To INT Or To UINT

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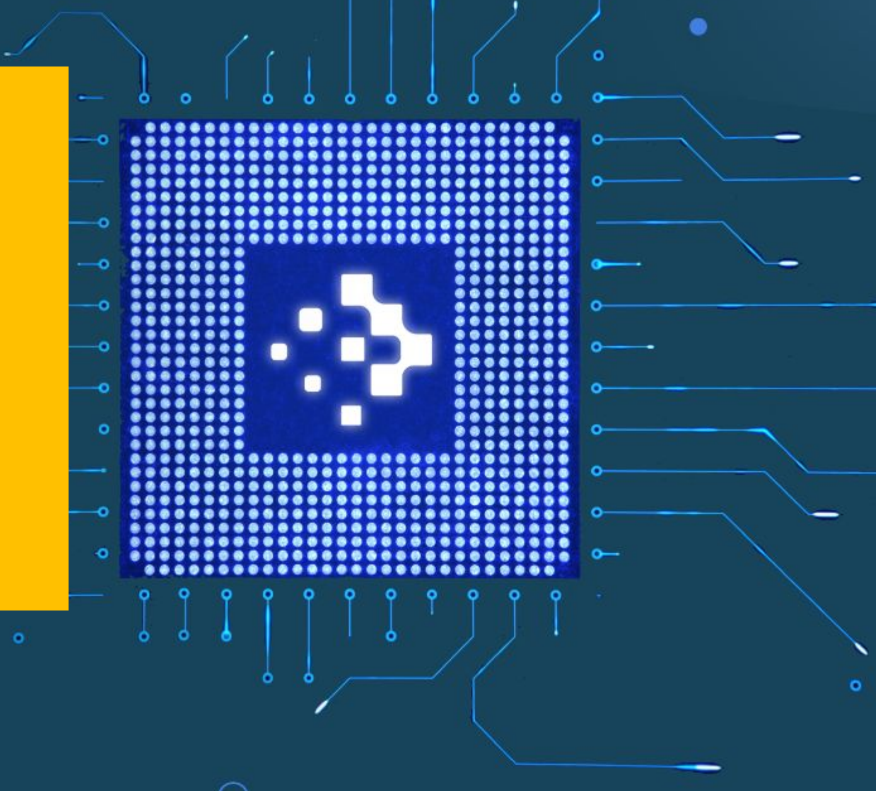


To INT Or To UINT

Alex Dathskovsky | alex.dathskovsky@speedata.io | www.linkedin.com/in/alexdathskovsky

> *"There are far too many integer types, there are far too lenient rules for mixing them together, and it's a major bug source, which is why I'm saying stay as simple as you can, use {signed} integers till you really need something else."*
>
> ~Bjarne Stroustrup

https://graphitemaster.github.io/aau/

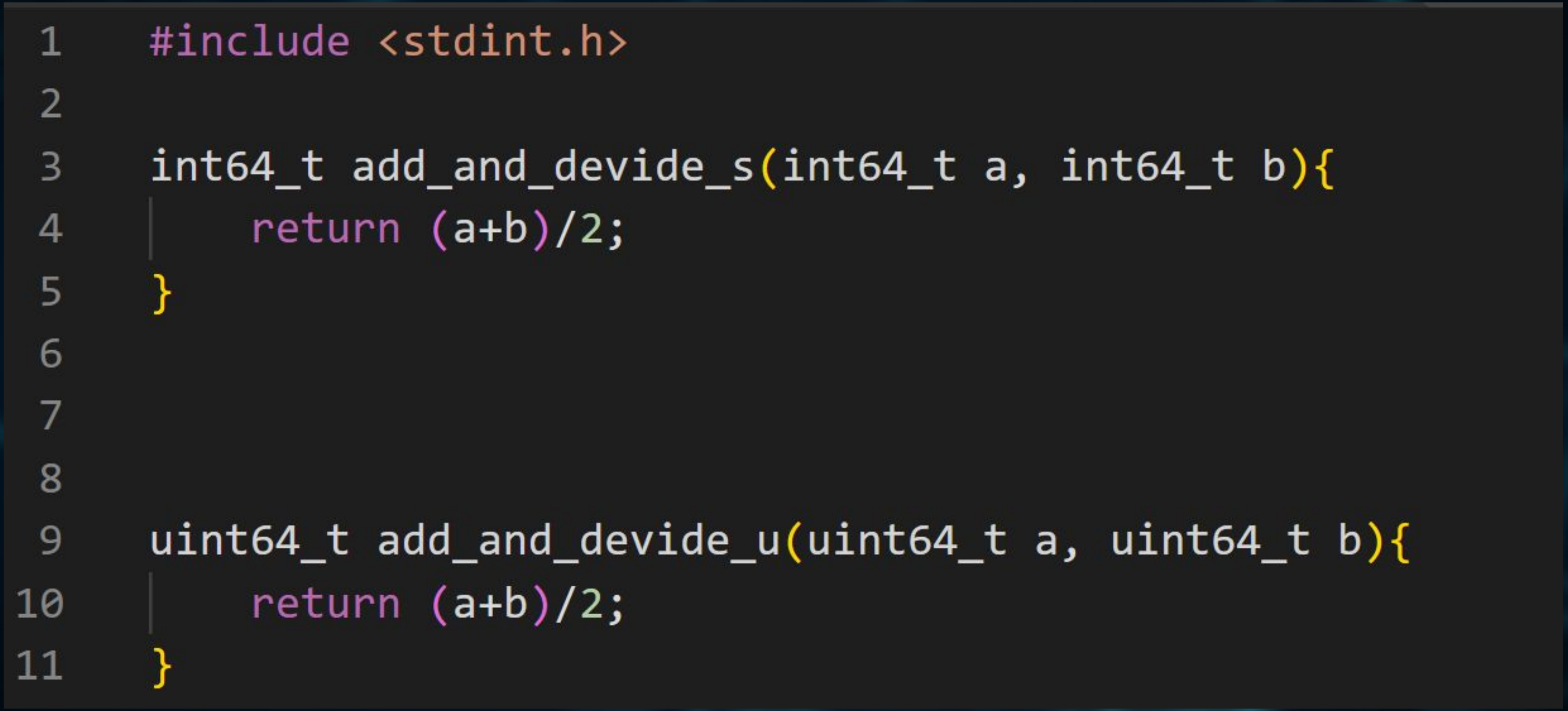
“The need for signed integer arithmetic is often misplaced as most integers never represent negative values within a program. The indexing of arrays and iteration count of a loop reflects this concept as well. There should be a propensity to use unsigned integers more often than signed, yet despite this, most coders incorrectly choses to use signed integers almost exclusively.”

~ Dale Weiler

https://graphitemaster.github.io/aau/

Disclaimer : X86 machines only in this talk

SIMPLE EXAMPLE:



```c
#include <stdint.h>

int64_t add_and_devide_s(int64_t a, int64_t b){
    return (a+b)/2;
}



uint64_t add_and_devide_u(uint64_t a, uint64_t b){
    return (a+b)/2;
}
```

SIMPLE EXAMPLE: UNSIGNED VERSION

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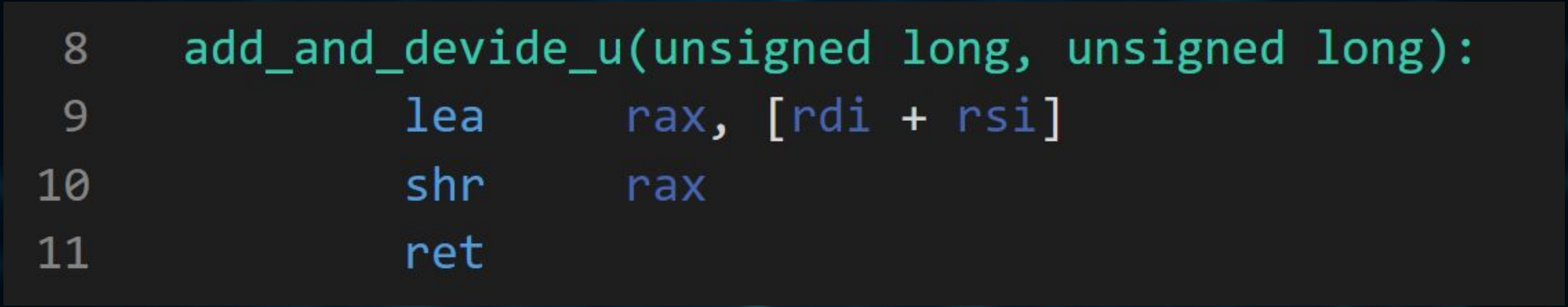
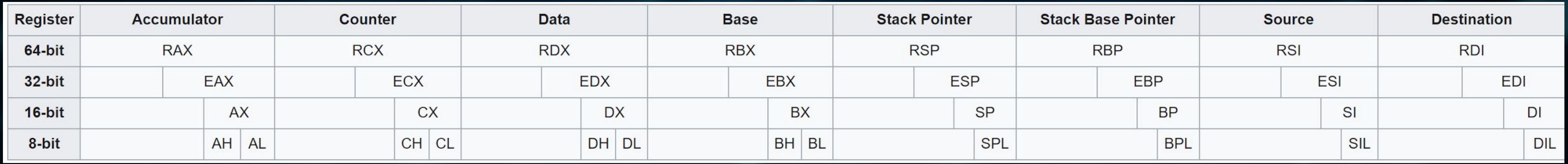


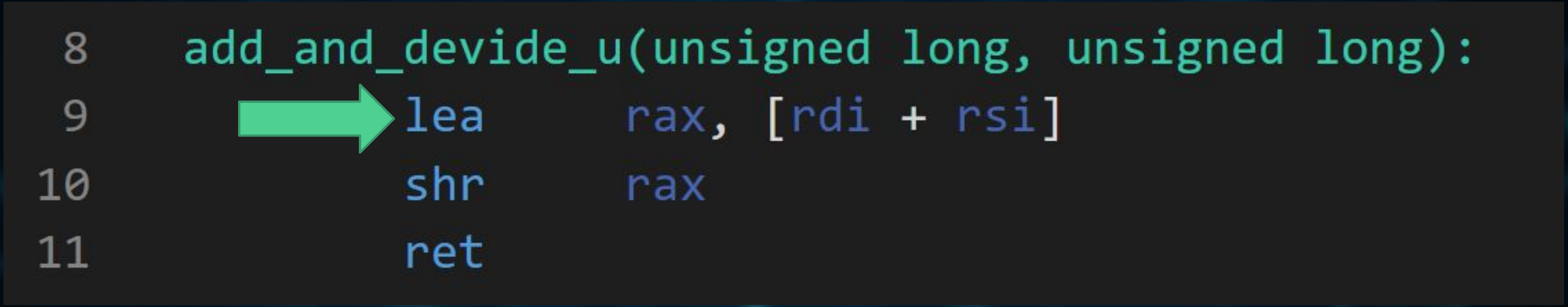
```
add_and_devide_u(unsigned long, unsigned long):
        lea     rax, [rdi + rsi]
        shr     rax
        ret
```

SIMPLE EXAMPLE: SOME ASSEMBLY



Register	Accumulator	Counter	Data	Base	Stack Pointer	Stack Base Pointer	Source	Destination
64-bit	RAX	RCX	RDX	RBX	RSP	RBP	RSI	RDI
32-bit	EAX	ECX	EDX	EBX	ESP	EBP	ESI	EDI
16-bit	AX	CX	DX	BX	SP	BP	SI	DI
8-bit	AH AL	CH CL	DH DL	BH BL	SPL	BPL	SIL	DIL

SIMPLE EXAMPLE: SOME ASSEMBLY



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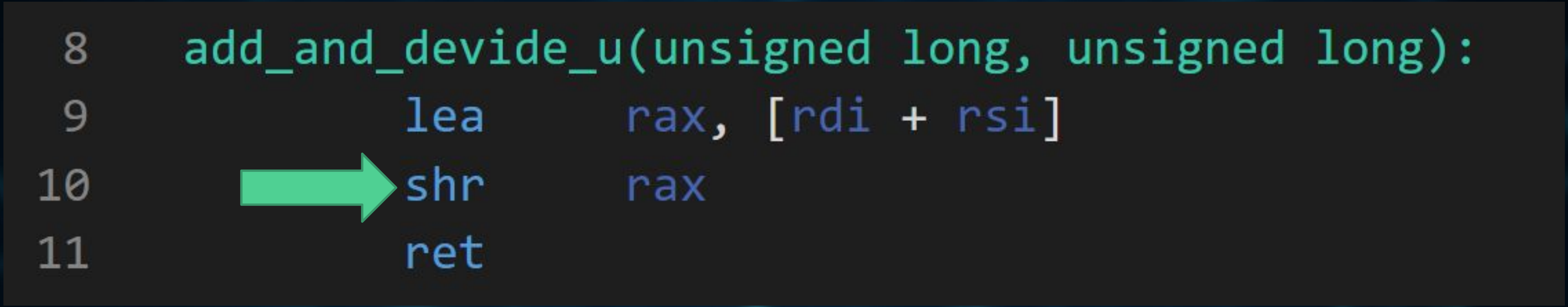

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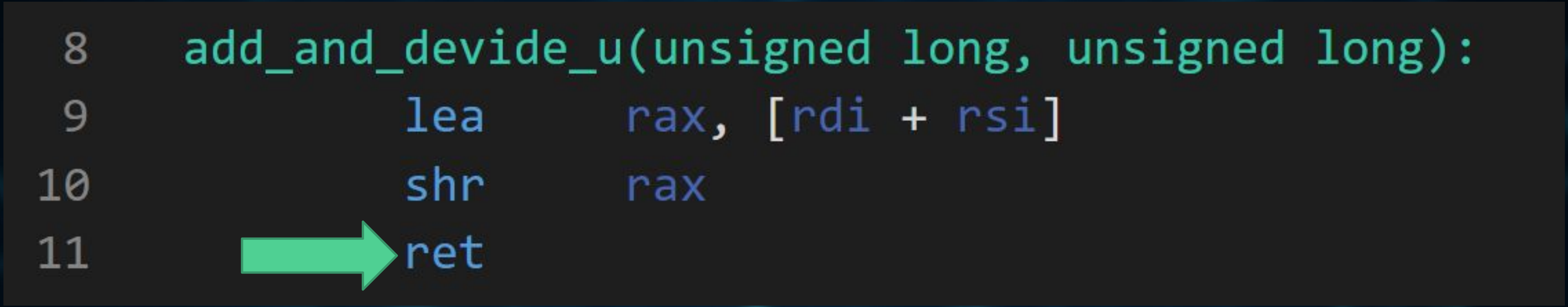

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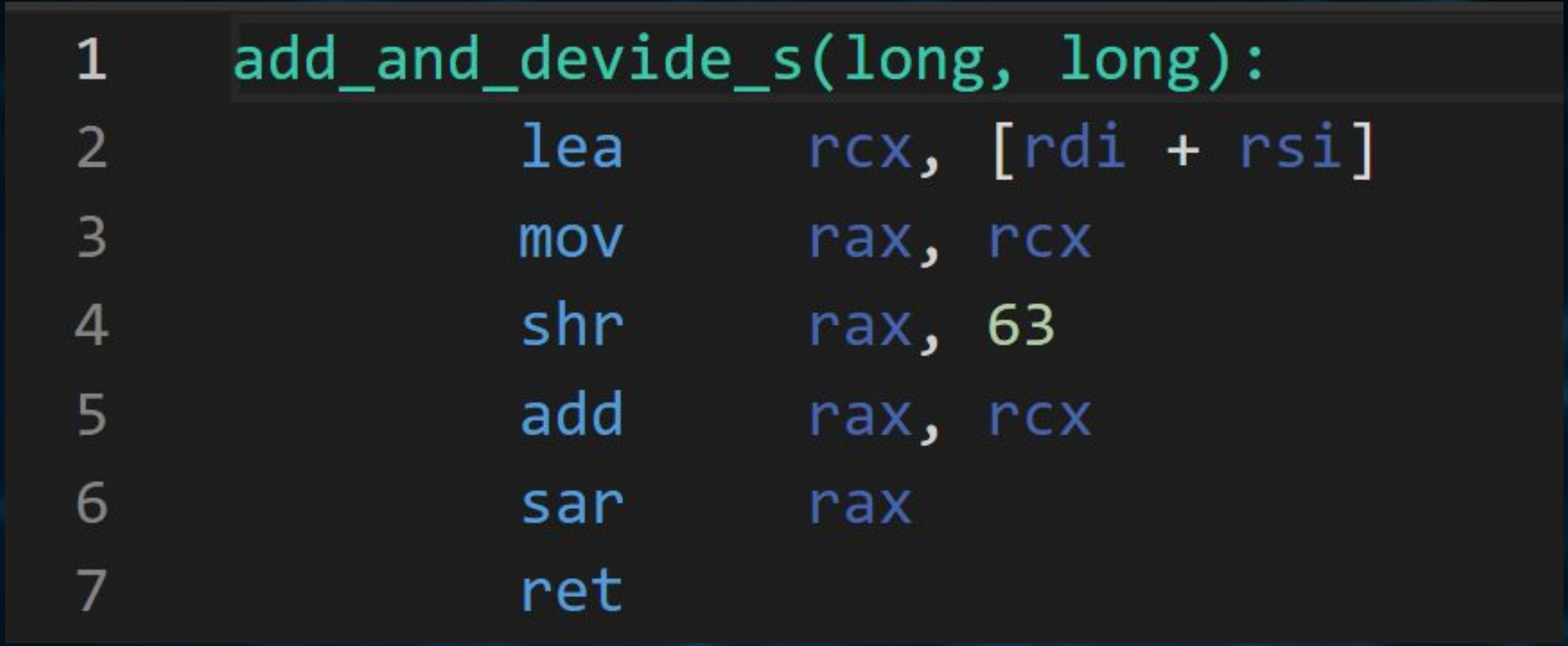
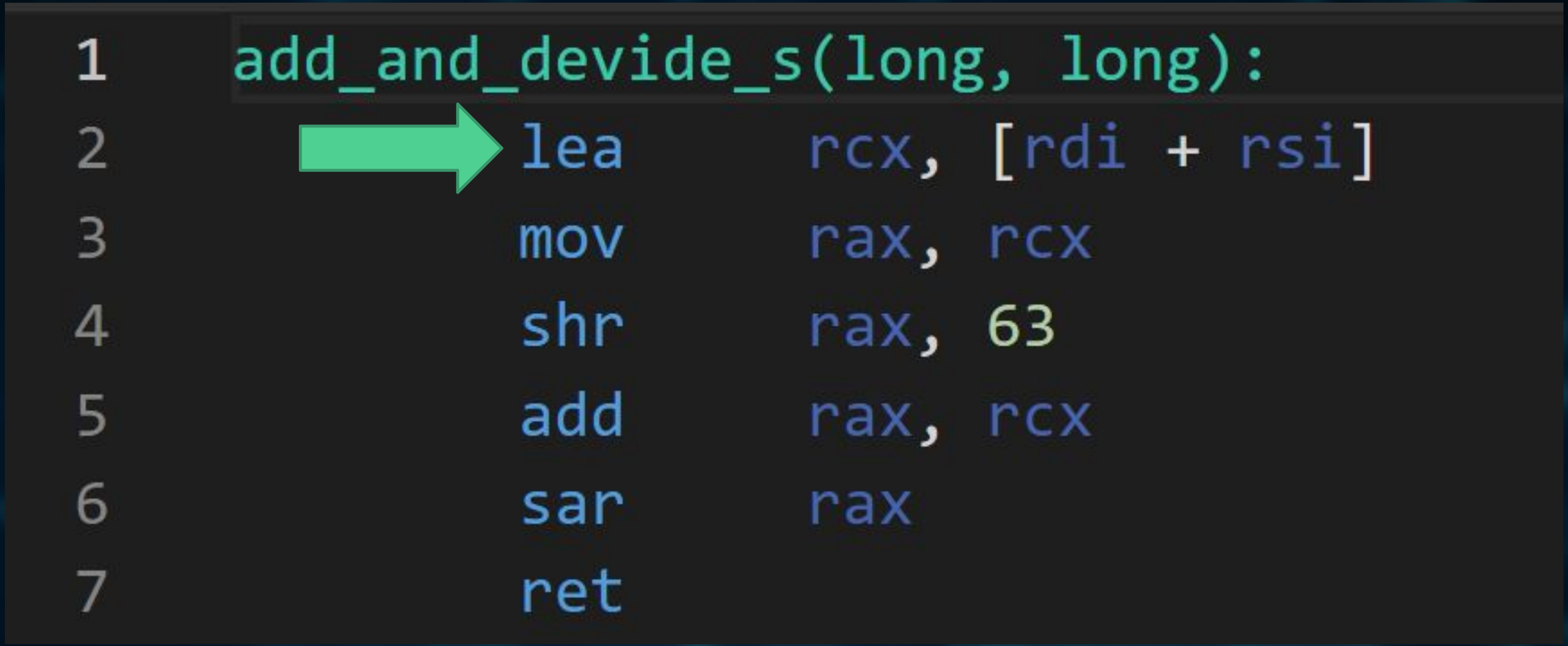


```
add_and_devide_s(long, long):
        lea     rcx, [rdi + rsi]
        mov     rax, rcx
        shr     rax, 63
        add     rax, rcx
        sar     rax
        ret
```

Surprise
☺️

SIMPLE EXAMPLE: SIGNED VERSION (ASSEMBLY)



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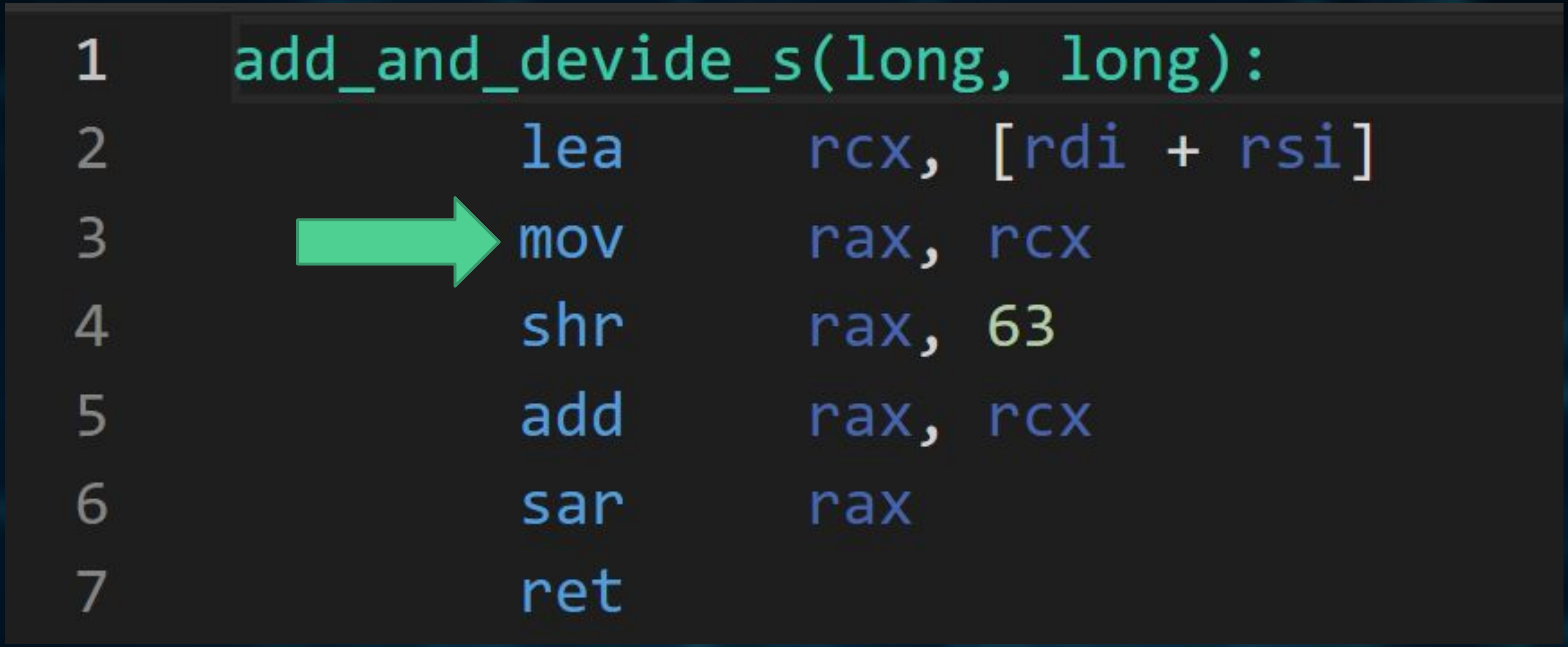

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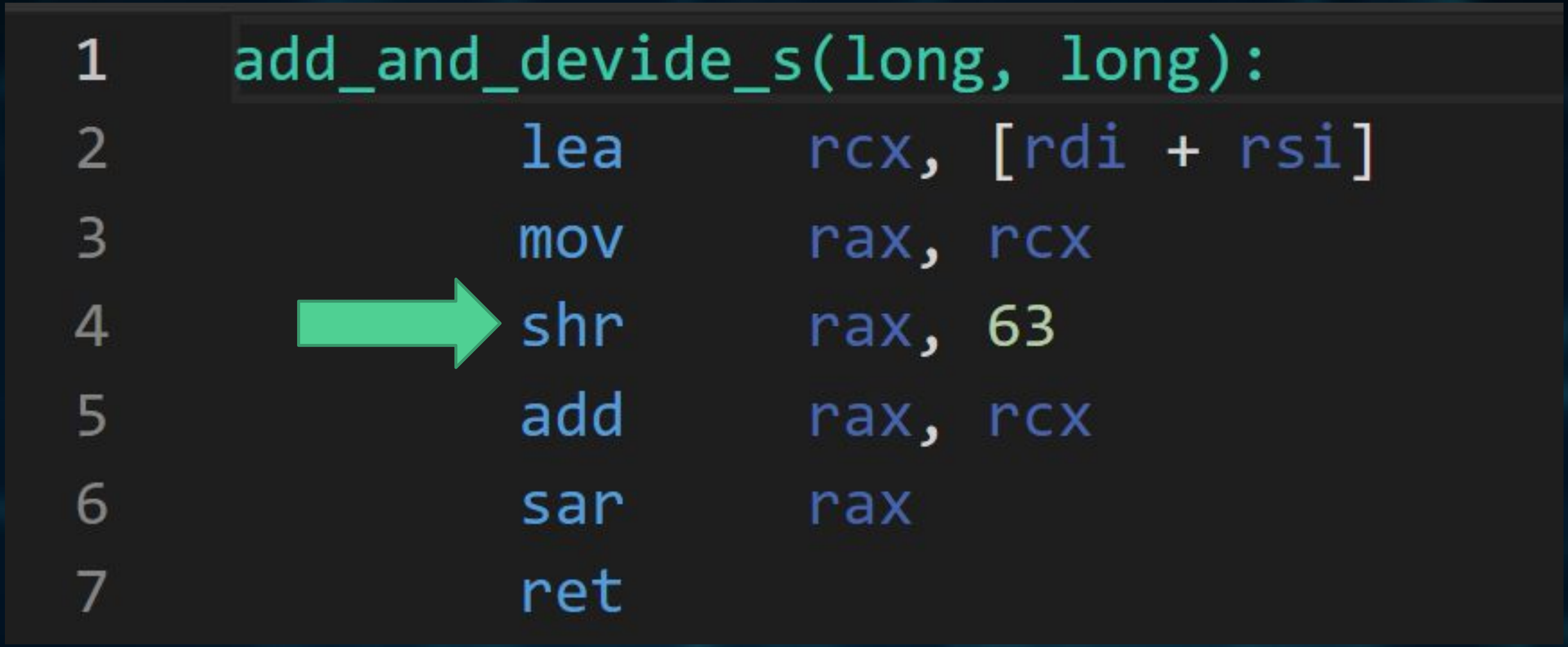

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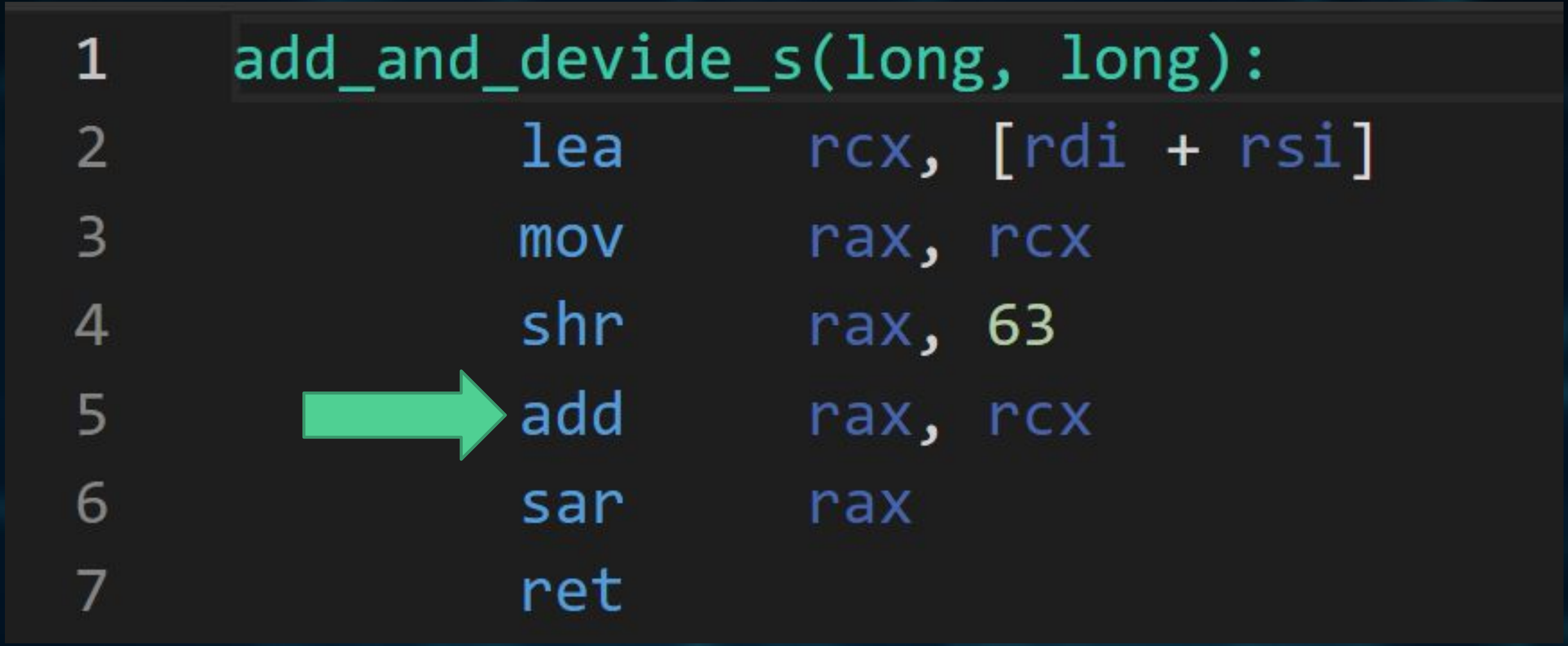

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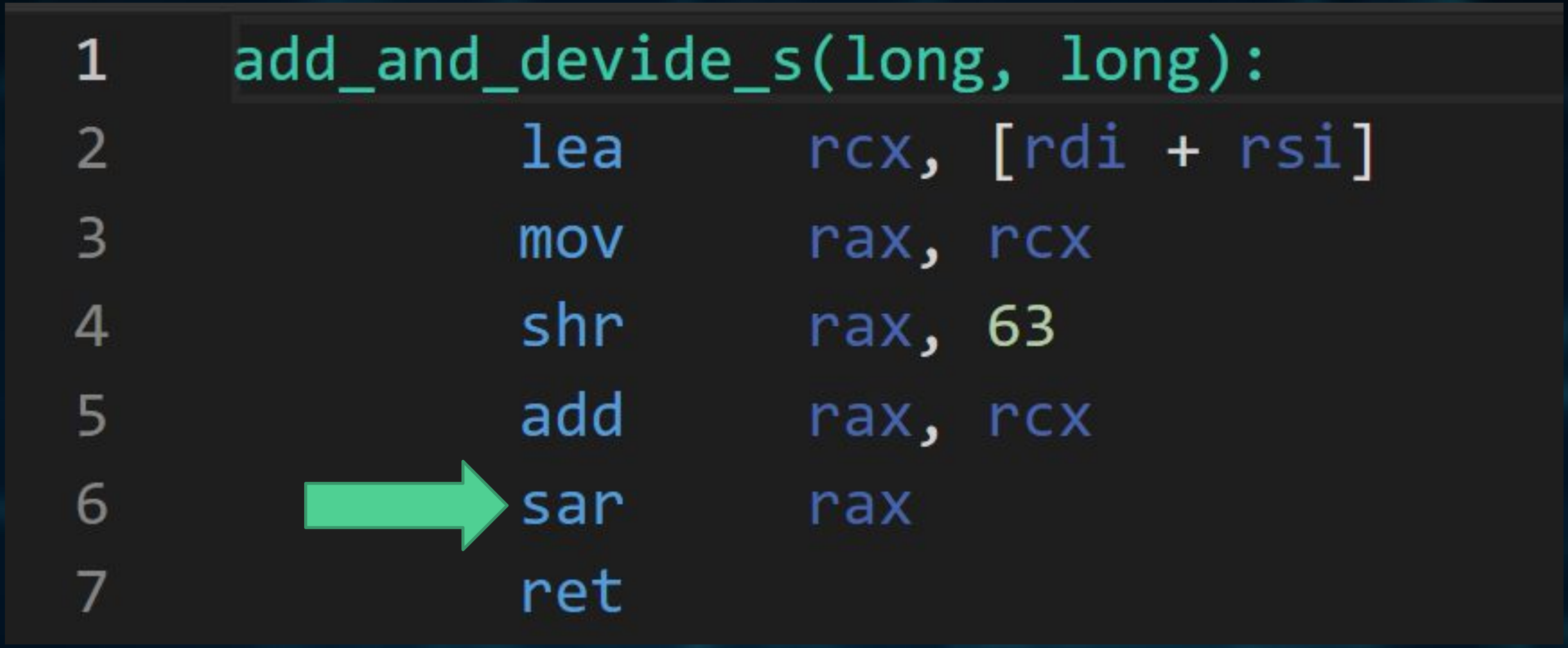

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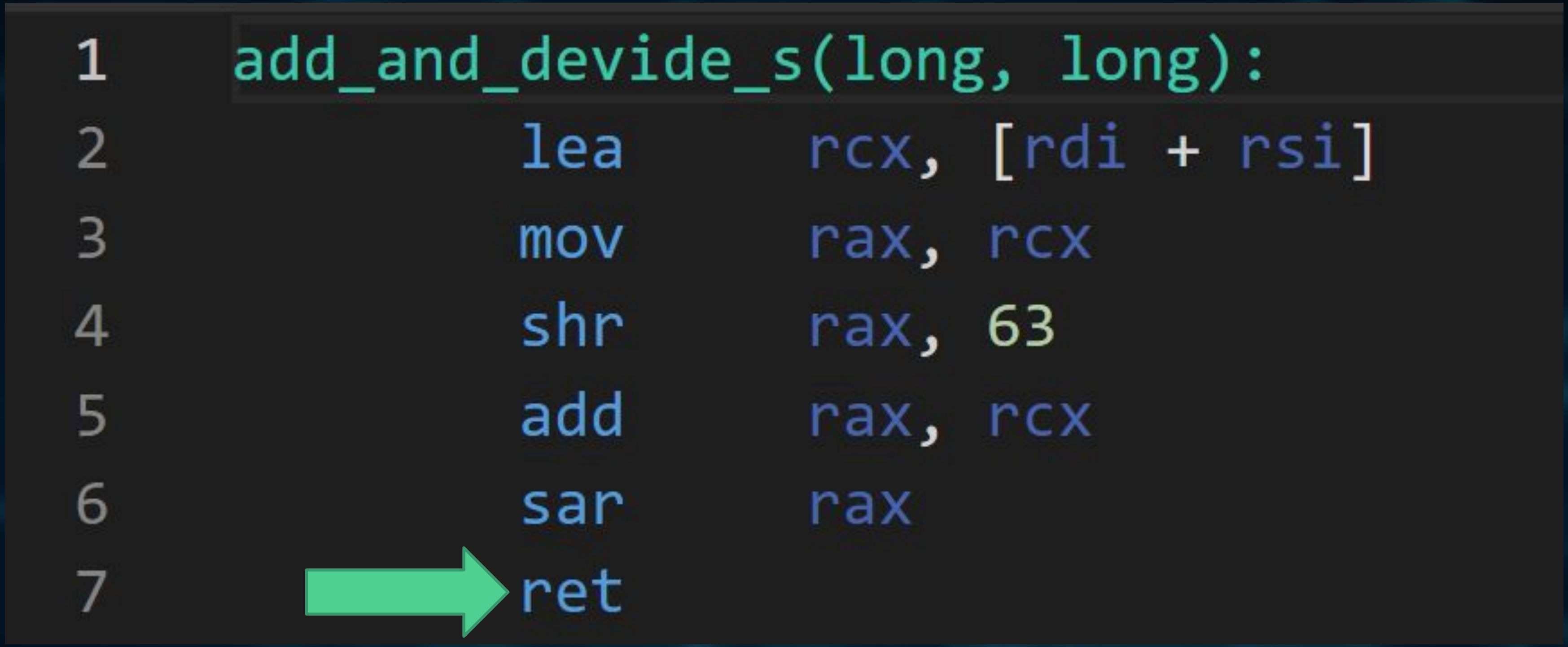

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WHY DID THIS HAPPEN?

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- Each execution has its own unit and there is a limited number of execution units. (depends on the **CPU**)

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- Each instruction that is fetched from the memory is pushed into a pipeline, one of the steps in the pipeline is execution, execution may be piped as well.
- Each execution has its own unit and there is a limited number of execution units. (depends on the **CPU**)
- Each instruction has its own latency

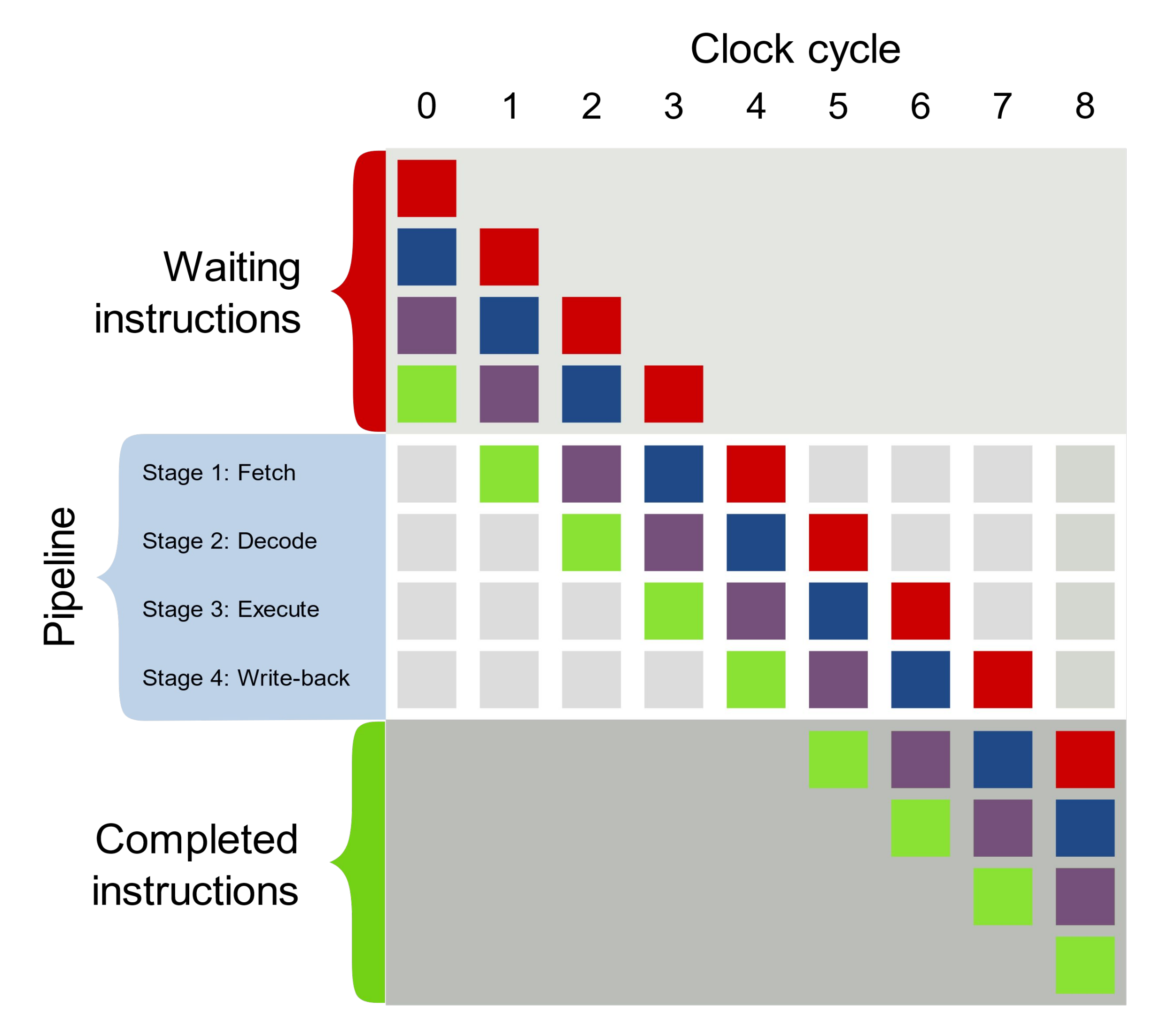
WHAT IS LATENCY?

- The number of cycles it takes to compute an instruction
    - Errors, misalignment, and cache misses might increase the cycles count
    - NAN’s and INFS do not increase the cycles

WHAT IS LATENCY: EXAMPLES

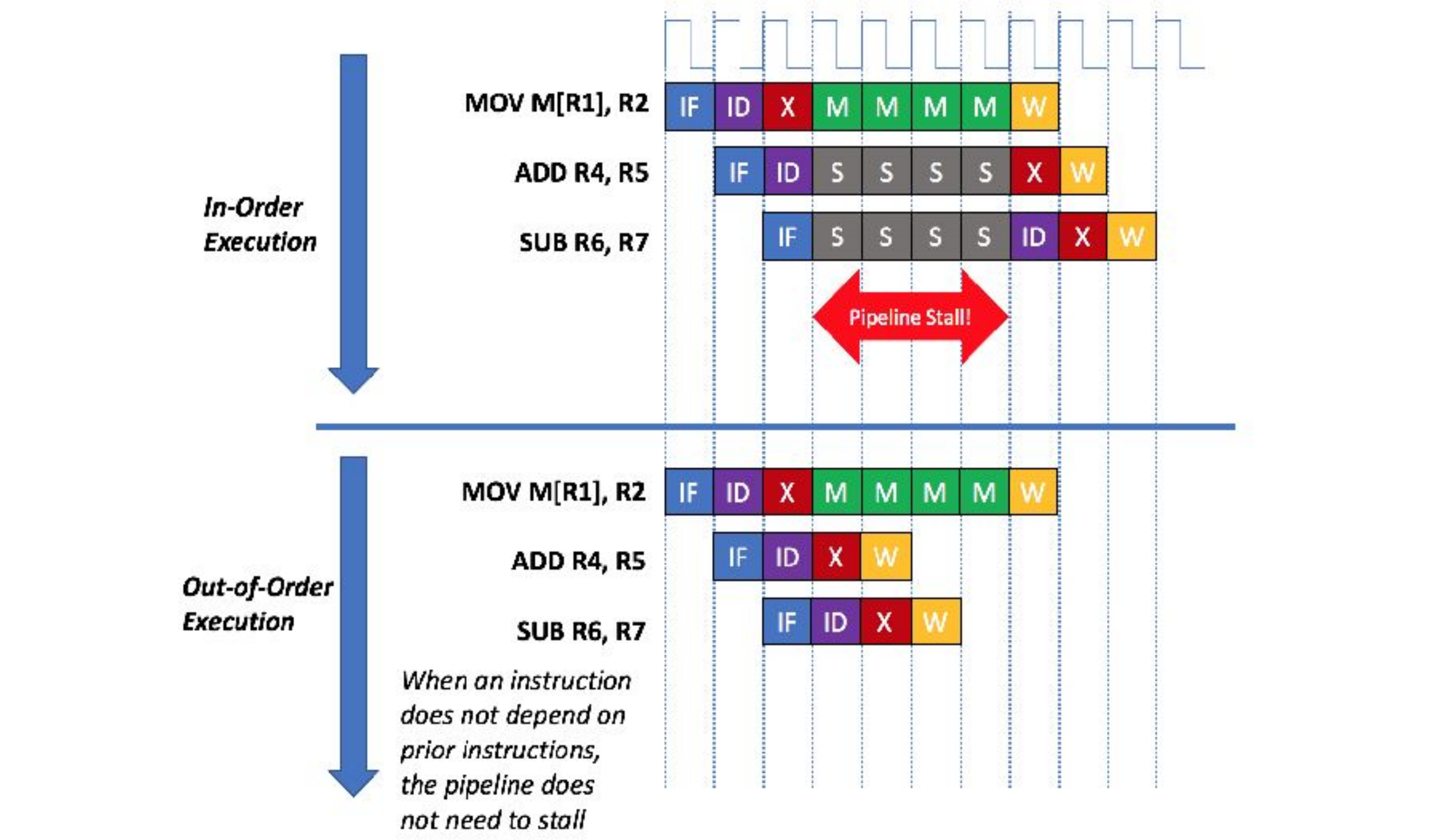
- ADD – 1 cycle (not piped)
- IMUL – 3 cycles
- DIV – at least x20 time slower than imul (depending on the architecture)

WHAT IS LATENCY: PIPES



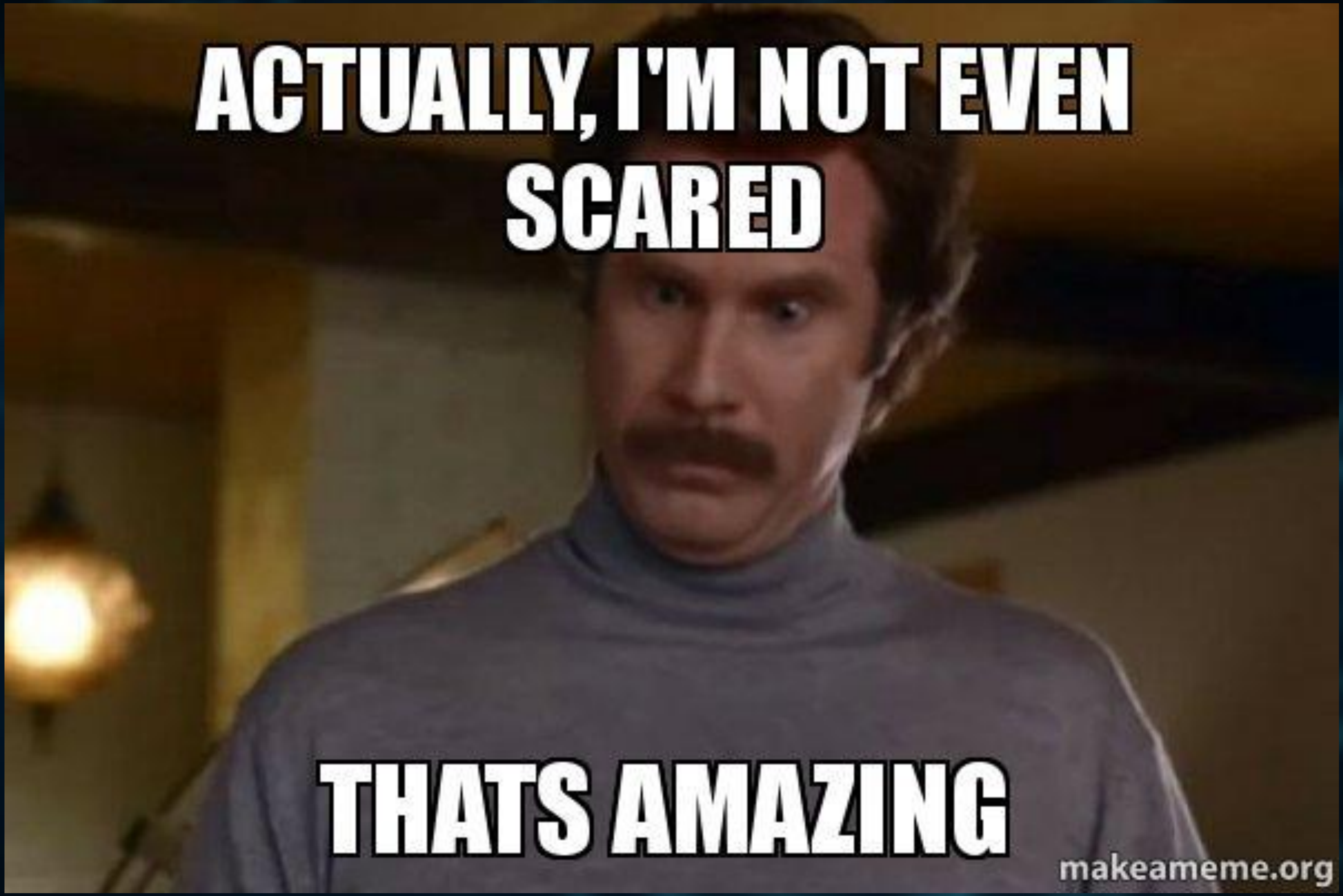
Source: https://en.wikipedia.org/wiki/Instruction_pipelining

WHAT IS LATENCY: PIPES

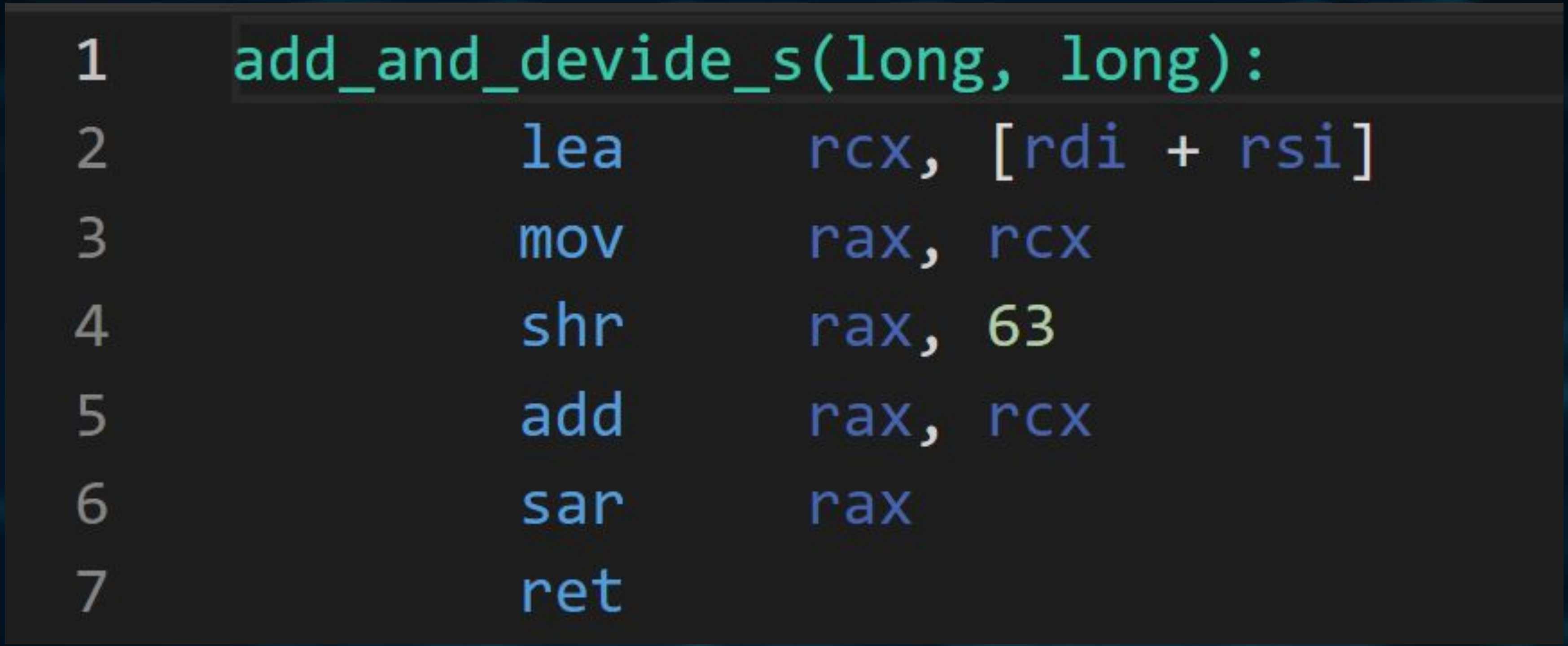


When an instruction does not depend on prior instructions, the pipeline does not need to stall

Source:
https://www.semanticscholar.org/paper/RISC-V-Reward:-Building-Out-of-Order-Processors-in-Zekany-Tan/f7f6d27f334604c3c85f0b8d21d2a9b4df22a983


ACTUALLY, I'M NOT EVEN SCARED
THATS AMAZING
makeameme.org

BACK TO OUR EXAMPLE: WHAT HAPPENED?



```
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        lea     rcx, [rdi + rsi]
        mov     rax, rcx
        shr     rax, 63
        add     rax, rcx
        sar     rax
        ret
```

SIGNED VS UNSIGNED INTEGERS

SIGNED VS UNSIGNED INTEGERS

- **Unsigned Integers**:
  - Stored using Modulo 2 representation
  - Support only positive numbers
  - Overflow is well-defined
  - The Range of a *64-bit* **unsigned integer** is *0* to *18,446,744,073,709,551,615 (2^n)*

SIGNED VS UNSIGNED INTEGERS

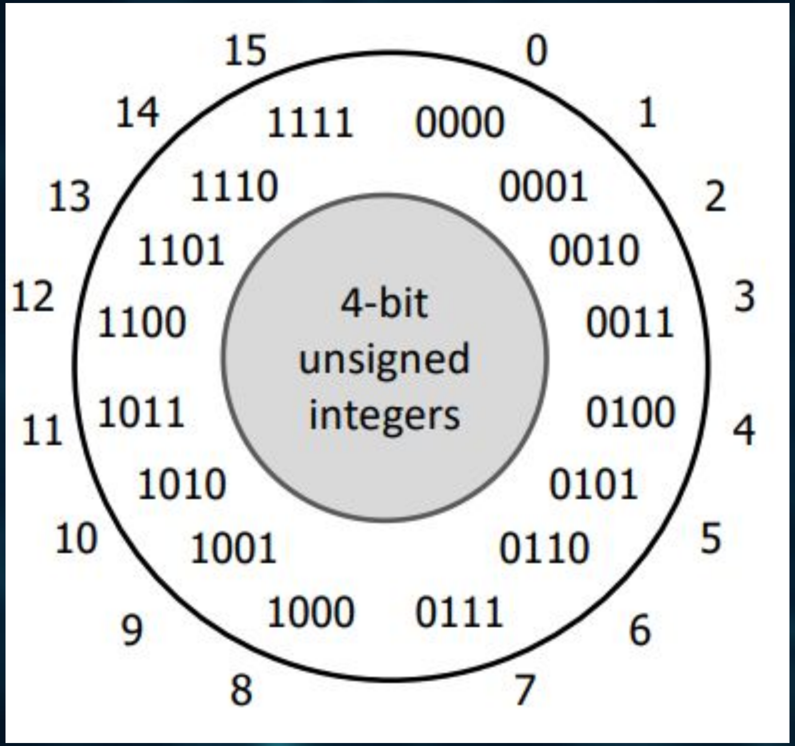
- **Unsigned Integers**: representation

Bits:	1	0	1	1	0
Wight:	2^4	2^3	2^2	2^1	2^0

Actual: $1*2^4+0*2^3+1*2^2+1*2^1+0*2^0 = 1*16+0*8+1*4+1*2+0*1 = 22$

SIGNED VS UNSIGNED INTEGERS

- **Unsigned Integers**: Overflow



15 + 2 = 1

1111 0010 = 0001

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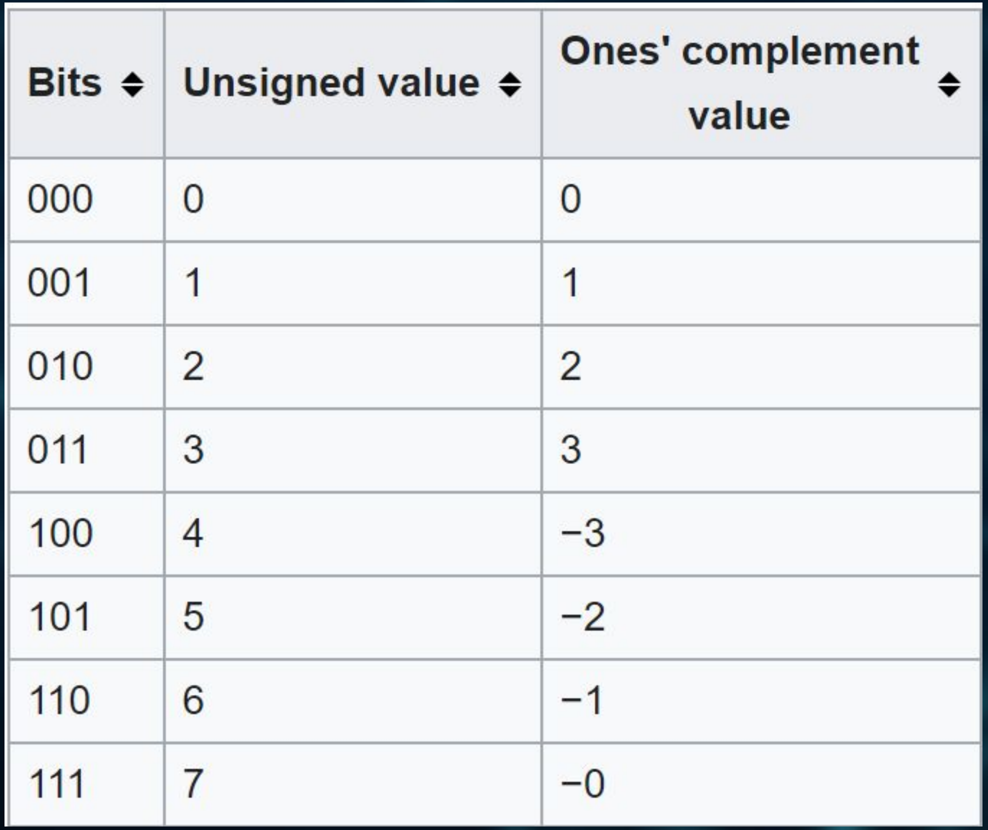
SIGNED VS UNSIGNED INTEGERS

- **Signed Integers:**
  - support negative numbers
  - Stored using:
    - Sign and magnitude
    - One’s complement
    - Two’s complement
  - overflow is considered undefined behavior
  - The range of a *64-bit* **signed integer** is *-9,223,372,036,854,775,808* to *9,223,372,036,854,775,807*

SIGNED VS UNSIGNED INTEGERS

- One’s Complement
  - Representing negative numbers by inverting all bits



Bits	Unsigned value	Ones' complement value
000	0	0
001	1	1
010	2	2
011	3	3
100	4	−3
101	5	−2
110	6	−1
111	7	−0

Source: https://en.wikipedia.org/wiki/Ones%27_complement

SIGNED VS UNSIGNED INTEGERS

- One’s Complement
  - Example: 4 bit number

F = 1111 (unsigned)

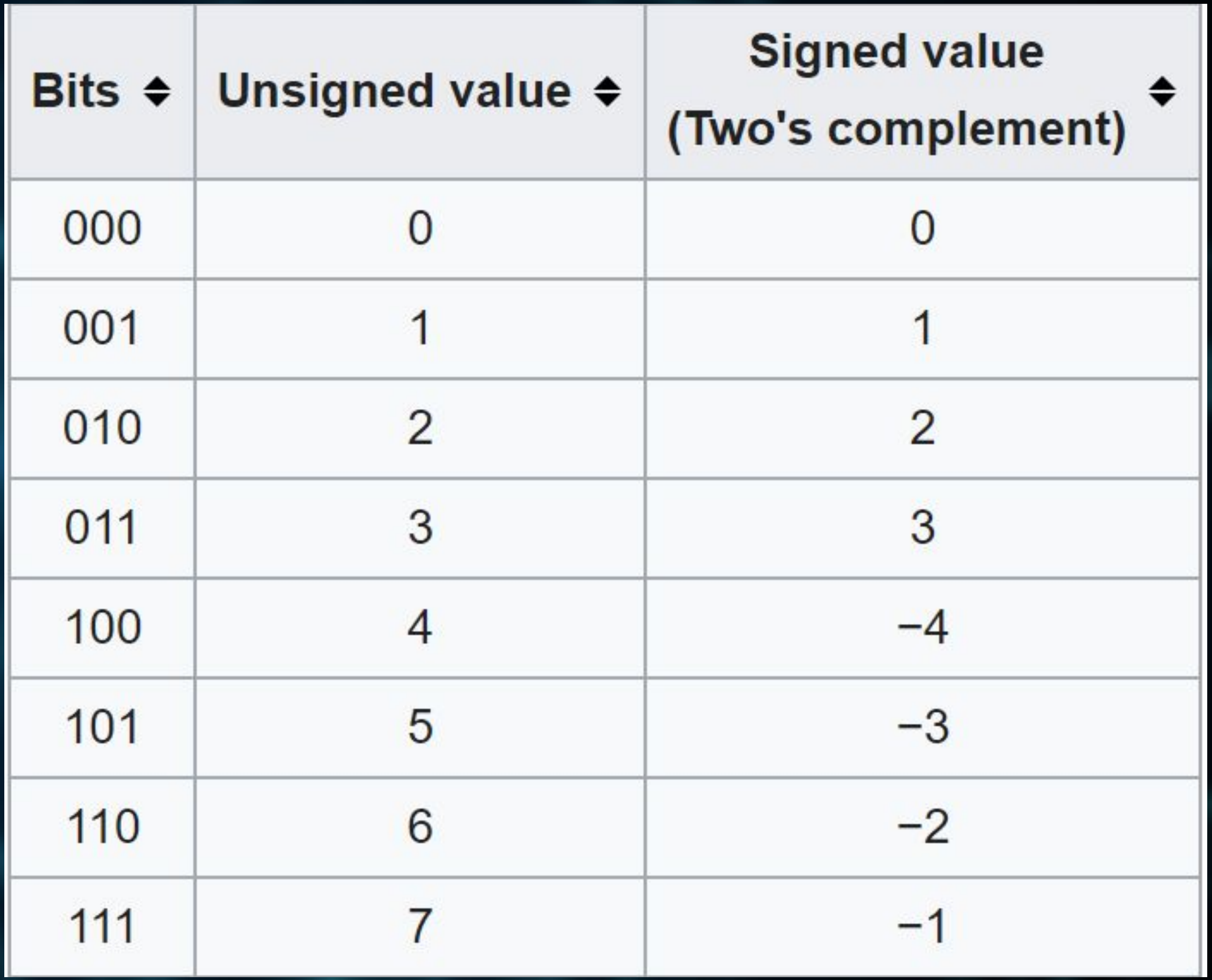
↓

0 0 0 0 = -0

Source: https://en.wikipedia.org/wiki/Ones%27_complement

SIGNED VS UNSIGNED INTEGERS

- Two’s Complement
  - Start with a positive number
  - Invert all bits
  - Add 1 and ignore overflows

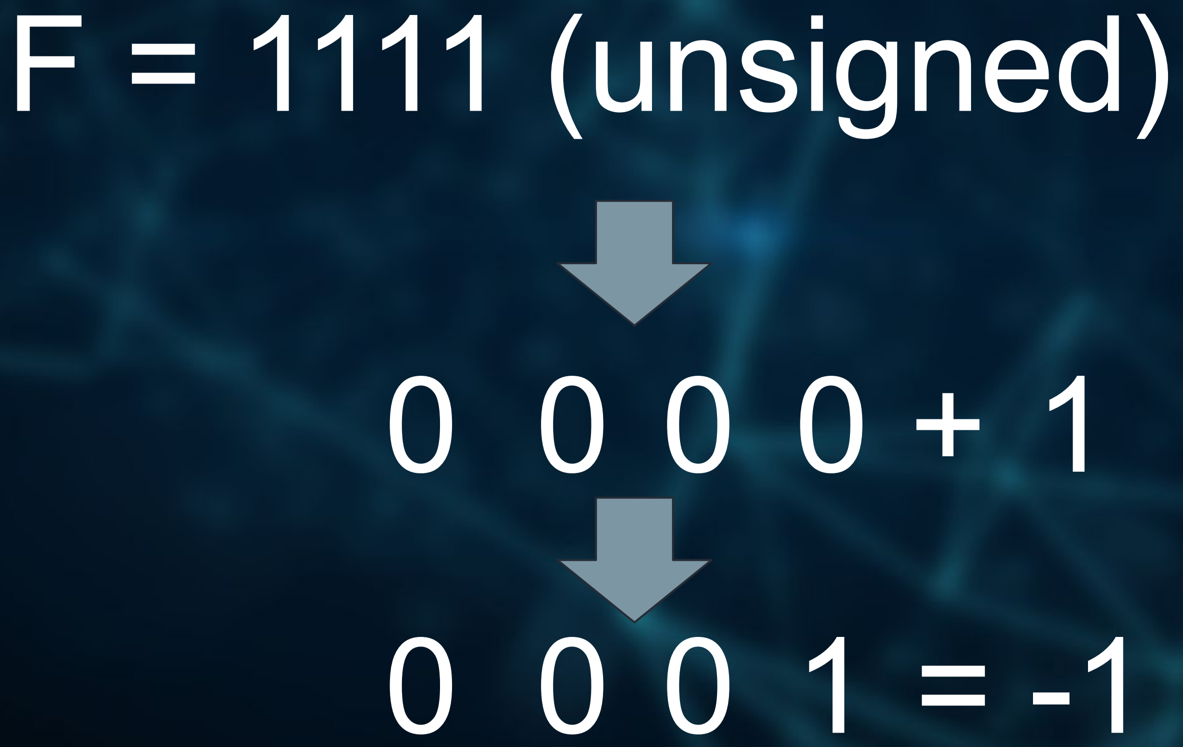


Bits	Unsigned value	Signed value (Two's complement)
000	0	0
001	1	1
010	2	2
011	3	3
100	4	−4
101	5	−3
110	6	−2
111	7	−1

Source: https://en.wikipedia.org/wiki/Two%27s_complement

SIGNED VS UNSIGNED INTEGERS

- Two’s Complement
    - Example: 4 bit number



F = 1111 (unsigned)

0 0 0 0 + 1

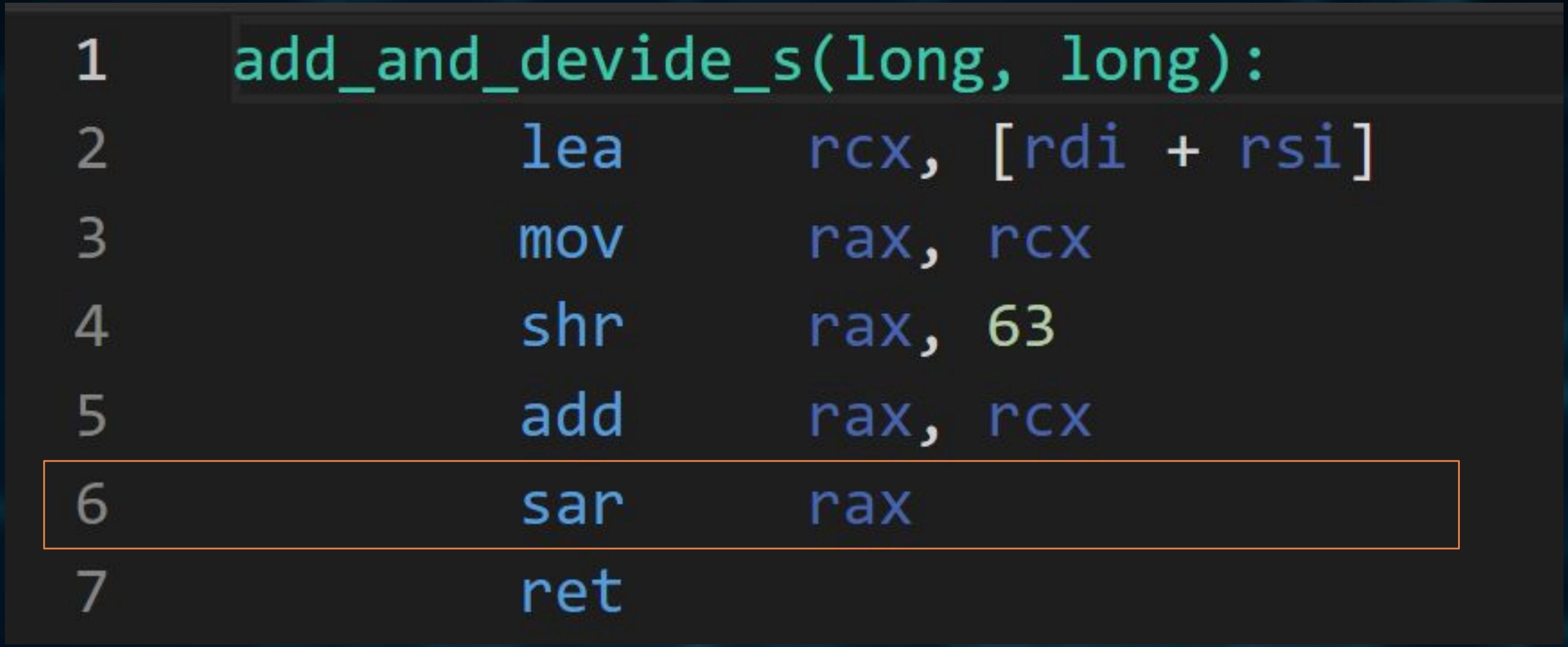
0 0 0 1 = -1

Source: https://en.wikipedia.org/wiki/Ones%27_complement

SIGNED VS UNSIGNED INTEGERS

- Positive numbers are represented in the same way for signed and unsigned
- Since C++20 negative numbers are represented only with Two’s complement

BACK TO OUR EXAMPLE: WHAT HAPPENED?



```
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        lea     rcx, [rdi + rsi]
        mov     rax, rcx
        shr     rax, 63
        add     rax, rcx
        sar     rax
        ret
```

DIFFERENCE BETWEEN SHR AND SAR

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SHR: Logical right shift means shifting the bits to the right and **MSB** becomes 0.

Example: shr **1** 0 1 1 0 1 1 1 = **0** 1 0 1 1 0 1 1

DIFFERENCE BETWEEN SHR AND SAR

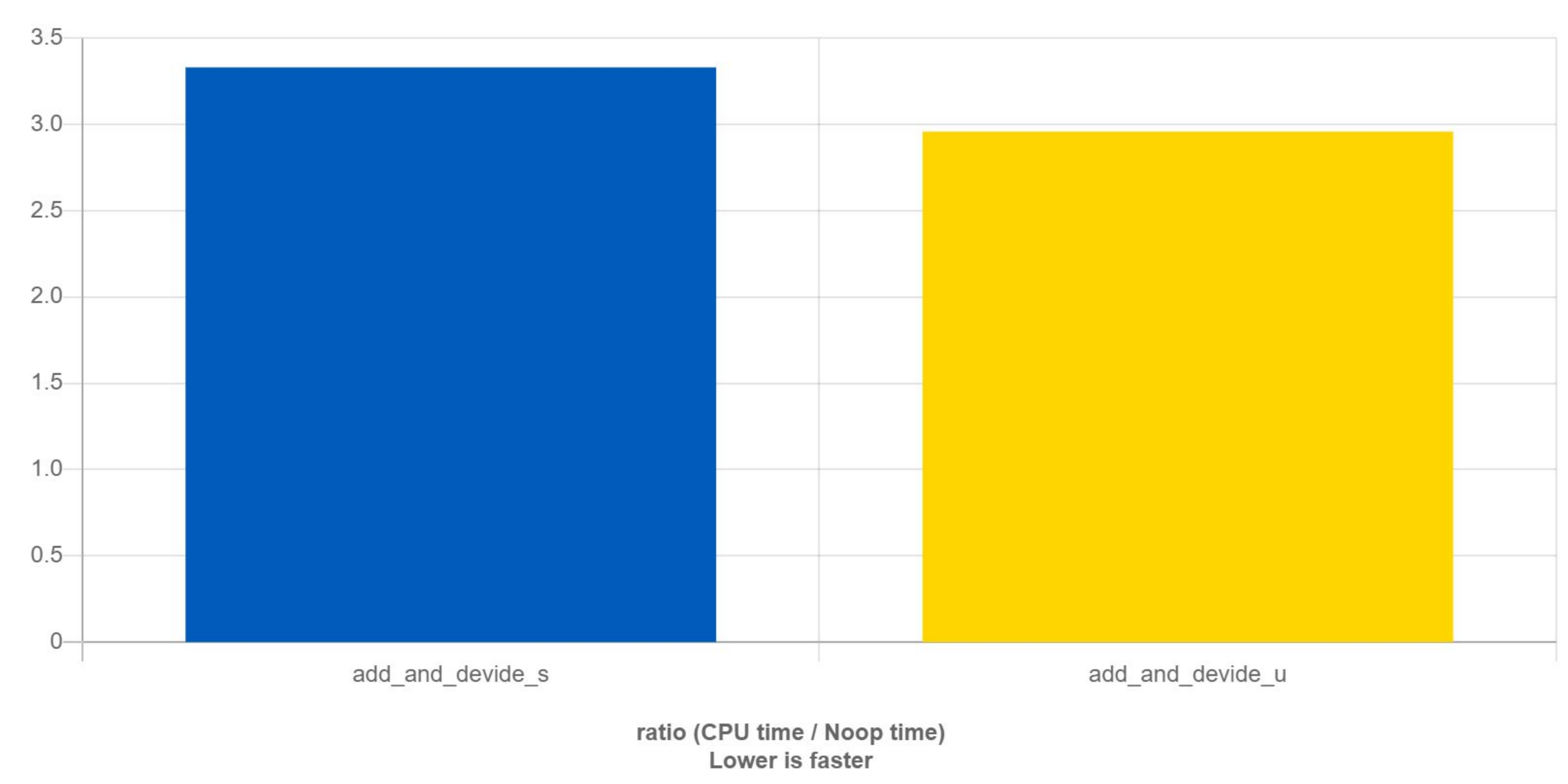
SAR: Arithmetic right shift means shifting the bits to the right and **MSB** bit is same as in the original number.

Example: sar **1** 0 1 1 0 1 0 1 = **1** 1 0 1 1 0 1 0.

BACK TO OUR EXAMPLE: WHAT HAPPENED?

```
add_
                    i]
```

BACK TO OUR EXAMPLE: PERFORMANCE



SIGNED AND UNSIGNED PITFALLS

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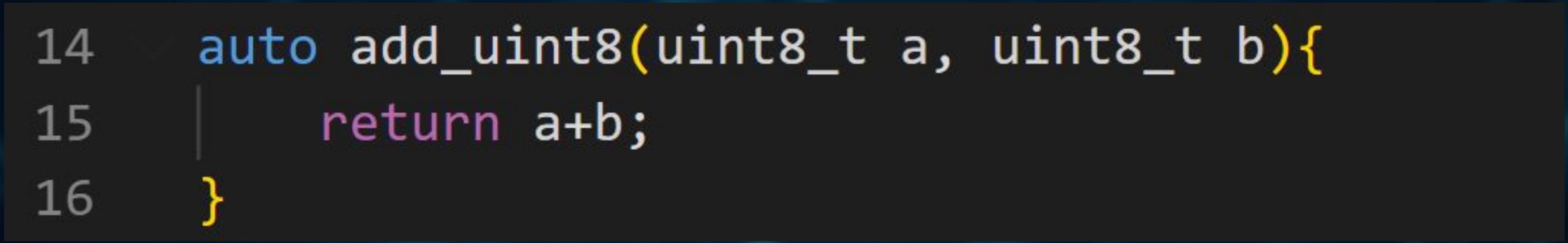
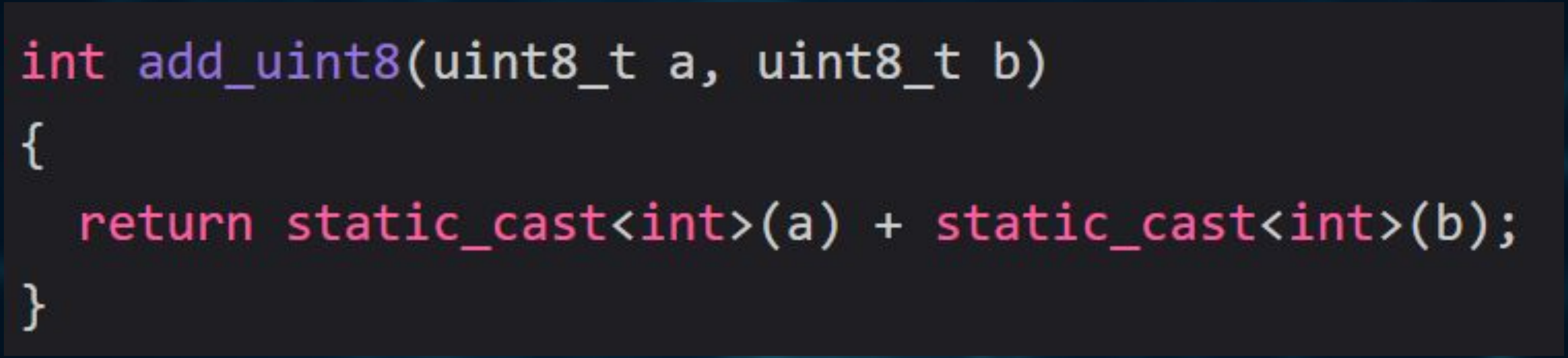


```
auto add_uint8(uint8_t a, uint8_t b){
    return a+b;
}
```

- what will the result be if we call add_uint8(255u, 1u)?

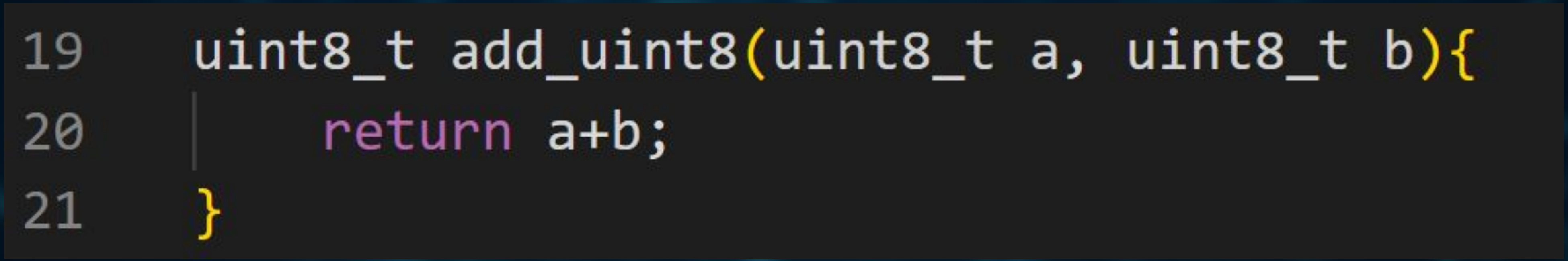
SURPRISE AGAIN: INTEGER PROMOTION



```
int add_uint8(uint8_t a, uint8_t b)
{
  return static_cast<int>(a) + static_cast<int>(b);
}
```

256

SIGNED AND UNSIGNED PITFALLS:



```
uint8_t add_uint8(uint8_t a, uint8_t b){
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}
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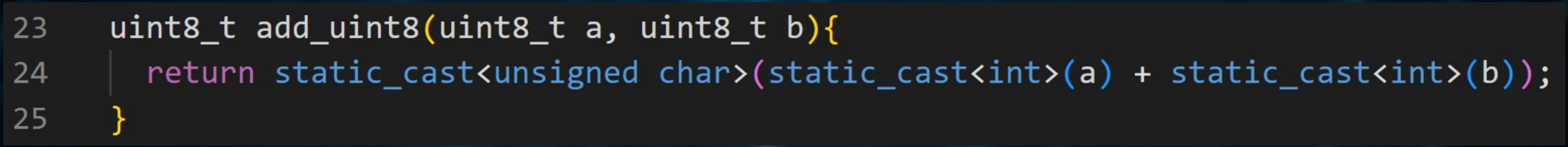
- what will be the result if we will call add_uint8(255u, 1u) ?

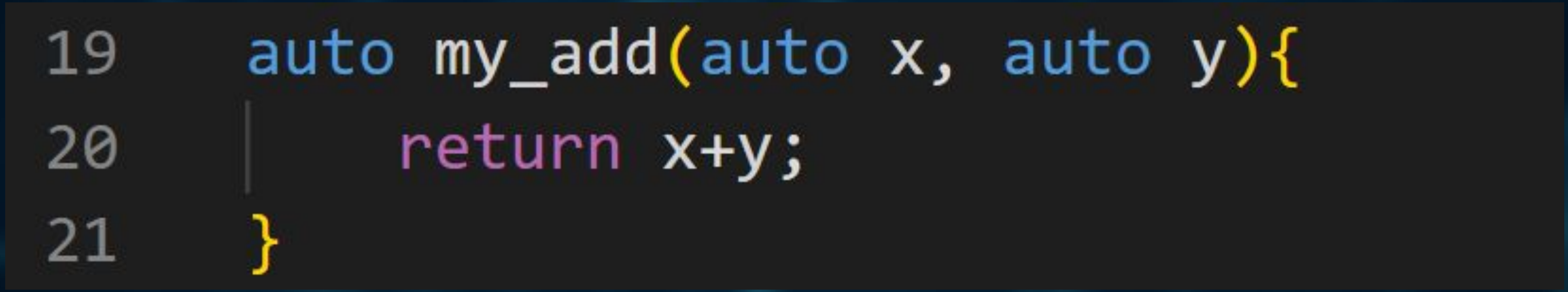
INTEGER NARROWING



```
uint8_t add_uint8(uint8_t a, uint8_t b){
  return static_cast<unsigned char>(static_cast<int>(a) + static_cast<int>(b));
}
```

0

SURPRISE AGAIN: WAIT THAT’S NOT ALL

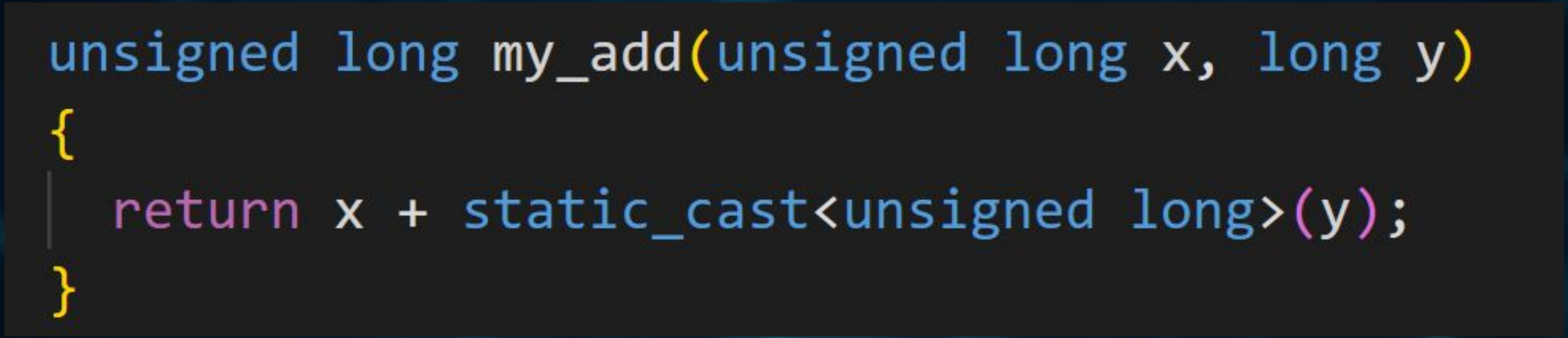


```
auto my_add(auto x, auto y){
    return x+y;
}
```

- what will be the result if we will call

  my_add(uint64_t(1), int64_t(-2)) ?

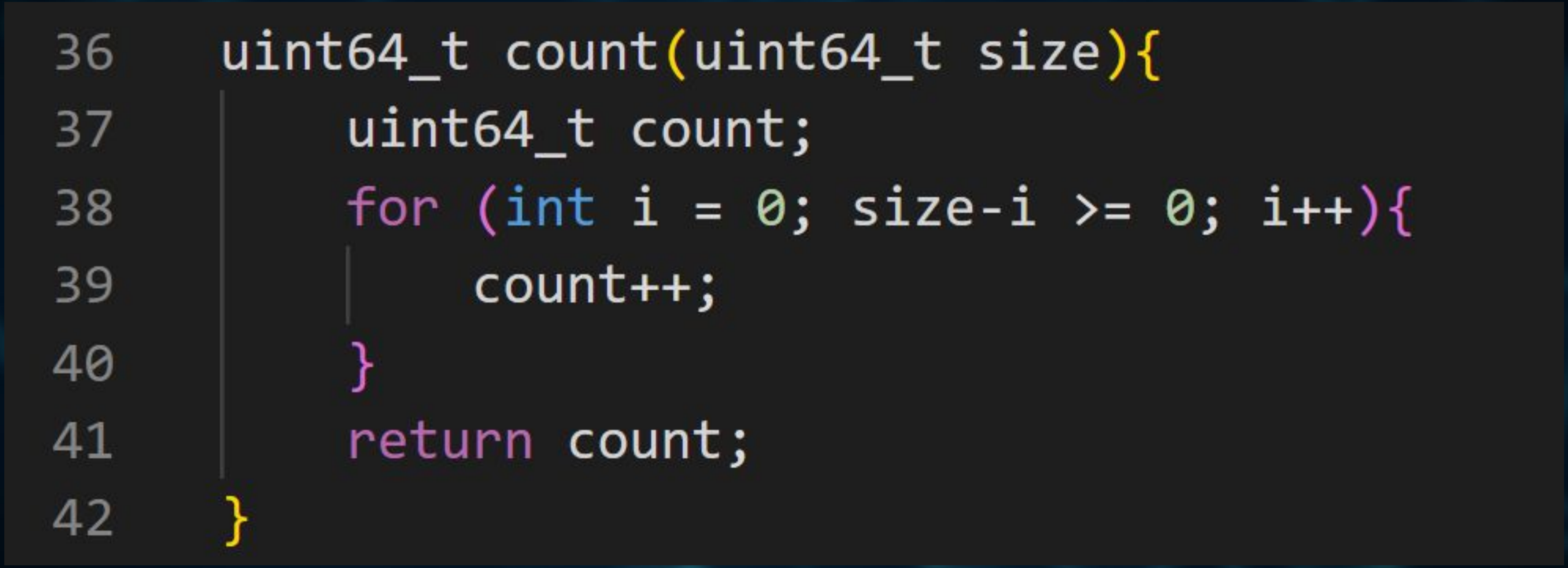
SURPRISE AGAIN: MORE INTEGER PROMOTION



```
unsigned long my_add(unsigned long x, long y)
{
  return x + static_cast<unsigned long>(y);
}
```

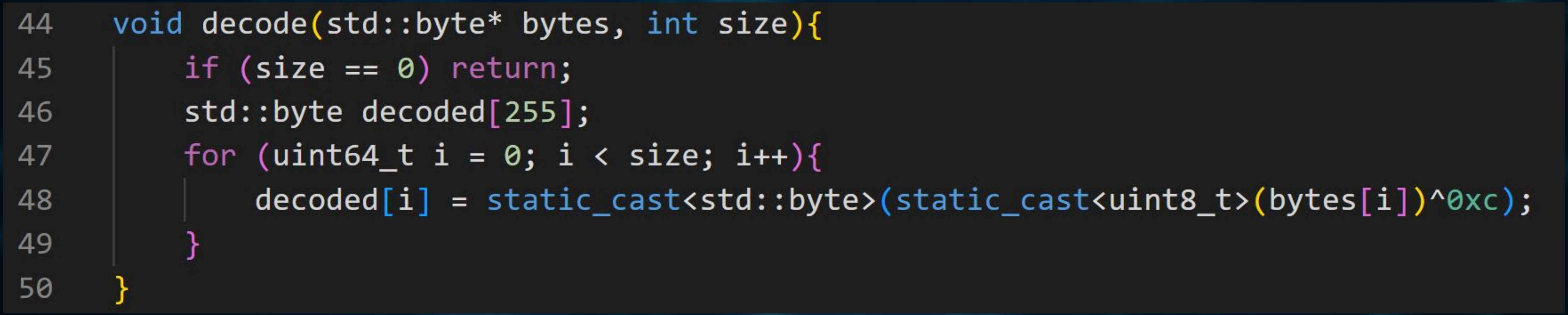
18446744073709551615

MIXING INTEGER TYPES MAY CAUSE HORRIBLE BUGS



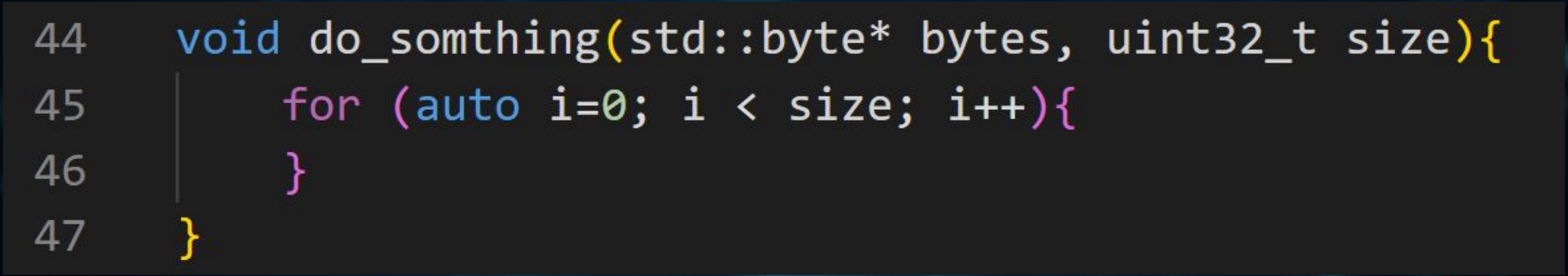
```
uint64_t count(uint64_t size){
    uint64_t count;
    for (int i = 0; size-i >= 0; i++){
        count++;
    }
    return count;
}
```

MIXING INTEGER TYPES MAY CAUSE HORRIBLE BUGS



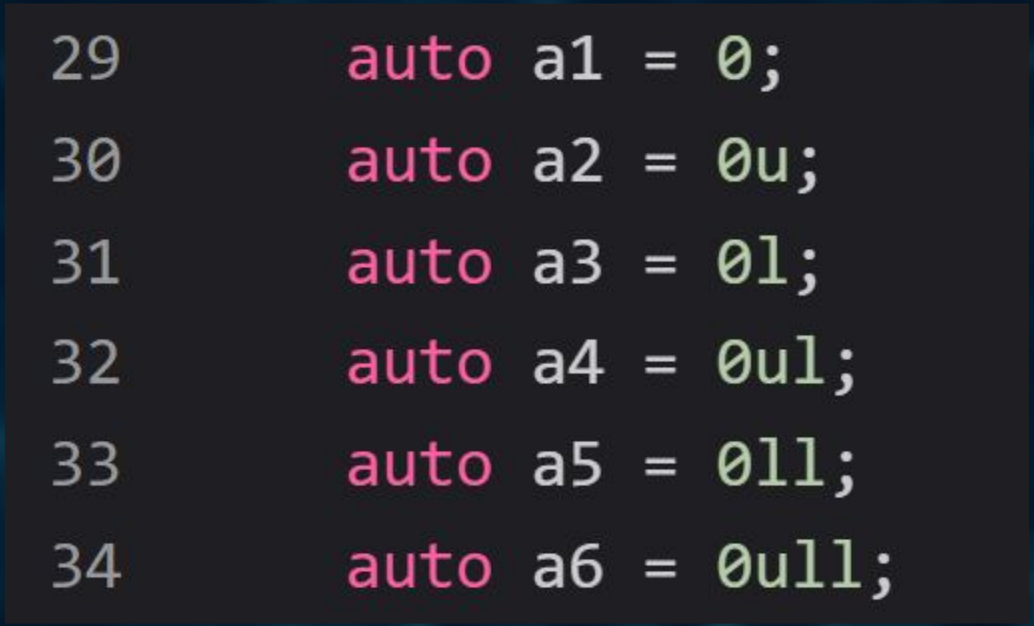
```cpp
void decode(std::byte* bytes, int size){
    if (size == 0) return;
    std::byte decoded[255];
    for (uint64_t i = 0; i < size; i++){
        decoded[i] = static_cast<std::byte>(static_cast<uint8_t>(bytes[i])^0xc);
    }
}
```

BEWARE OF THIS PATTERN



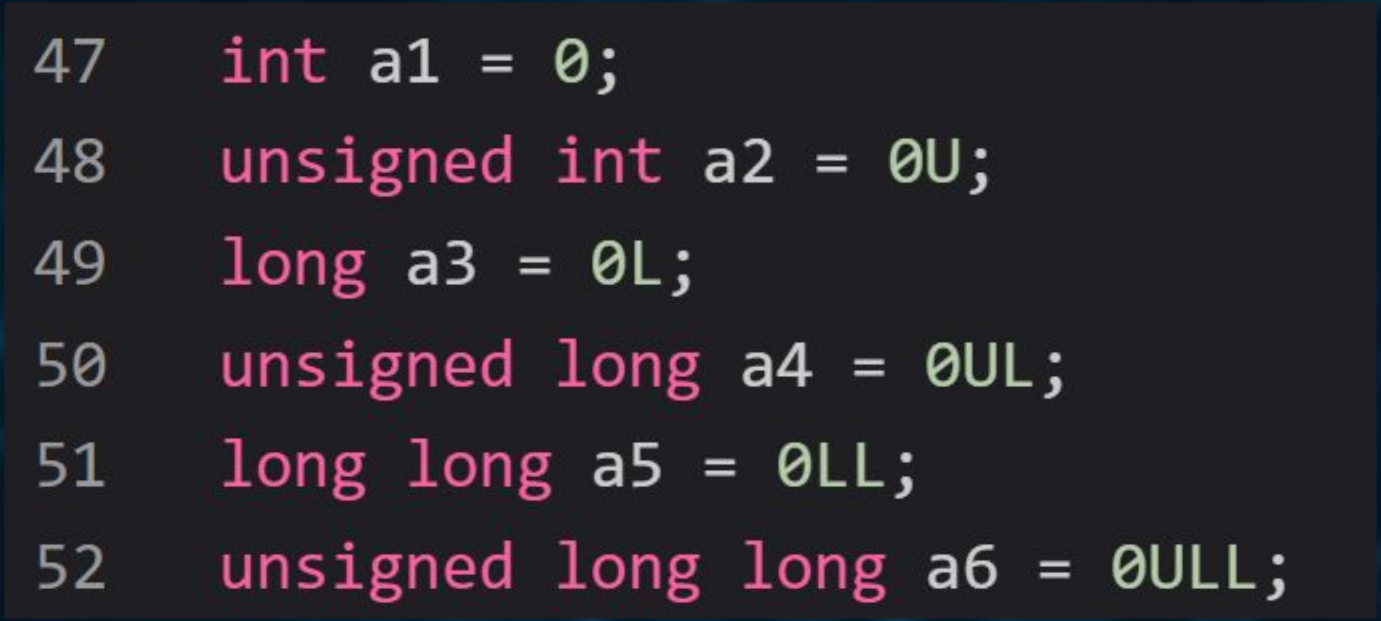
```
void do_somthing(std::byte* bytes, uint32_t size){
    for (auto i=0; i < size; i++){
    }
}
```

AUTO IS GREAT: USE IT DON’T ABUSE IT



```cpp
        auto a1 = 0;
        auto a2 = 0u;
        auto a3 = 0l;
        auto a4 = 0ul;
        auto a5 = 0ll;
        auto a6 = 0ull;
```

AUTO IS GREAT: USE IT DON'T ABUSE IT



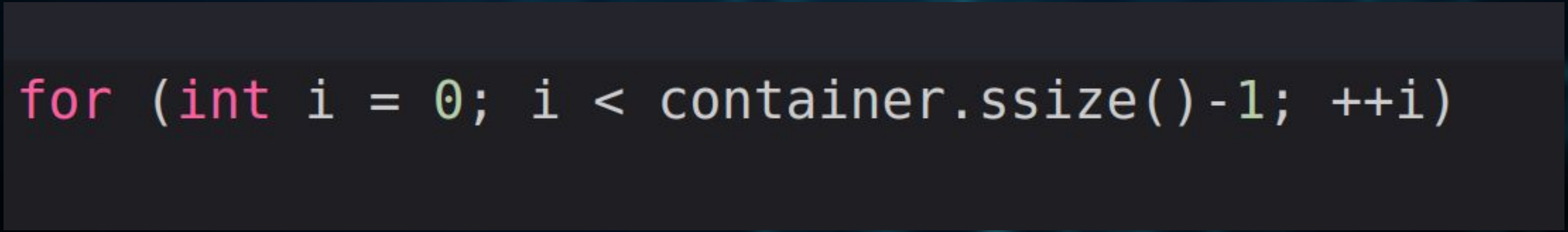
```
int a1 = 0;
unsigned int a2 = 0U;
long a3 = 0L;
unsigned long a4 = 0UL;
long long a5 = 0LL;
unsigned long long a6 = 0ULL;
```

SIZE_T AND SSIZE_T

- **size_t:**
  - Unsigned integer
  - Used for size operations
  - Defined in cstddef
  - size_t limit is SIZE_MAX
  - Introduced in C89 to eliminate portability problems

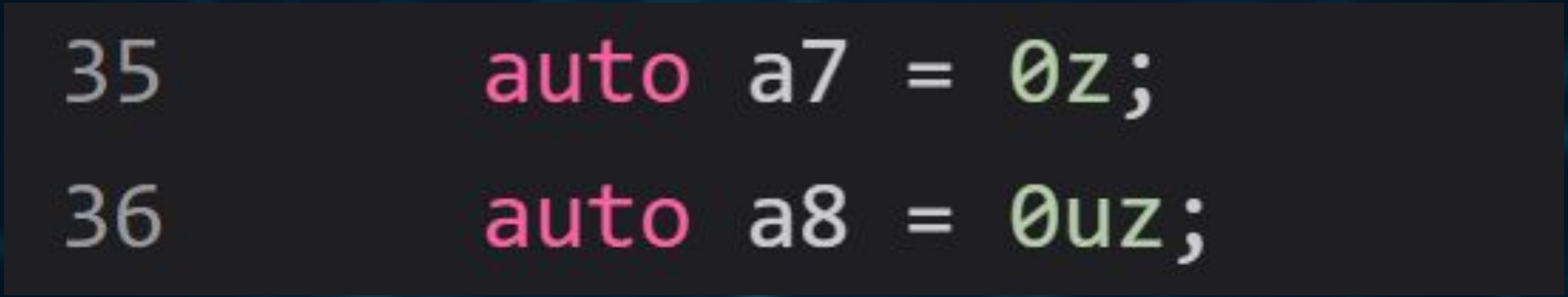
SIZE_T AND SSIZE_T

- **ssize_t:**
  - Signed version of size_t
  - Defined by POSIX.1-2017
  - Represent at least the range [-1,{SSIZE_MAX}].



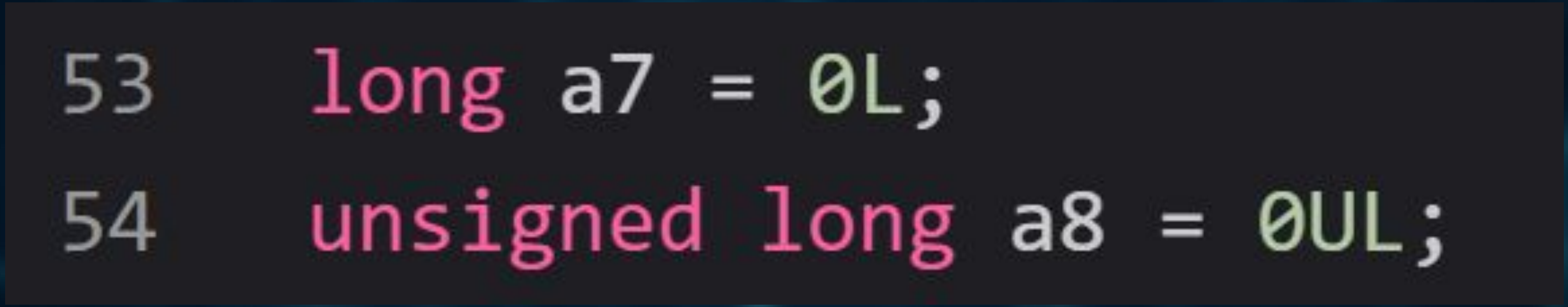
```
for (int i = 0; i < container.ssize()-1; ++i)
```

AUTO IS GREAT: USE IT DON’T ABUSE IT (C++23 ADDITIONS)



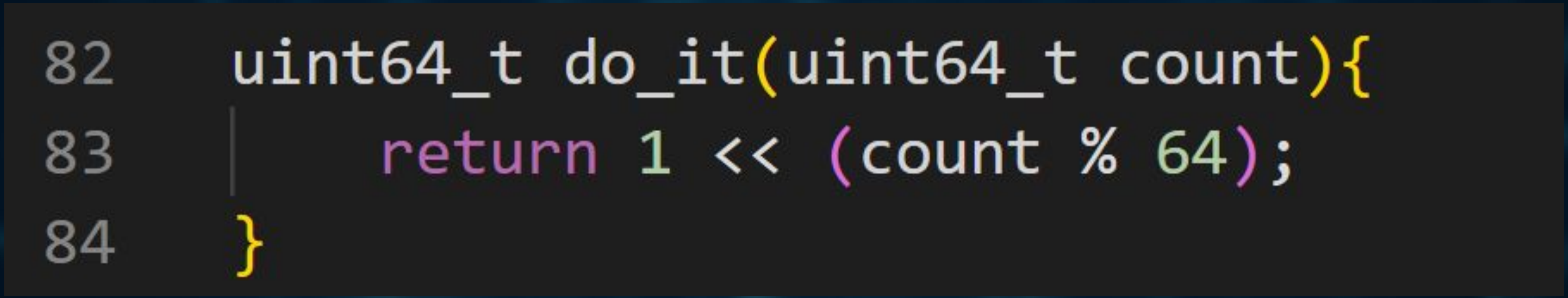
```
    auto a7 = 0z;
    auto a8 = 0uz;
```

AUTO IS GREAT: USE IT DON’T ABUSE IT (C++23 ADDITIONS)



```
long a7 = 0L;
unsigned long a8 = 0UL;
```

POP QUIZ ☺



```
uint64_t do_it(uint64_t count){
    return 1 << (count % 64);
}
```

MORE COMPLEX EXAMPLE: ARITHMETIC SERIES

MORE COMPLEX EXAMPLE: ARITHMETIC SERIES

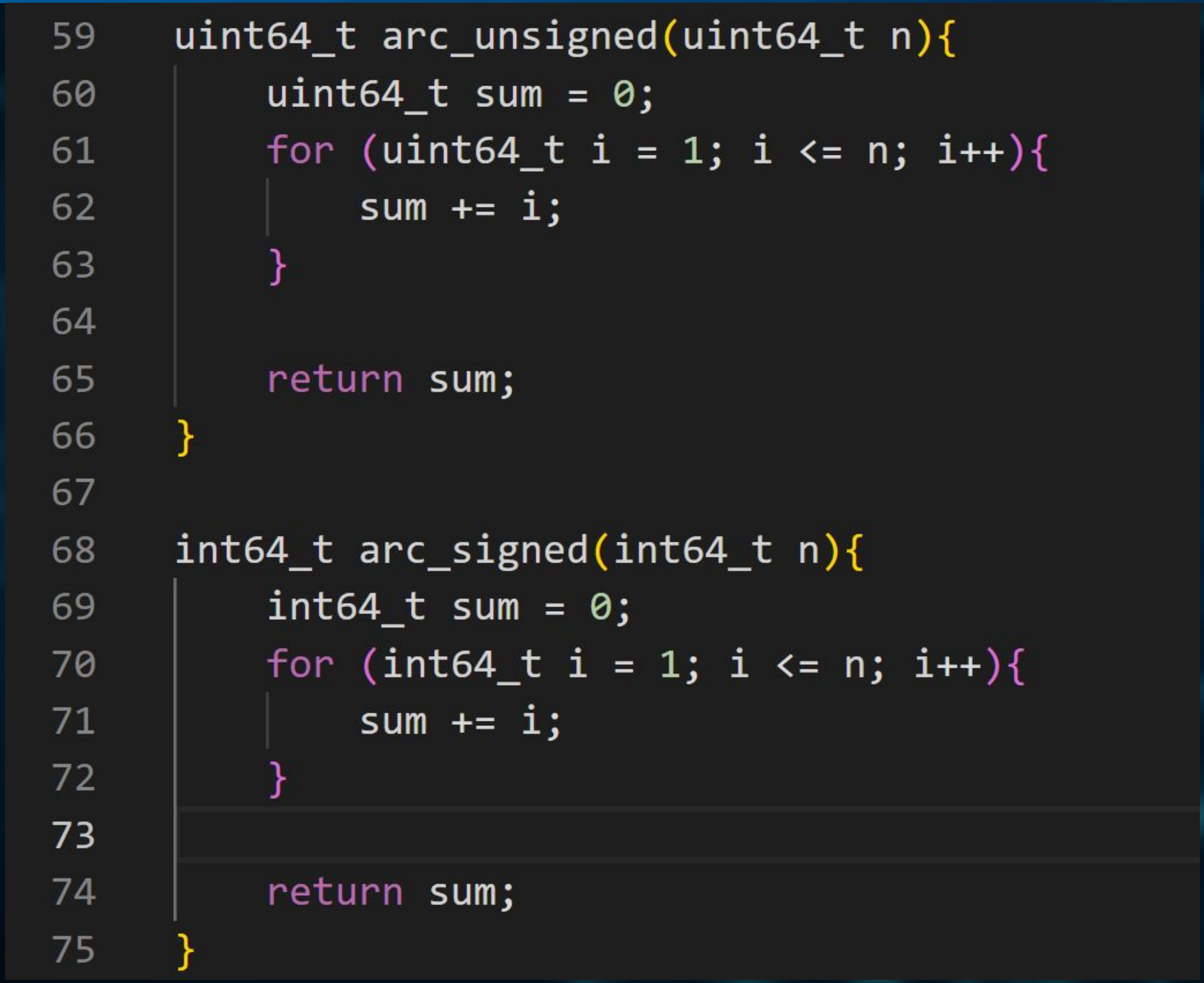
- Series of numbers where the difference between any two sequential numbers is constant.

For example, *1,2,3,4,5,6,7,8,9,10,…,n* is an **Arithmetic Series** where the difference between any two sequential numbers is *1*.

MORE COMPLEX EXAMPLE: ARITHMETIC SERIES

$$\sum_{k=1}^{n} a_k = \frac{n(a_1 + \ a_n)}{2}$$

MORE COMPLEX EXAMPLE: ARITHMETIC SERIES



```
uint64_t arc_unsigned(uint64_t n){
    uint64_t sum = 0;
    for (uint64_t i = 1; i <= n; i++){
        sum += i;
    }

    return sum;
}

int64_t arc_signed(int64_t n){
    int64_t sum = 0;
    for (int64_t i = 1; i <= n; i++){
        sum += i;
    }

    return sum;
}
```

MORE COMPLEX EXAMPLE: UNSIGNED ASSEMBLY

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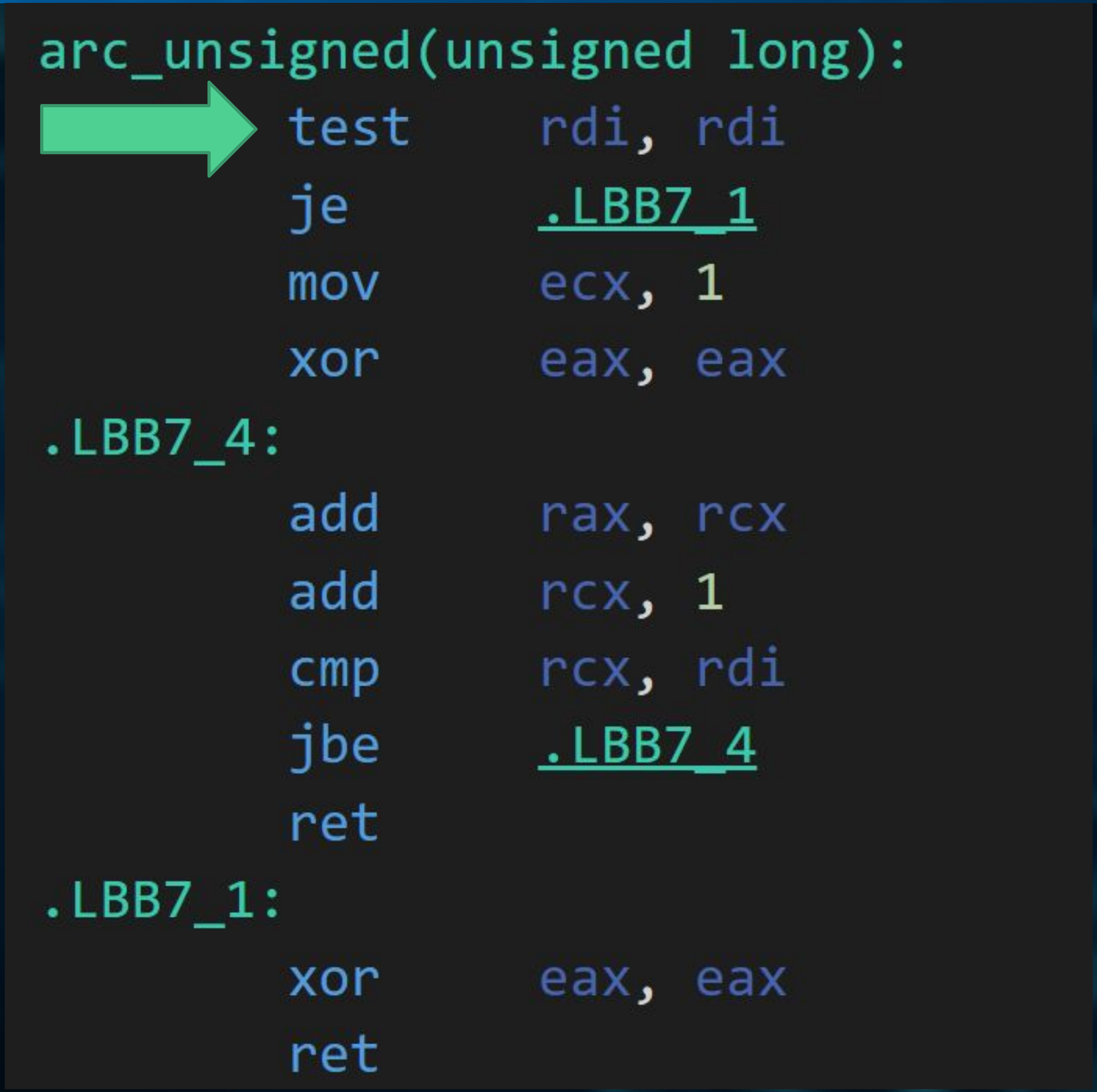

```
arc_unsigned(unsigned long):
        test    rdi, rdi
        je      .LBB7_1
        mov     ecx, 1
        xor     eax, eax
.LBB7_4:
        add     rax, rcx
        add     rcx, 1
        cmp     rcx, rdi
        jbe     .LBB7_4
        ret
.LBB7_1:
        xor     eax, eax
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```
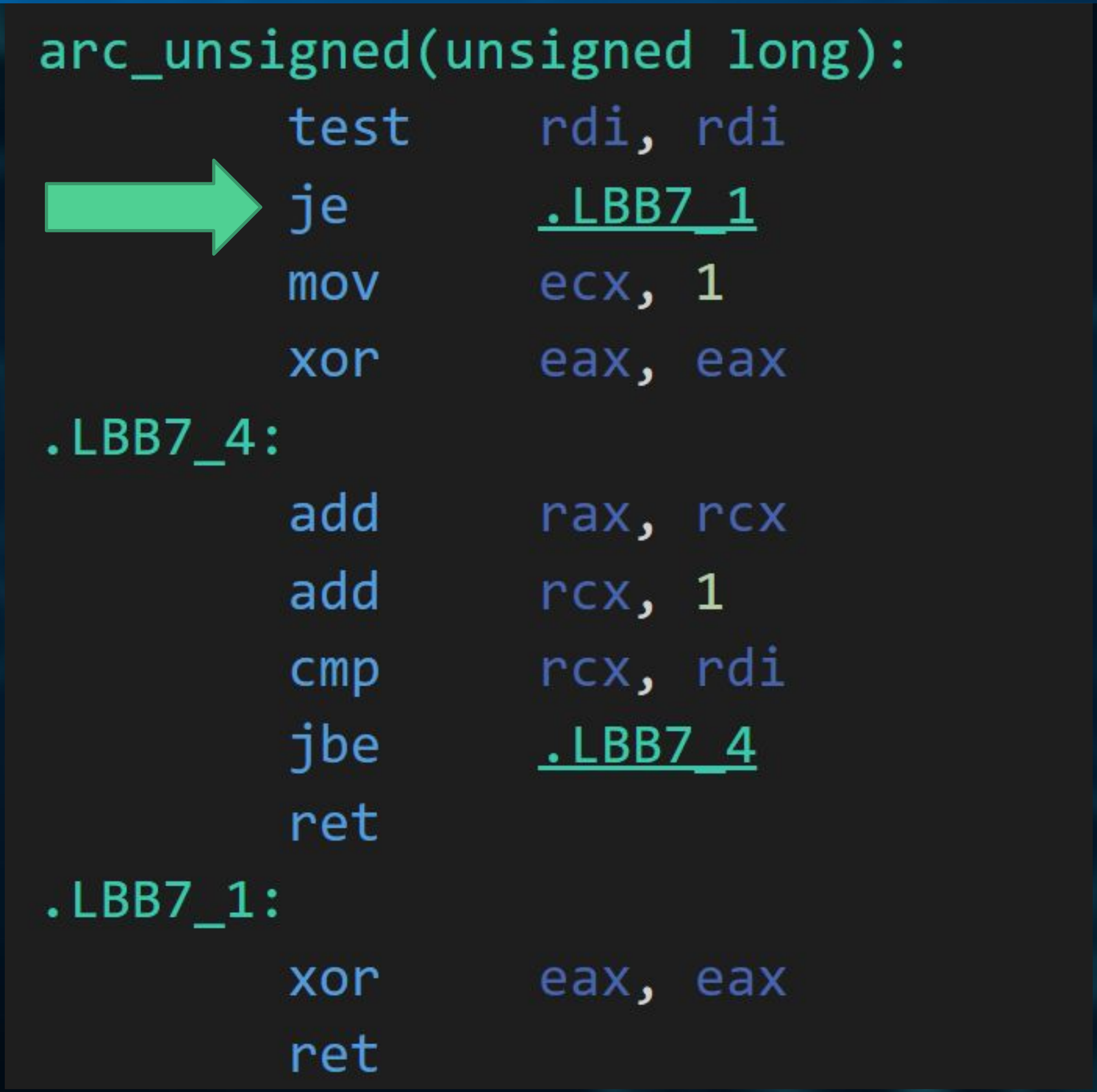

MORE COMPLEX EXAMPLE: UNSIGNED ASSEMBLY



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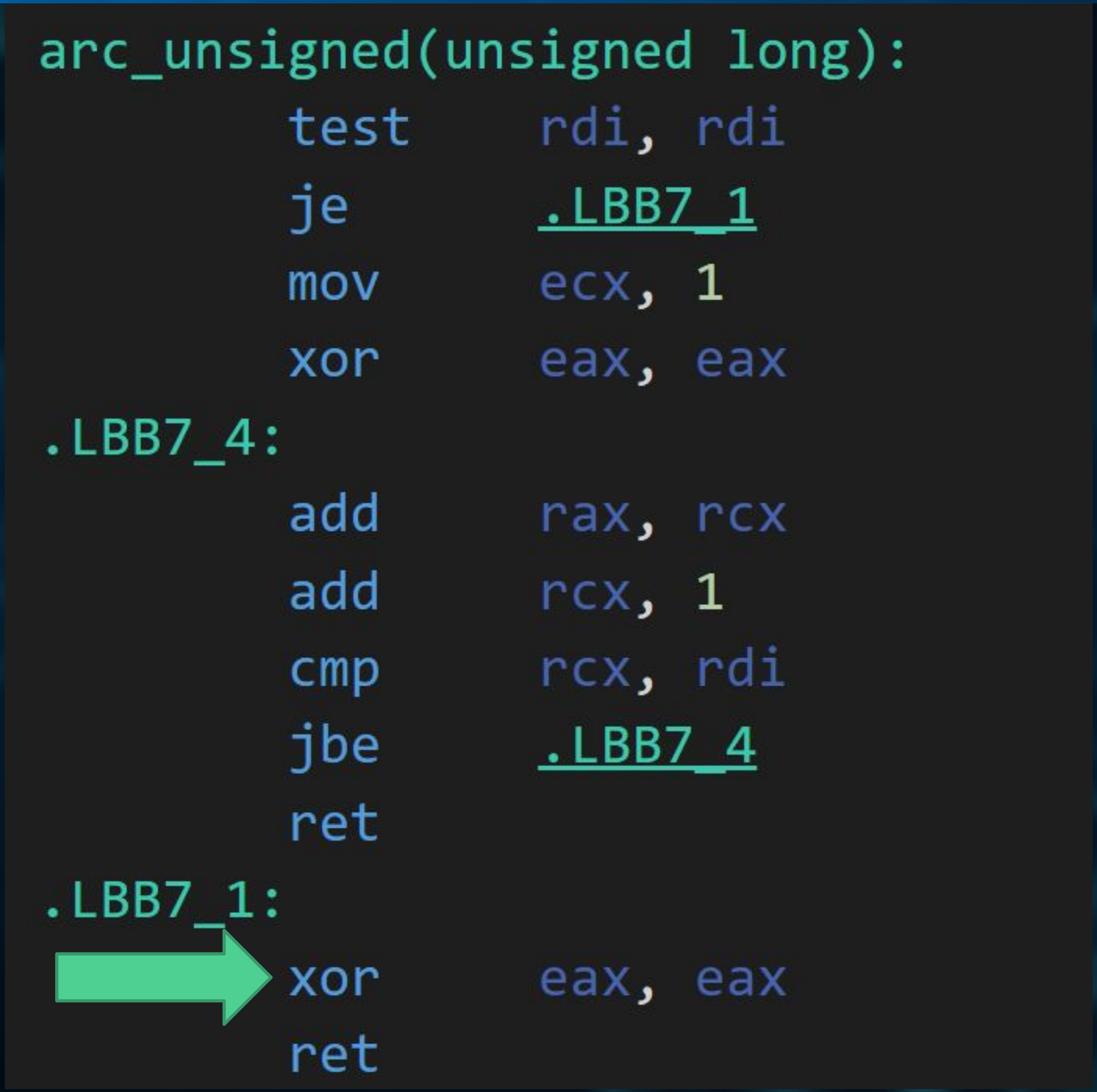

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.LBB7_4:
        add     rax, rcx
        add     rcx, 1
        cmp     rcx, rdi
        jbe     .LBB7_4
        ret
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        xor     eax, eax
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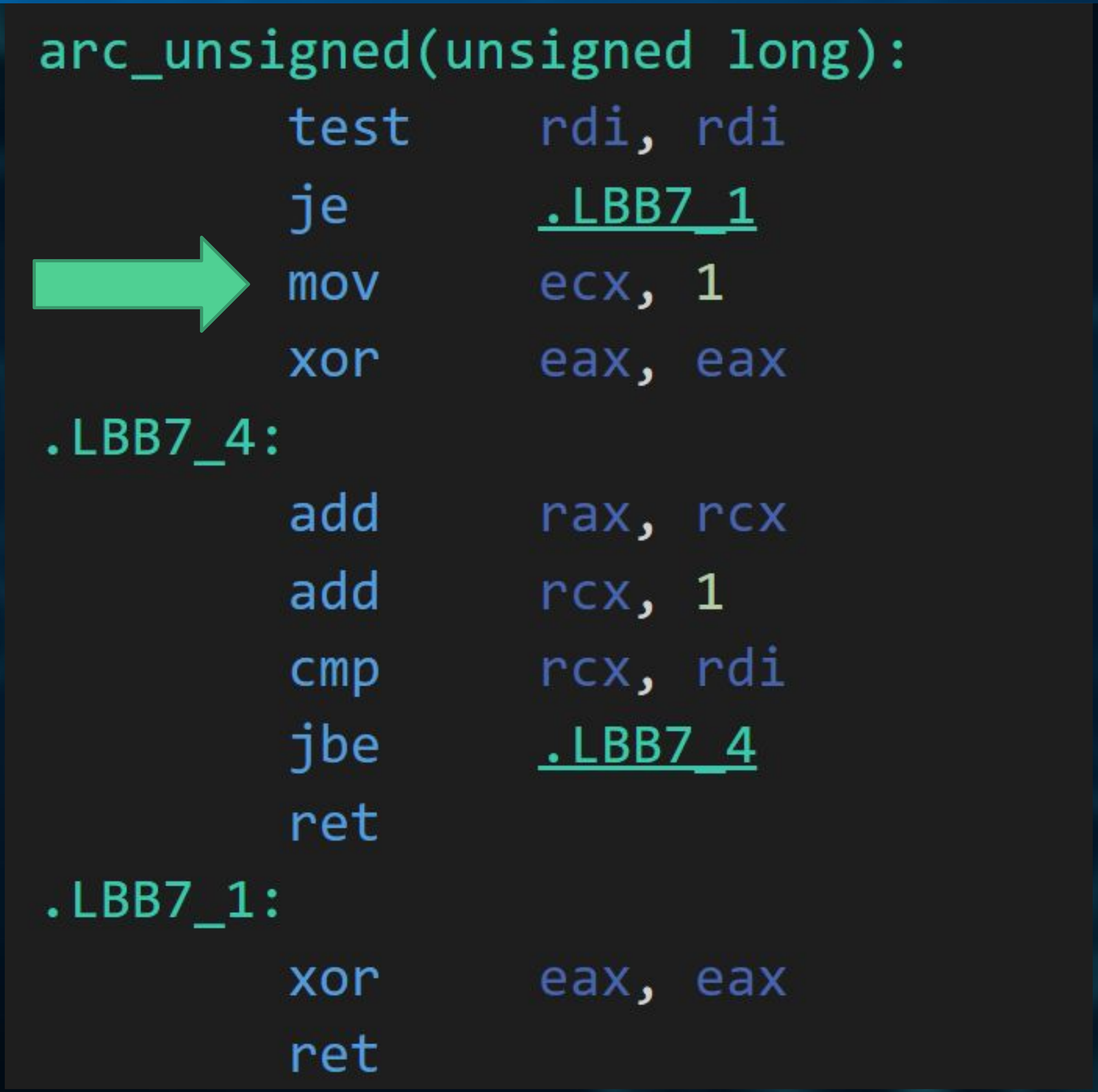

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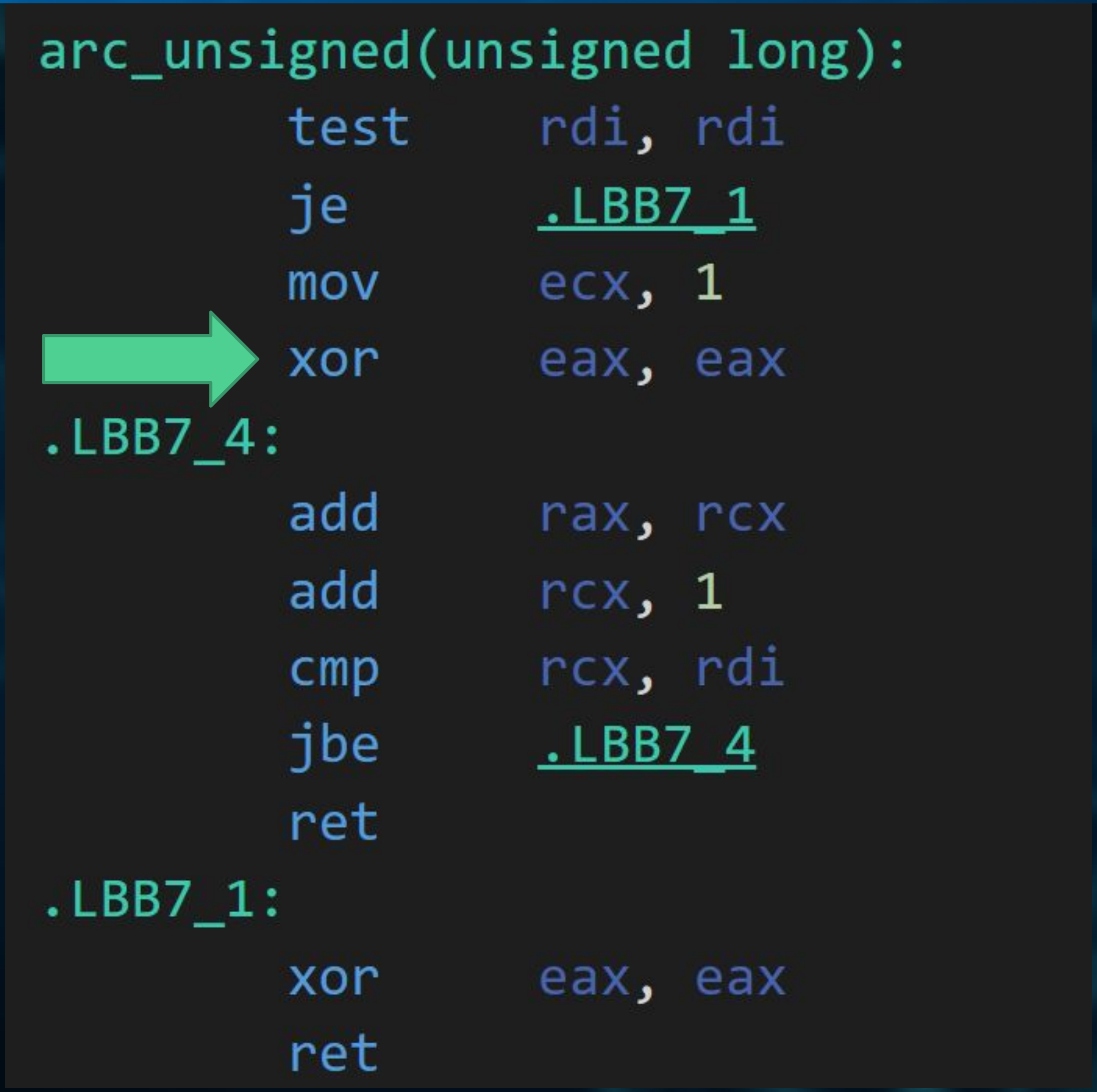

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        je      .LBB7_1
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        xor     eax, eax
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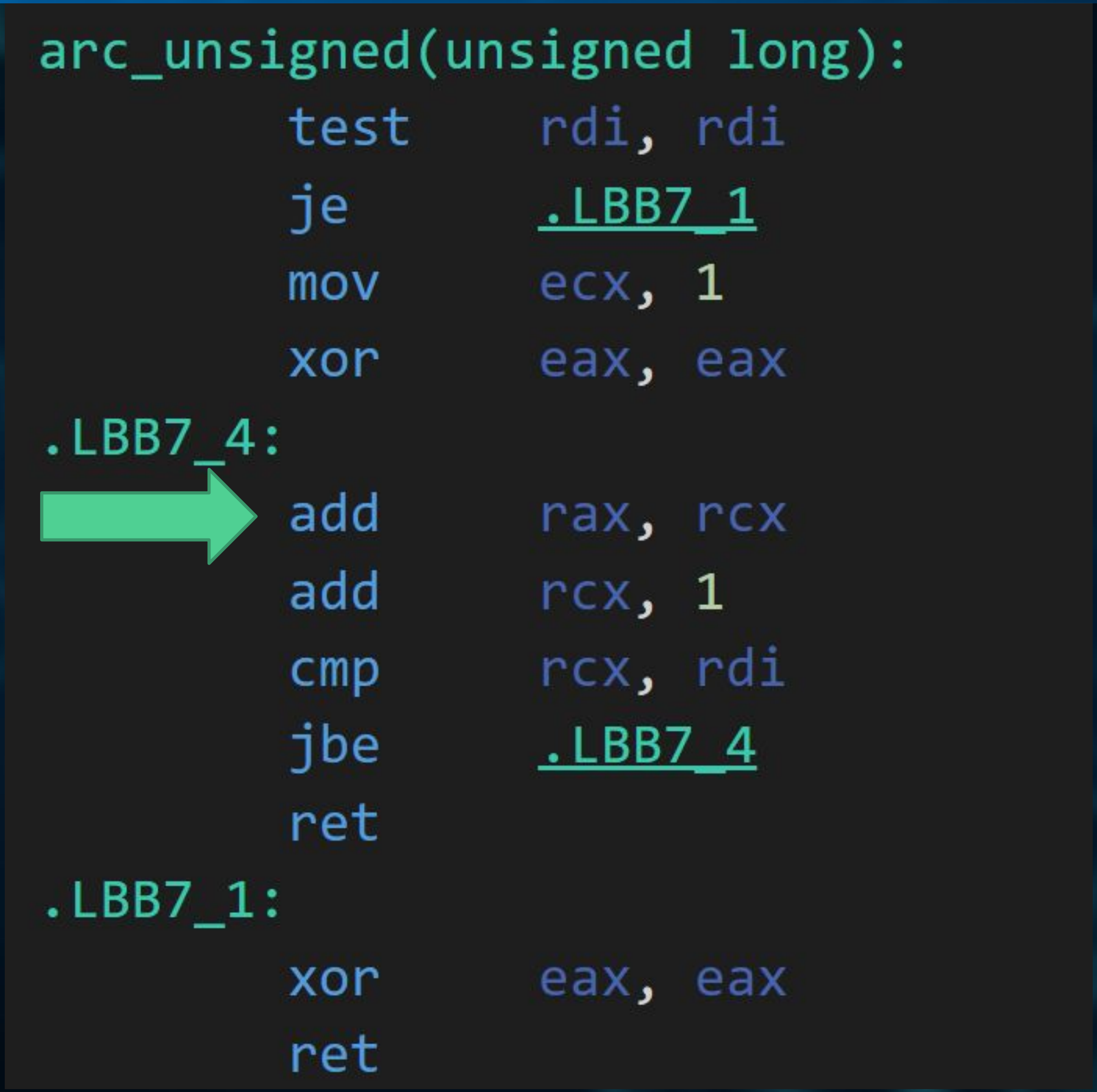
        add     rax, rcx
        add     rcx, 1
        cmp     rcx, rdi
        jbe     .LBB7_4
        ret
.LBB7_1:
        xor     eax, eax
        ret
```

MORE COMPLEX EXAMPLE: UNSIGNED ASSEMBLY



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        add     rcx, 1
        cmp     rcx, rdi
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        ret
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        xor     eax, eax
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```

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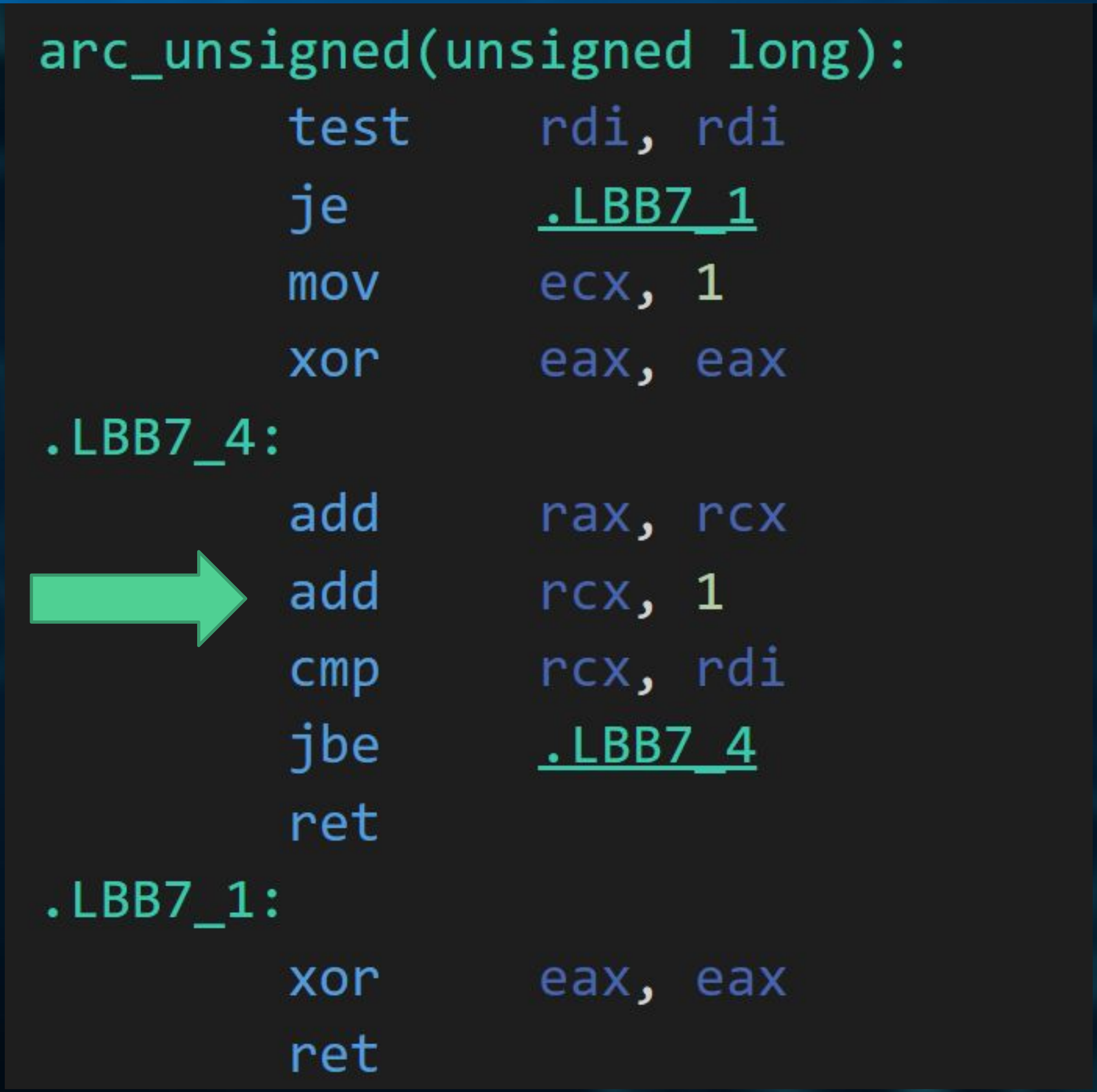

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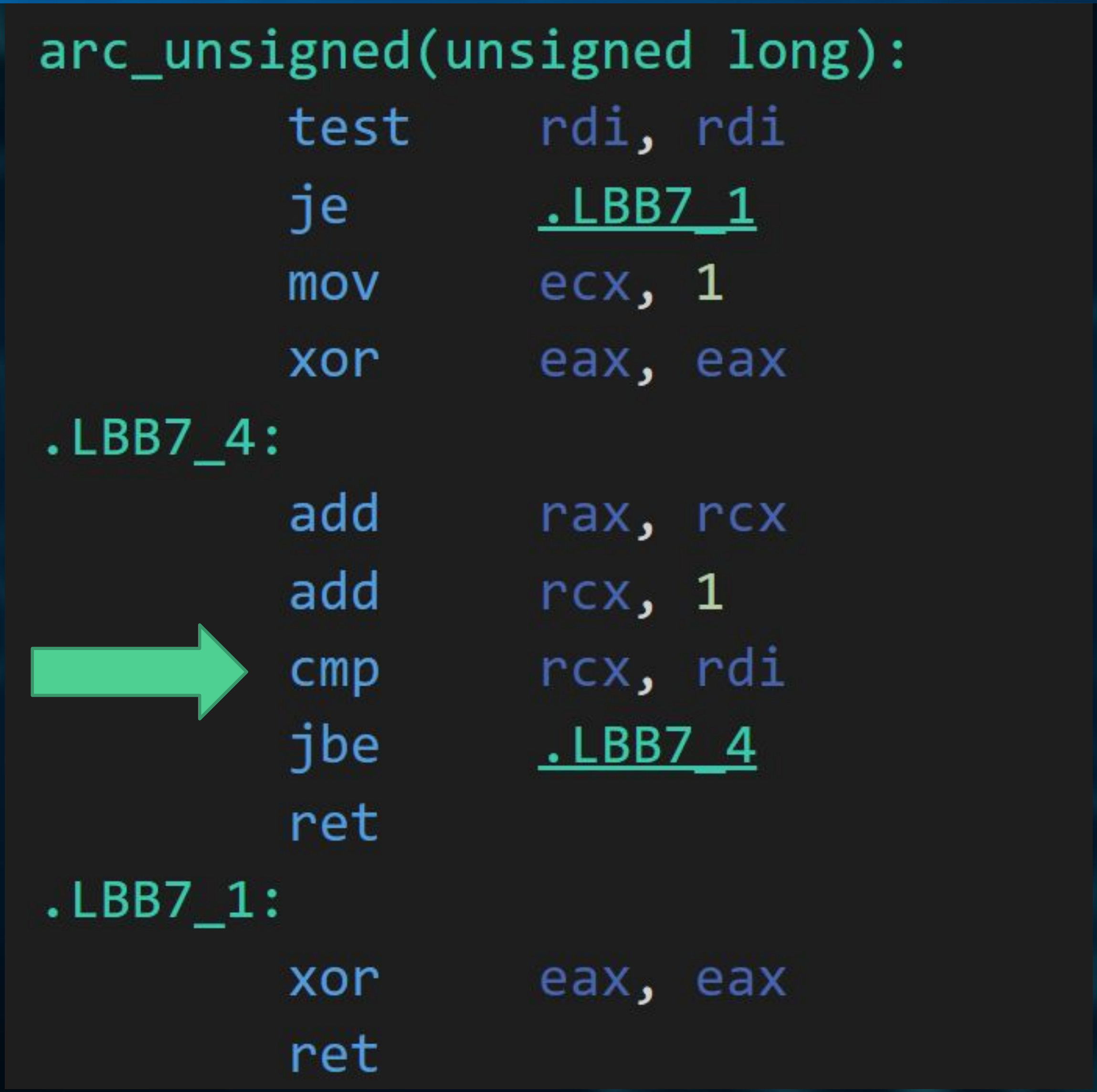
        mov     ecx, 1
        xor     eax, eax
.LBB7_4:
        add     rax, rcx
        add     rcx, 1
        cmp     rcx, rdi
        jbe     .LBB7_4
        ret
.LBB7_1:
        xor     eax, eax
        ret
```

MORE COMPLEX EXAMPLE: UNSIGNED ASSEMBLY



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        cmp     rcx, rdi
        jbe     .LBB7_4
        ret
.LBB7_1:
        xor     eax, eax
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```
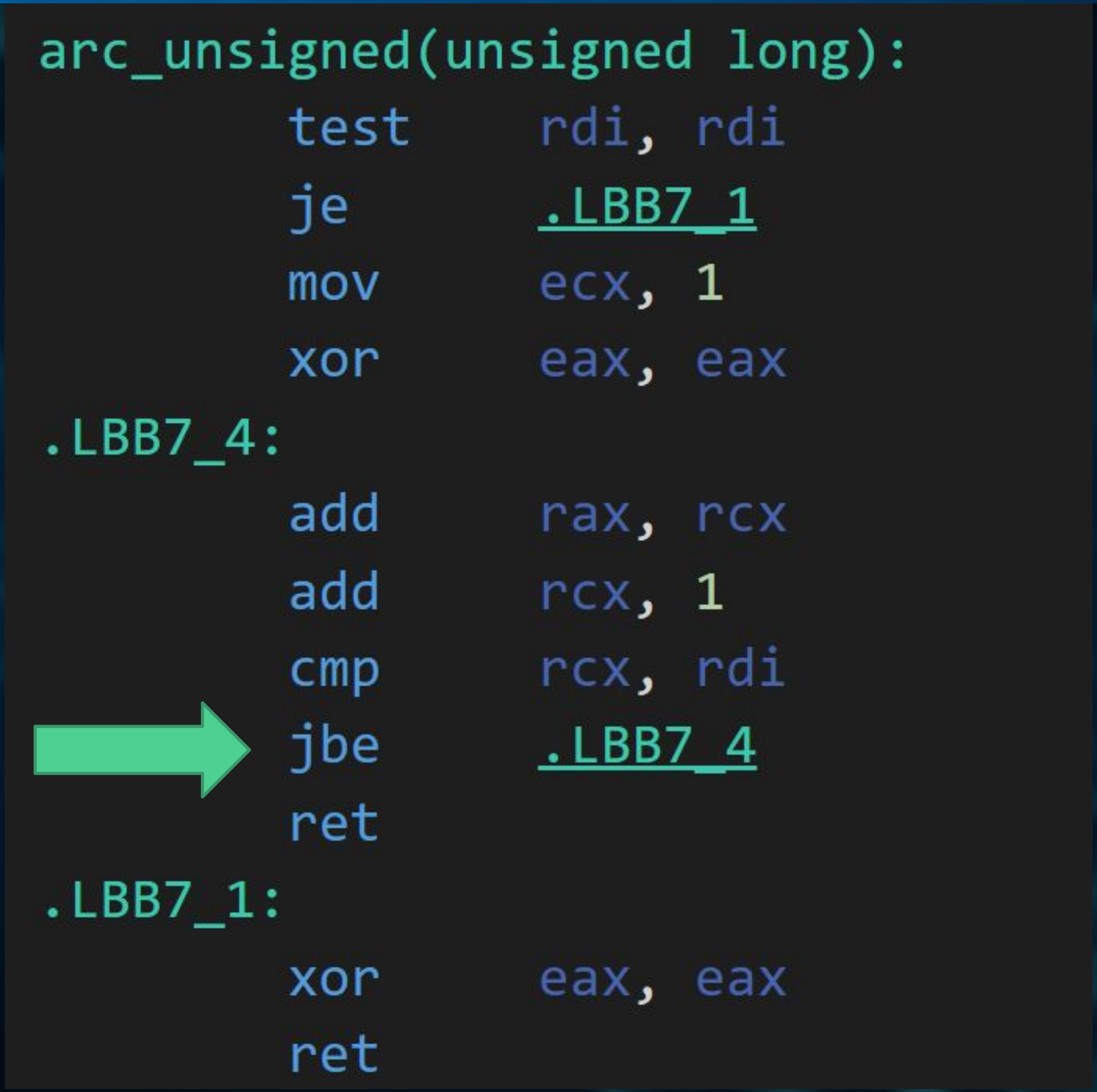
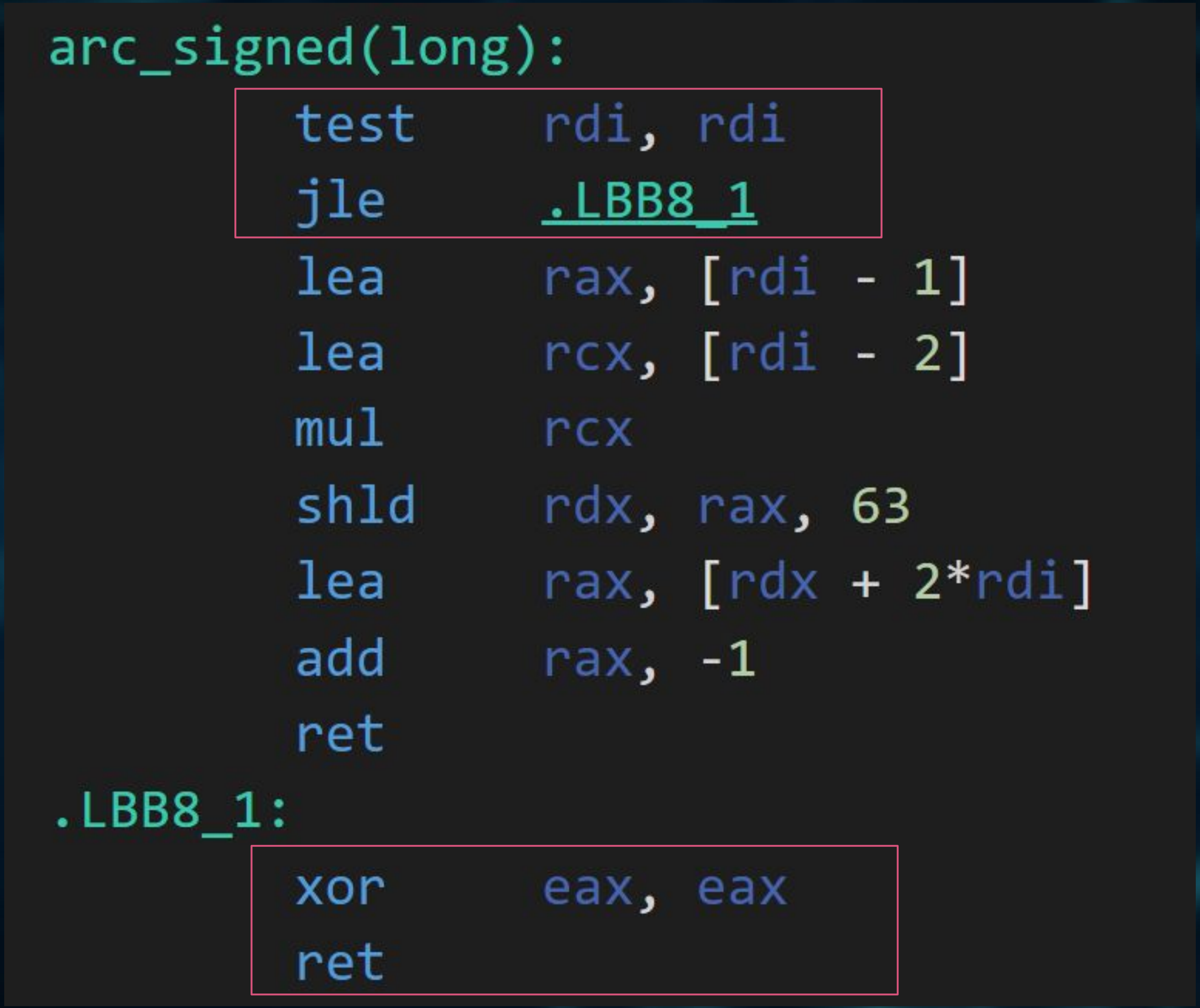

MORE COMPLEX EXAMPLE: UNSIGNED ASSEMBLY



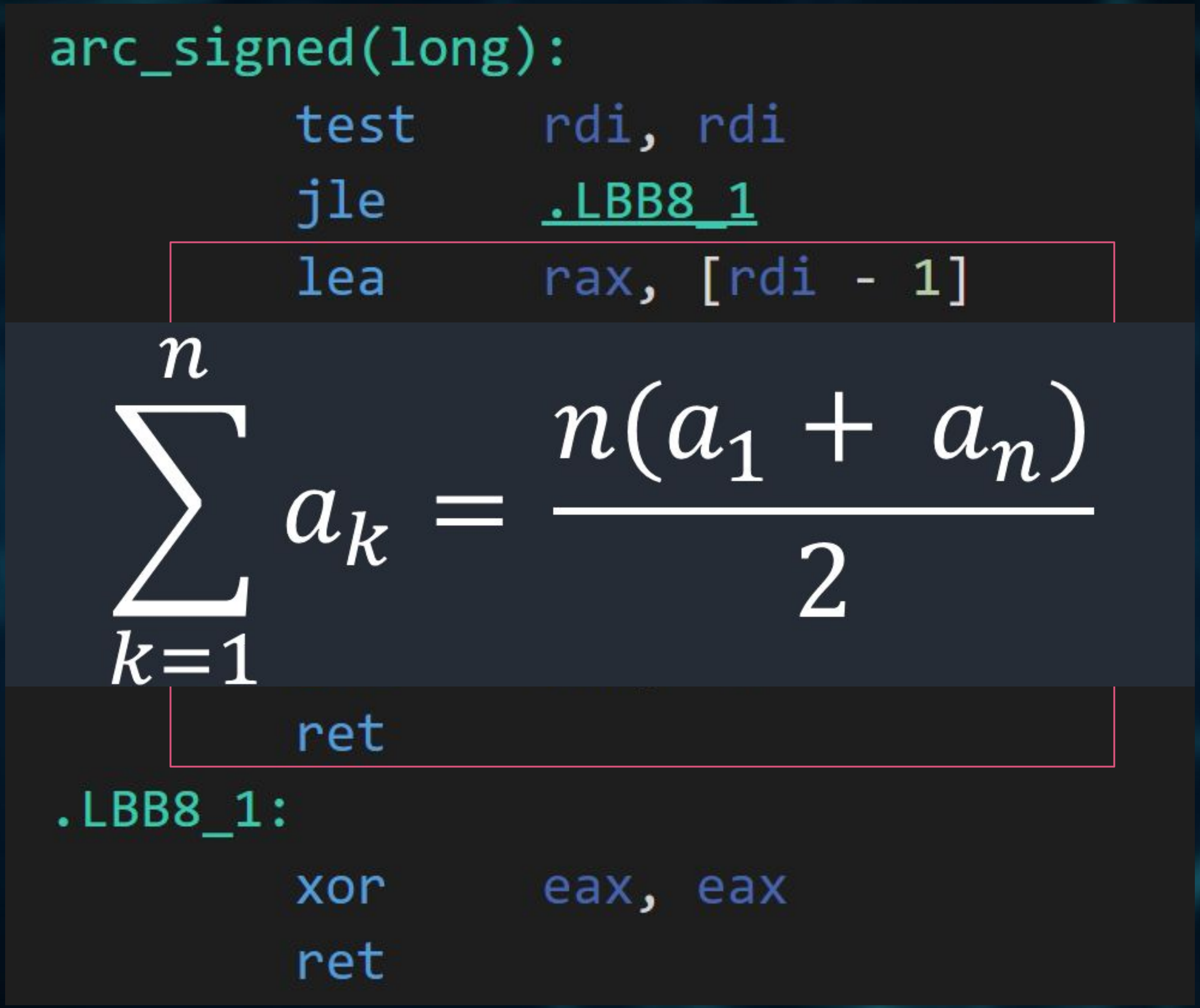
```
arc_unsigned(unsigned long):
        test    rdi, rdi
        je      .LBB7_1
        mov     ecx, 1
        xor     eax, eax
.LBB7_4:
        add     rax, rcx
        add     rcx, 1
        cmp     rcx, rdi
        jbe     .LBB7_4
        ret
.LBB7_1:
        xor     eax, eax
        ret
```

MORE COMPLEX EXAMPLE: SIGNED ASSEMBLY



```
arc_signed(long):
        test    rdi, rdi
        jle     .LBB8_1
        lea     rax, [rdi - 1]
        lea     rcx, [rdi - 2]
        mul     rcx
        shld    rdx, rax, 63
        lea     rax, [rdx + 2*rdi]
        add     rax, -1
        ret
.LBB8_1:
        xor     eax, eax
        ret
```

MORE COMPLEX EXAMPLE: UNSIGNED ASSEMBLY

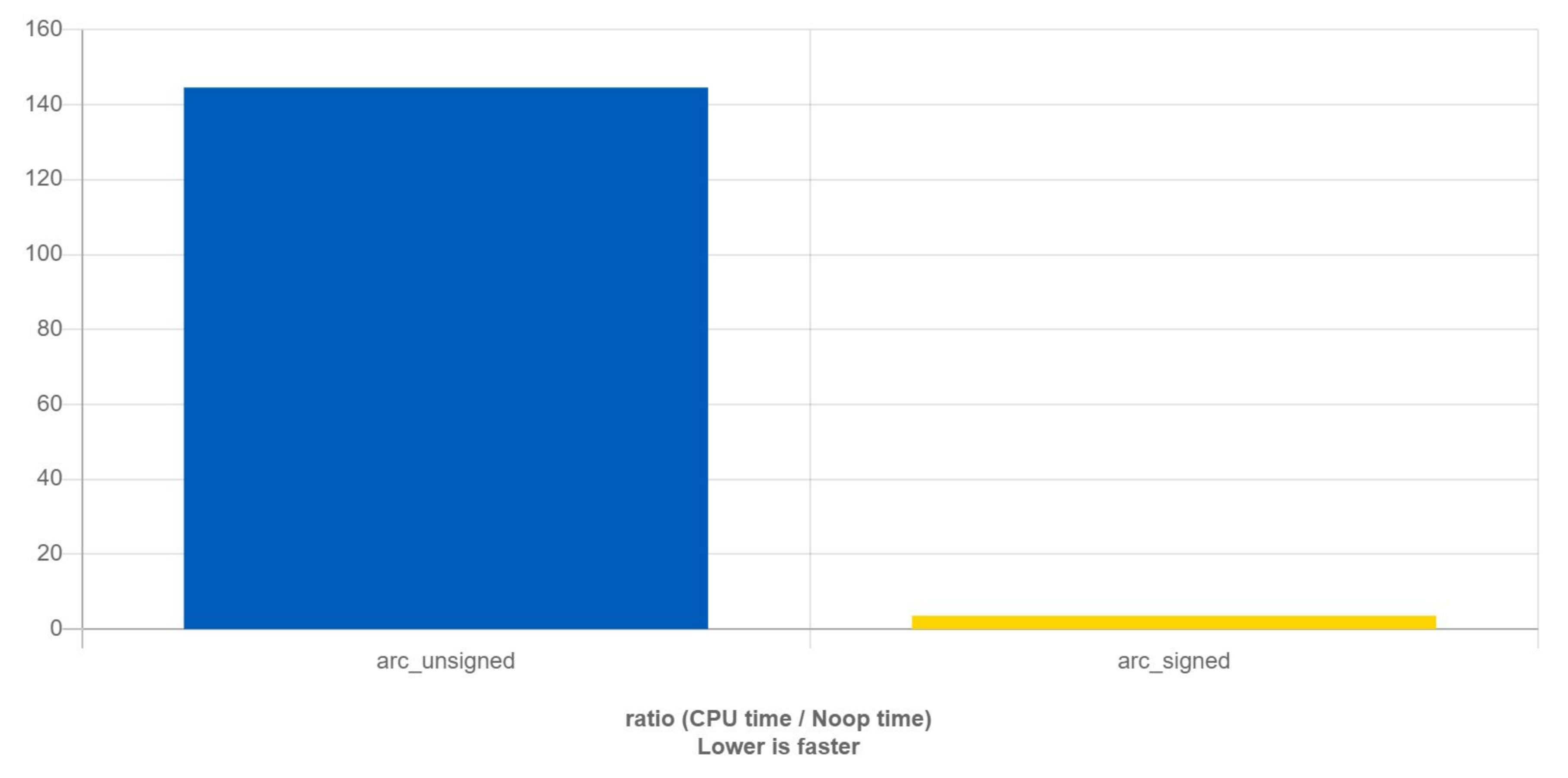


```
arc_signed(long):
        test    rdi, rdi
        jle     .LBB8_1
        lea     rax, [rdi - 1]
```

$$\sum_{k=1}^{n} a_k = \frac{n(a_1 + a_n)}{2}$$

```
        ret
.LBB8_1:
        xor     eax, eax
        ret
```

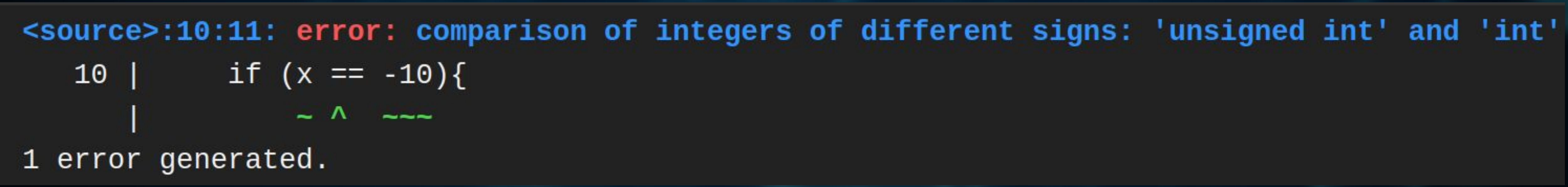
MORE COMPLEX EXAMPLE: PERFORMANCE



MORE COMPLEX EXAMPLE: WHY?

WHAT TO DO?

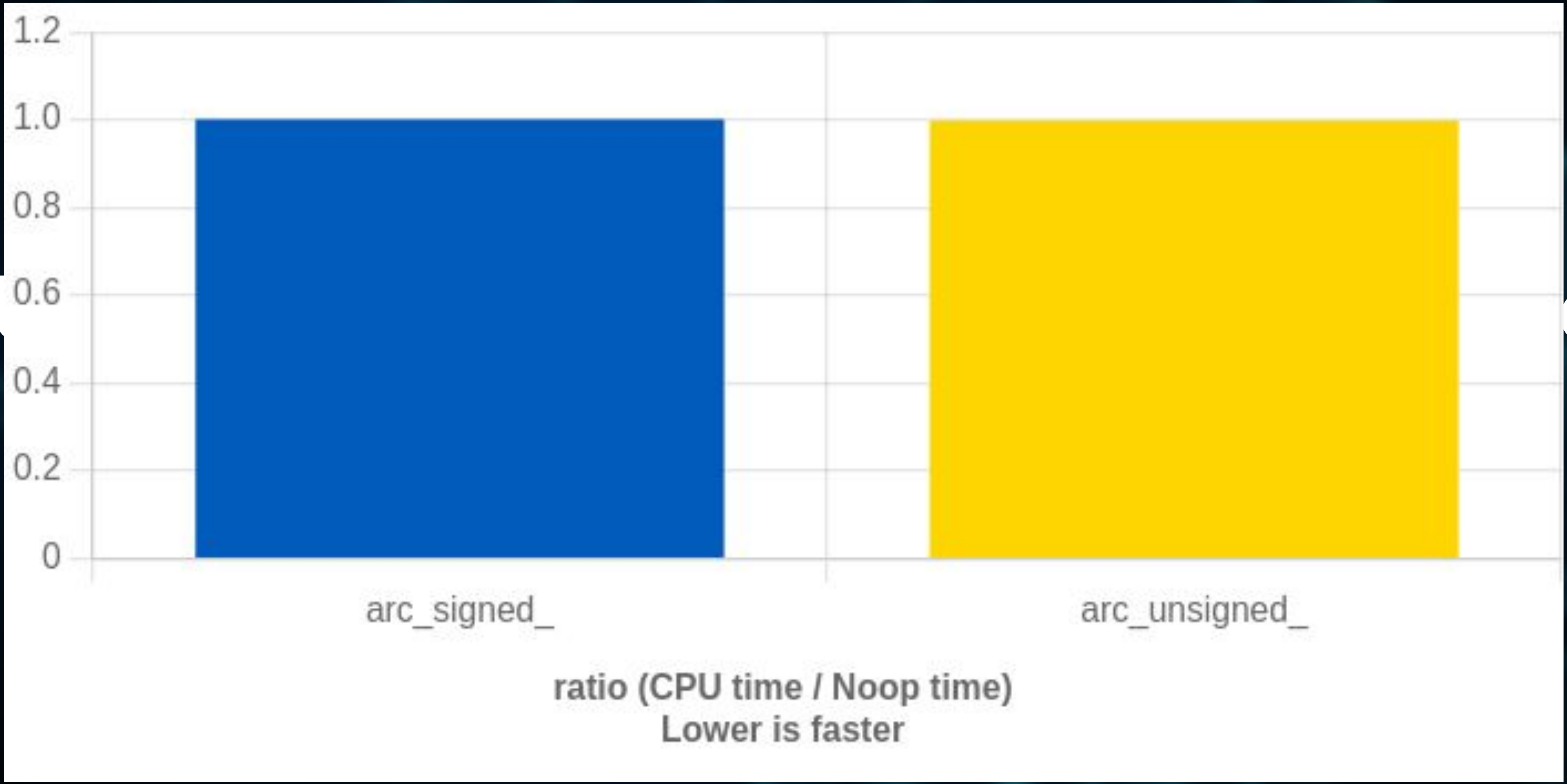
WHAT TO DO?



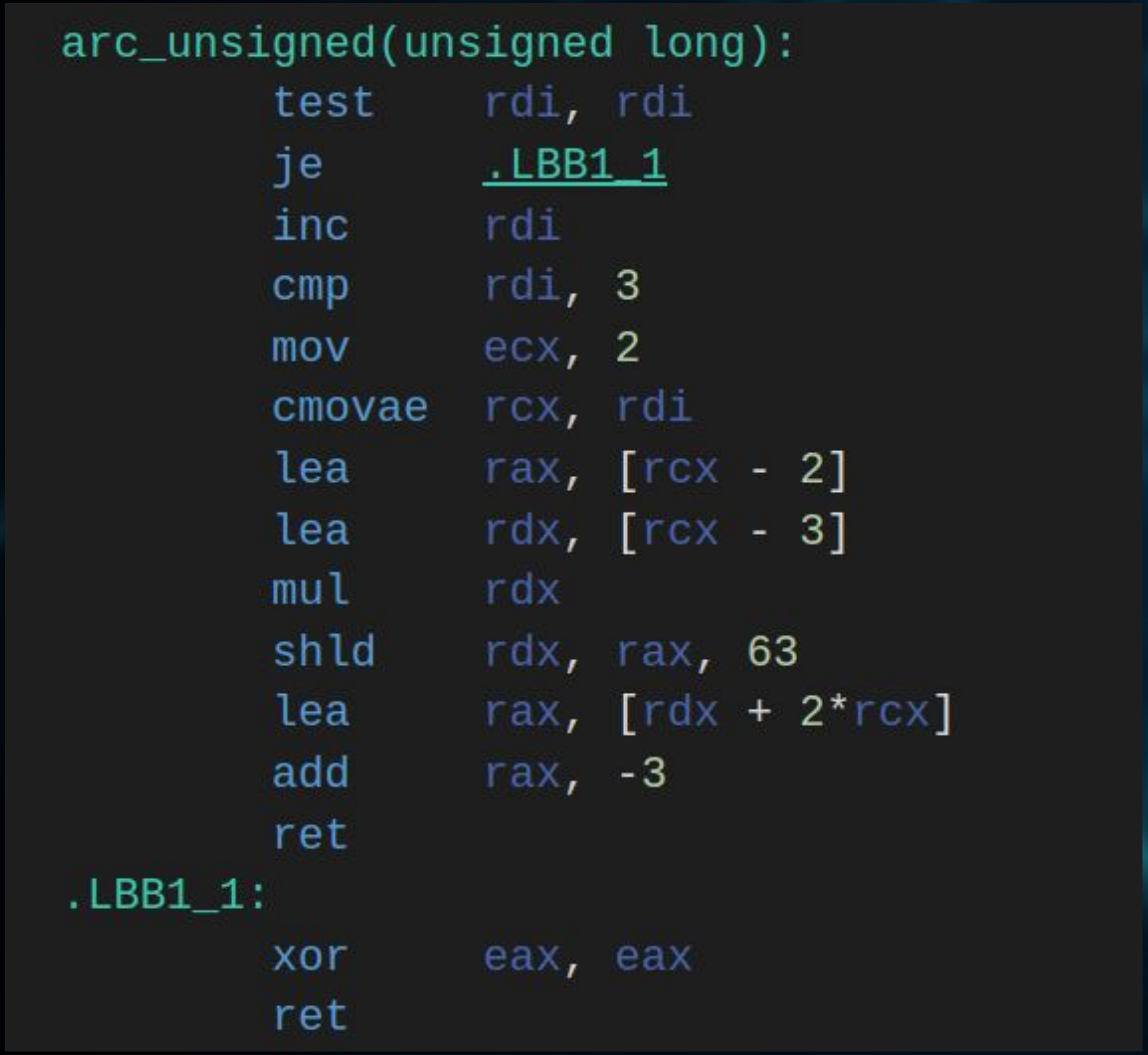
```
<source>:10:11: error: comparison of integers of different signs: 'unsigned int' and 'int'
   10 |     if (x == -10){
      |         ~ ^  ~~~
1 error generated.
```

WHAT TO DO?

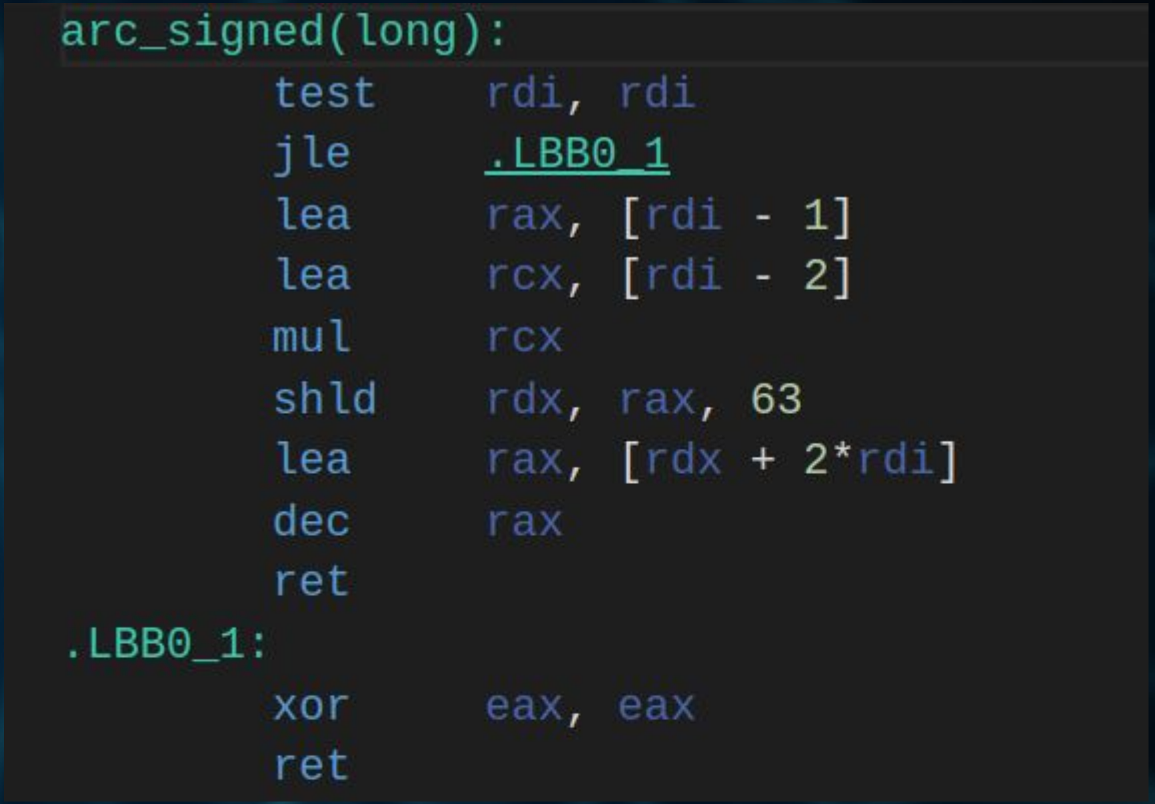
- U er!



WHAT TO DO?



```
arc_unsigned(unsigned long):
        test    rdi, rdi
        je      .LBB1_1
        inc     rdi
        cmp     rdi, 3
        mov     ecx, 2
        cmovae  rcx, rdi
        lea     rax, [rcx - 2]
        lea     rdx, [rcx - 3]
        mul     rdx
        shld    rdx, rax, 63
        lea     rax, [rdx + 2*rcx]
        add     rax, -3
        ret
.LBB1_1:
        xor     eax, eax
        ret
```



```
arc_signed(long):
        test    rdi, rdi
        jle     .LBB0_1
        lea     rax, [rdi - 1]
        lea     rcx, [rdi - 2]
        mul     rcx
        shld    rdx, rax, 63
        lea     rax, [rdx + 2*rdi]
        dec     rax
        ret
.LBB0_1:
        xor     eax, eax
        ret
```

WHAT TO DO?

- Use Sanitizers

```
-fsanitize=signed-integer-overflow
-fsanitize=unsigned-integer-overflow
```

WHAT TO DO?

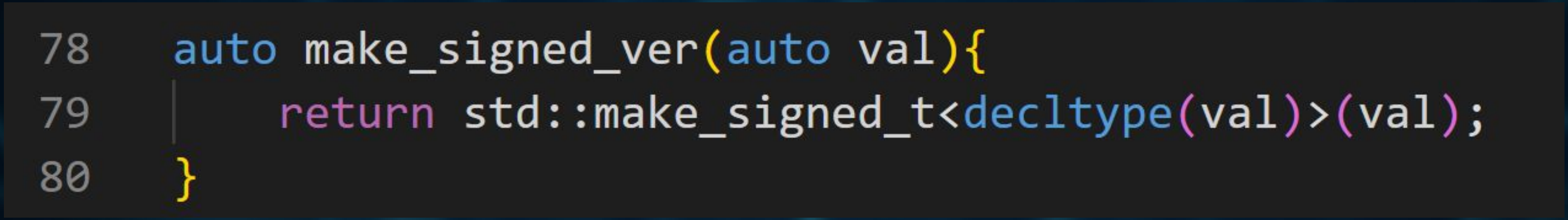
- Use special types for better performance
  - `int_fastN_t, uint_fastN_t`

WHAT TO DO?

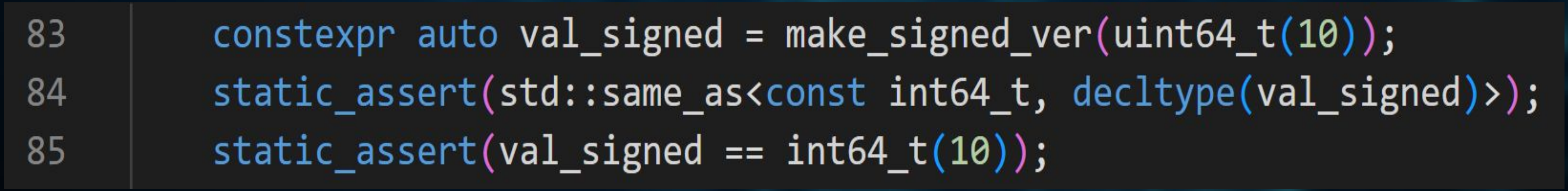
- Know your CPU

WHAT TO DO?

- Use special helpers from the standard
  - MAKE_SIGNED
  - MAKE_UNSIGNED



```
auto make_signed_ver(auto val){
    return std::make_signed_t<decltype(val)>(val);
}
```

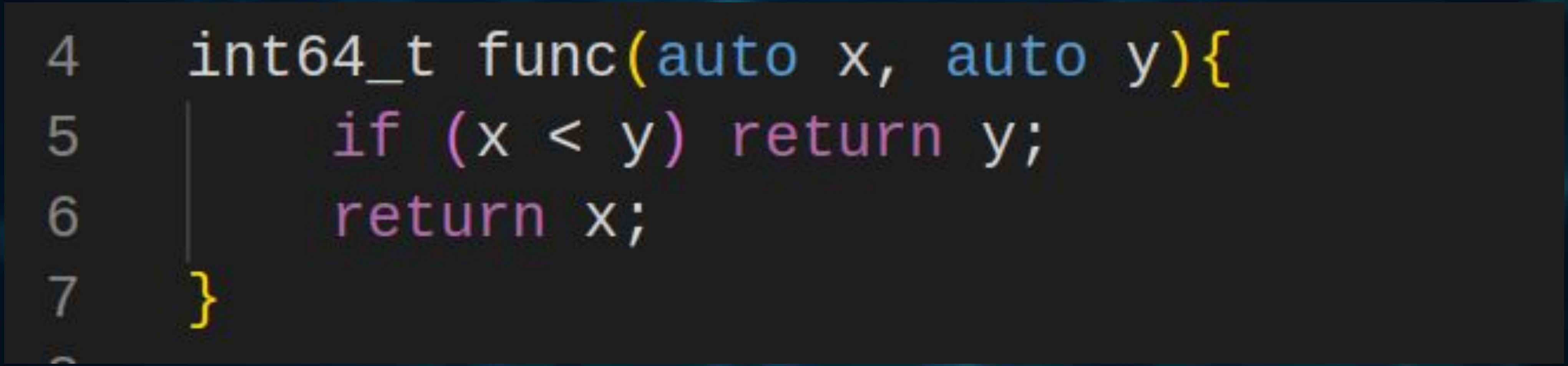


```
    constexpr auto val_signed = make_signed_ver(uint64_t(10));
    static_assert(std::same_as<const int64_t, decltype(val_signed)>);
    static_assert(val_signed == int64_t(10));
```

WHAT TO DO?

- Use C++20 safe comparators
  - `std::cmp_equal: ==`
  - `std::cmp_not_equal: !=`
  - `std::cmp_less: <`
  - `std::cmp_less_equal: <=`
  - `std::cmp_greater: >`
  - `std::cmp_greater_equal: >=`

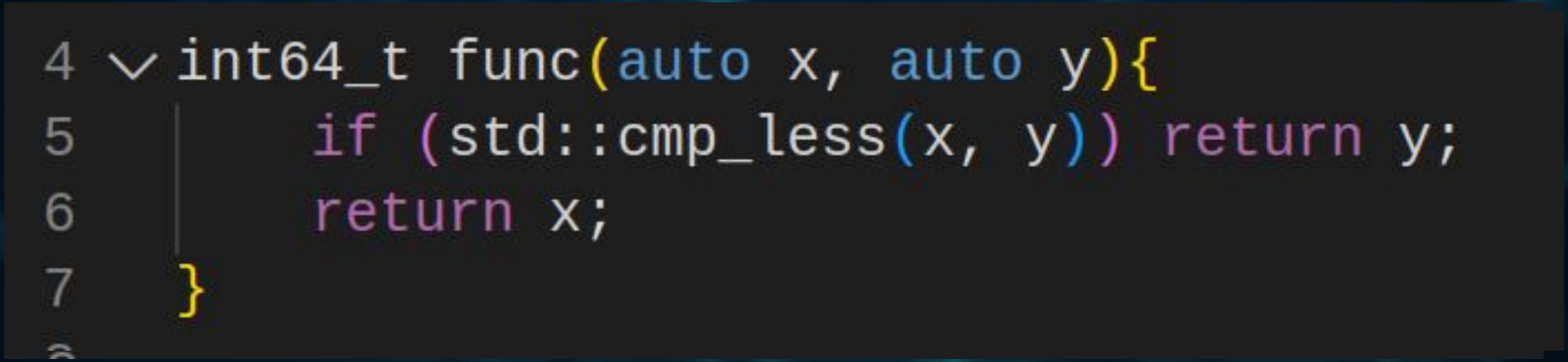
WHAT TO DO?



```
int64_t func(auto x, auto y){
    if (x < y) return y;
    return x;
}
```

func(-10, 20ul) —> -10

WHAT TO DO?



```
int64_t func(auto x, auto y){
        if (std::cmp_less(x, y)) return y;
        return x;
}
```

func(-10, 20ul) —> 20

WHAT TO DO?

- Avoid using auto when not sure about the type

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- Avoid using auto when not sure about the type
- Use concrete types when possible!

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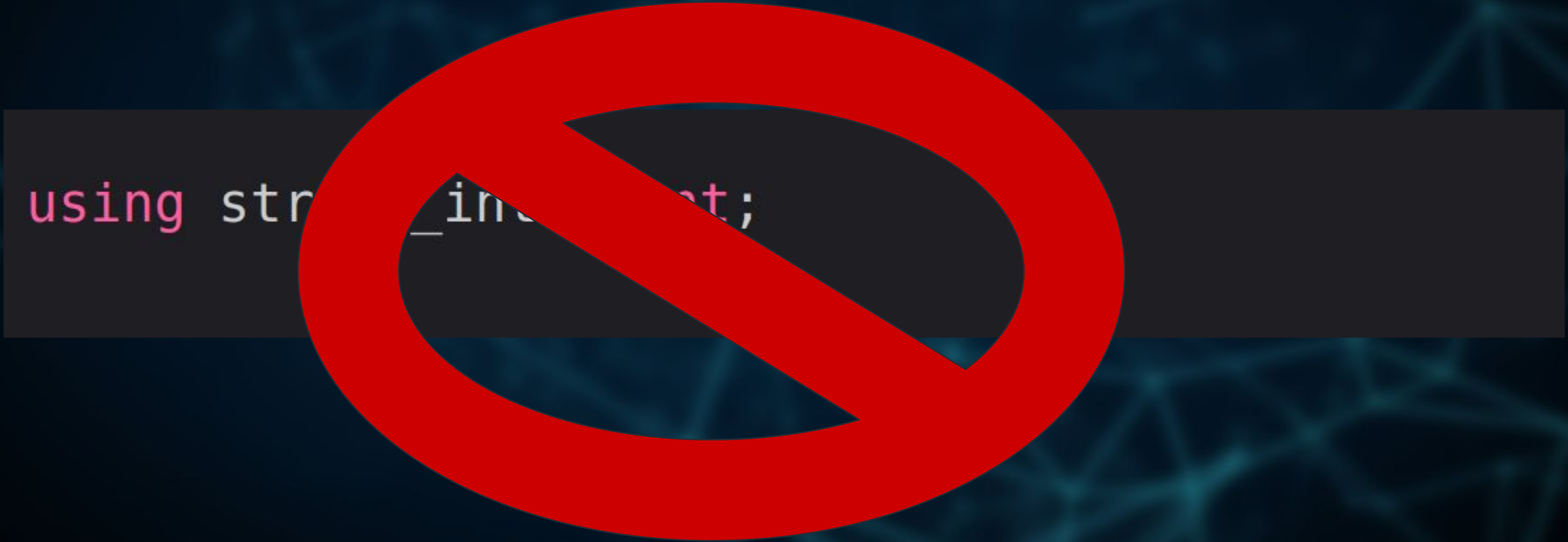
- Avoid using auto when not sure about the type
- Use concrete types when possible!
- Use modern loops as much as you can
- Use strong types.

WHAT TO DO?

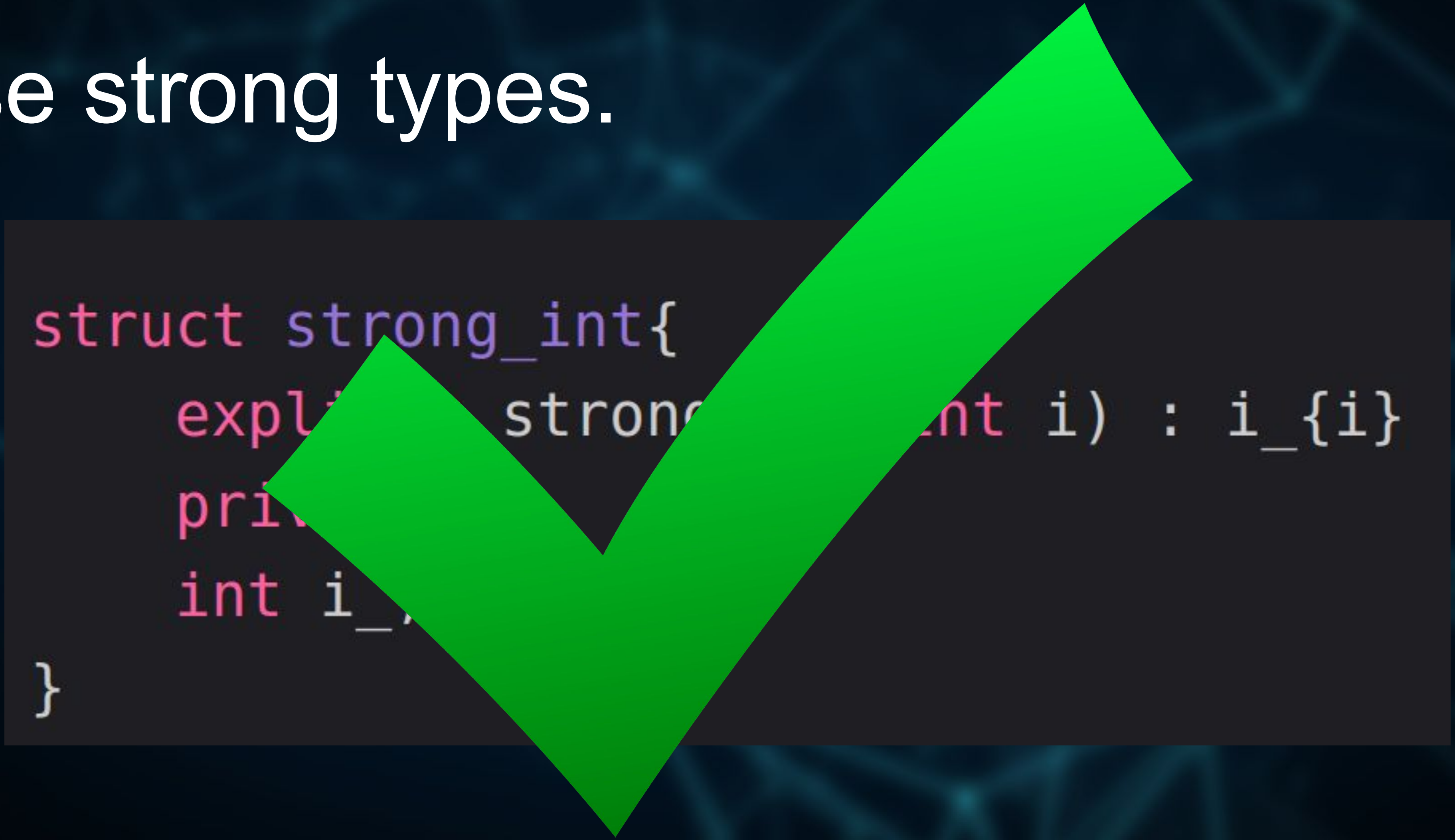
- Use strong types.



```
using str    _in     t;
```

WHAT TO DO?

- Use strong types.



```
struct strong_int{
    expl      strong      nt i) : i_{i}
    pri
    int i_
}
```

QUESTIONS

?

Alex Dathskovsky | alex.dathskovsky@speedata.io | www.linkedin.com/in/alexdathskovsky

THANK YOU FOR LISTENING

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Link to presented code: https://godbolt.org/z/W6zvzMzv7