101
B_{08}	01100101
B_{09}	10001000
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Bit-slicing:

What for?

In cryptography:

- Block ciphers are SIMD systems
- Input-independent execution time is key

Bit-slicing:

What for?

In cryptography:

- Block ciphers are SIMD systems
- Input-independent execution time is key:
  - the execution time of boolean operations does not depend on the input

The '*bit-slicer*'

The *'bit-slicer'*

An LLVM pass that provides the programmer with:

- Automated bit-slicing of selected areas of the source code
- Simple data bit-slicing

The *'bit-slicer'*: Automated bit-slicing

Automated bit-slicing

```
#pragma bitslice(array1, array2, array3)
{
   for ( i=0; i<n; i++ ){
          array3[i] = array1[i] ^ array2[i];
   }

}
```

The *'bit-slicer'*: Automated bit-slicing

```
#pragma bitslice(array1, array2, array3)
{
for ( i=0; i<n; i++ ){
    array3[i] = array1[i] ^ array2[i];
}
}


for ( i=0; i<n; i++ ){
    for ( j=0; j<8; j++ ){
        array3_slices[i] = array1_slices[i] ^ array2_slices[i];
    }
}
```

The *'bit-slicer'*

Simple data bit-slicing

The bit-slicer spares you from touching bit-sliced data

but what if we need to?

The *'bit-slicer'*: Simple data bit-slicing

```
#define N 10
uint8_t array[N];
slice_t array_slices[BLOCK_LEN * 8];

__builtin_get_bitsliced_data(array, array_slices);
```

A few considerations

A few considerations

Bit-slicing is very niche technique

Never forget the cons:

- Increase of allocated space
- Increase of code size (to create and manage the slices)
- Only some algorithms can be efficiently bit-sliced

A few considerations

SIMD programs are the best candidates:

increased throughput

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A few considerations

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Block ciphers:

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input independent execution time

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Block ciphers:

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→ resistence against timing side channel attacks

A few considerations

BUT!

A few considerations

Any operation that involves a dependency among the bits of an operand (like the carry in an addition) might cause a loss of efficiency or may not even be bit-sliced at all

A few considerations

Even among block ciphers

it might well be that only some implementations of the same block cipher benefit from bit-slicing

Questions?

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Examples of bit-sliced implementations

Faster and Timing-Attack Resistant AES-GCM

https://link.springer.com/chapter/10.1007/978-3-642-04138-9_1

Lightweight Fault Attack Resistance in Software Using Intra-Instruction Redundancy

https://eprint.iacr.org/2016/850

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