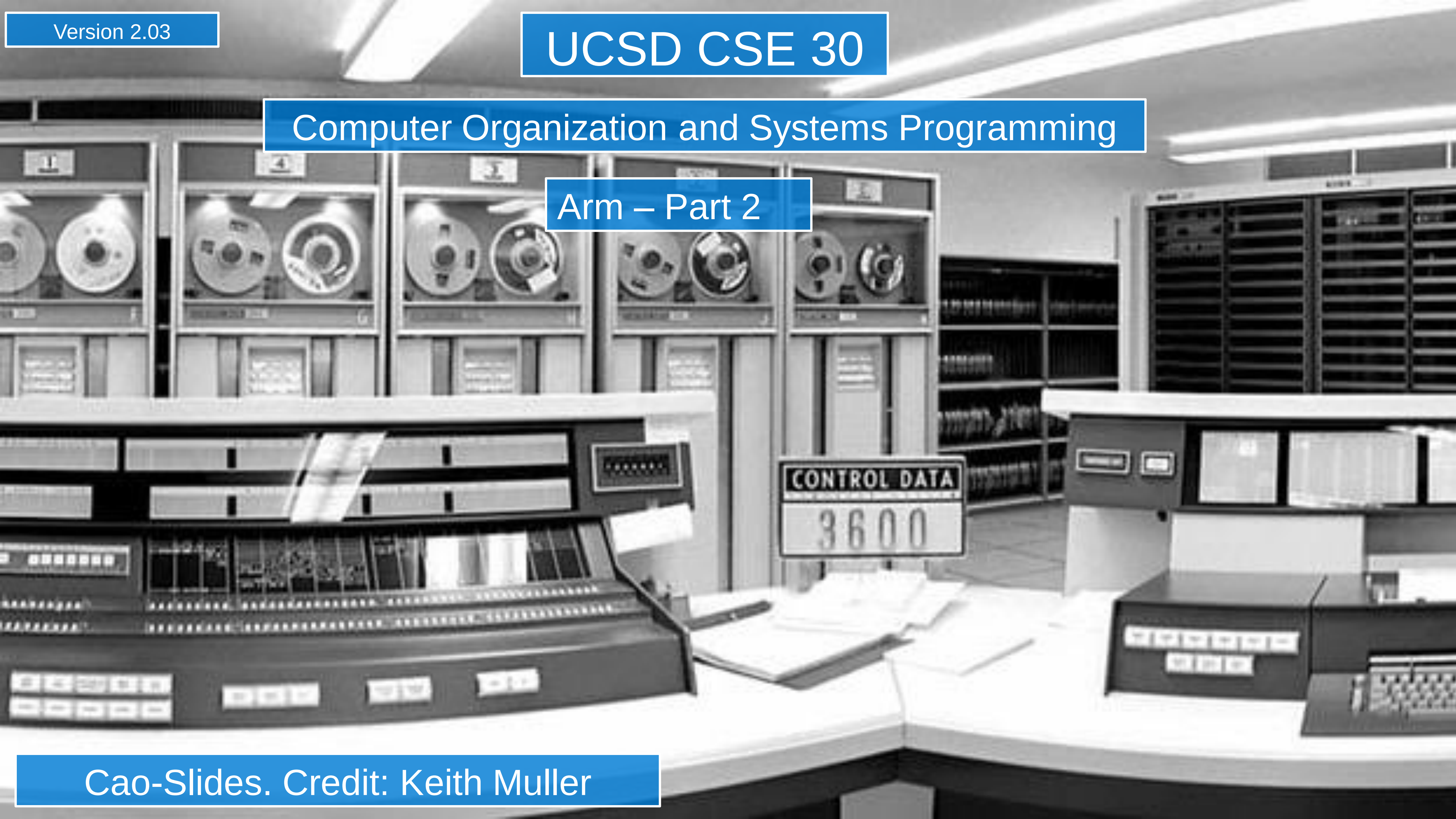
Version 2.03

UCSD CSE 30

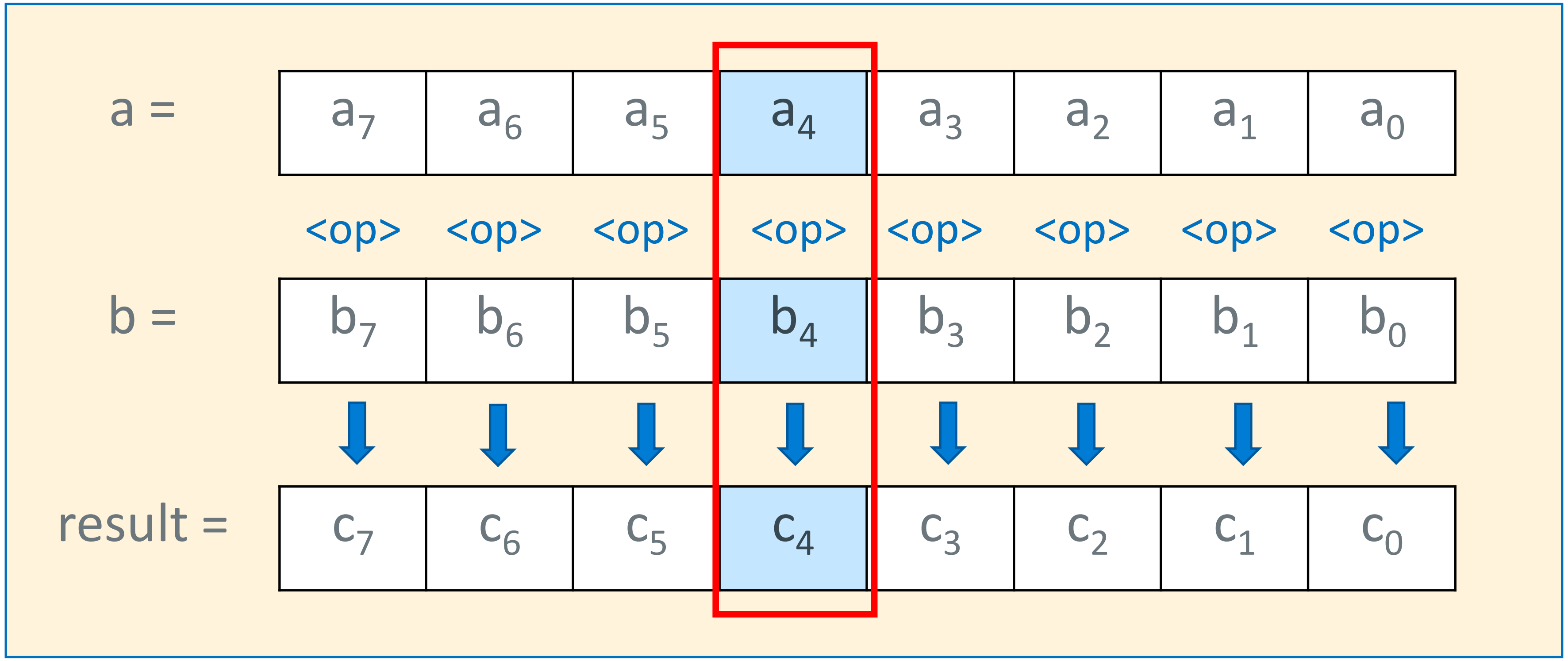
Computer Organization and Systems Programming

Arm – Part 2



Cao-Slides. Credit: Keith Muller

What is a Bitwise Operation?



a =	a_7	a_6	a_5	a_4	a_3	a_2	a_1	a_0
	<op>	<op>	<op>	<op>	<op>	<op>	<op>	<op>
b =	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0
result =	c_7	c_6	c_5	c_4	c_3	c_2	c_1	c_0

- Bitwise operators are applied independently to each of the corresponding bit positions in each variable
- Each bit position of the result depends only on bits in the same bit position within the operands

Bitwise (Bit to Bit) Operators in C

$a \oplus b$

`output = ~a;`

a	~a
0	1
1	0

`output = a & b;`

a	b	a & b
0	0	0
0	1	0
1	0	0
1	1	1

& with 1 to let a **bit through**
& with 0 to **set a bit to 0**

`output = a | b;`

a	b	a | b
0	0	0
0	1	1
1	0	1
1	1	1

| with 1 to **set a bit to 1**
| with 0 to let a **bit through**

`output = a ^ b; //EOR`

a	b	a ^ b
0	0	0
0	1	1
1	0	1
1	1	0

^ with 1 **will flip the bit**
^ with 0 to let a **bit through**

Bitwise NOT

```
~ 1100
  ----
  0011
```

Bitwise AND

```
  0110
& 1100
  ----
  0100
```

Bitwise OR

```
  0110
| 1100
  ----
  1110
```

Bitwise EOR

```
  0110
^ 1100
  ----
  1010
```

Bitwise Not (vs Boolean Not)

in C

```c
int output = ~a;
```

a	~a
0	1
1	0

Bitwise NOT

```
~ 1100
  ----
  0011
```

	Bitwise Not
number	0101 1010 0101 1010 1111 0000 1001 0110
~number	1010 0101 1010 0101 0000 1111 0110 1001

Meaning	*Operator*	*Operator*	*Meaning*
Boolean NOT	!b	~b	Bitwise NOT

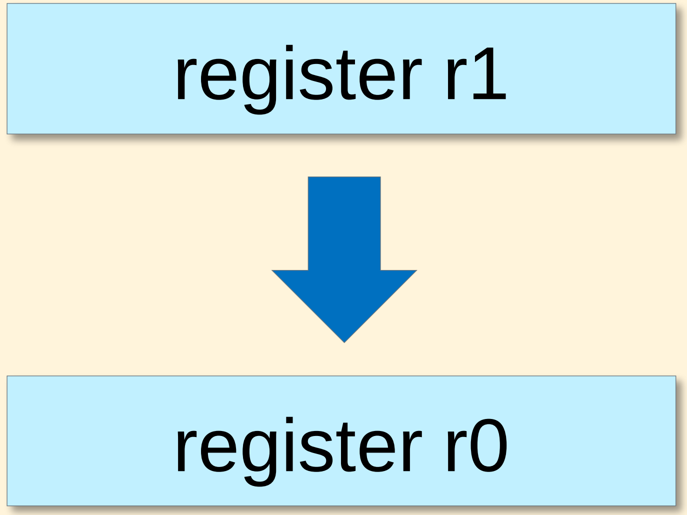
Boolean operators act on the entire value not the individual bits

Type	*Operation*	result
bitwise	~0x01	1111 1111 1111 1111 1111 1111 1111 1110
Boolean	!0x01 True	0000 0000 0000 0000 0000 0000 0000 0000

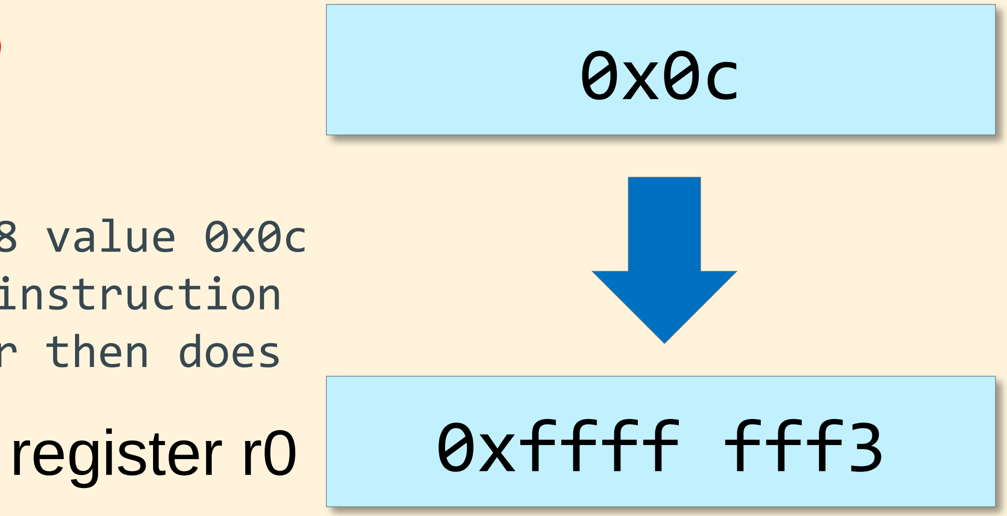
X

MVN (not)

```
mvn   r0, r1


// Copies all 32 bits
// of the value held
// in register r1 into
// the register r0
// then does a bitwise NOT
```



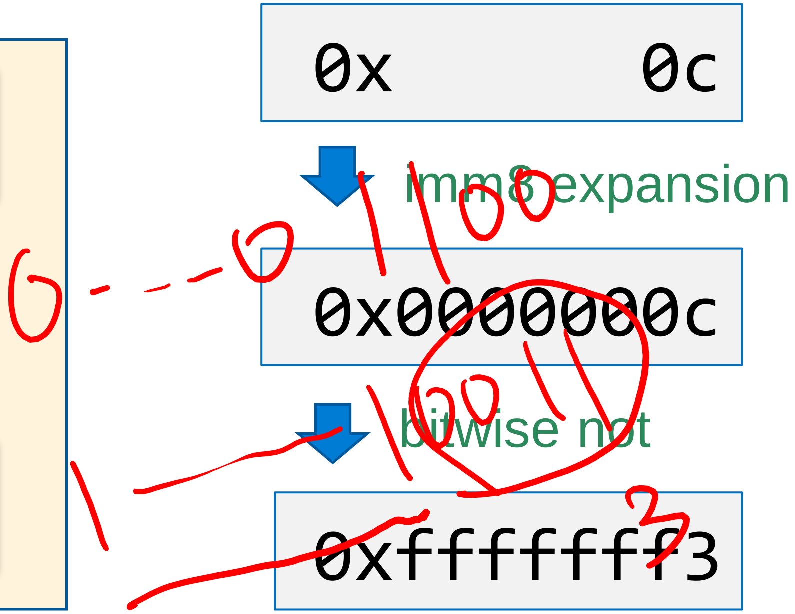
```
mvn   r0, 12


// Expands an imm8 value 0x0c
// stored in the instruction
// into a register then does
// a bitwise NOT
```



Bitwise NOT

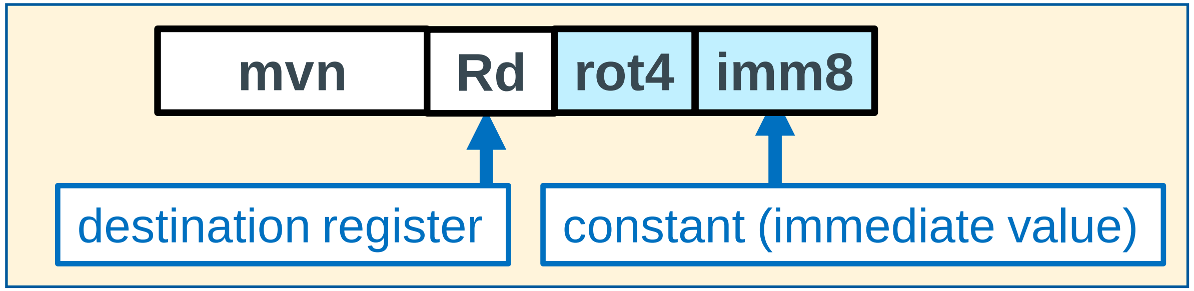
```
~ 1100
  ----
  0011
```

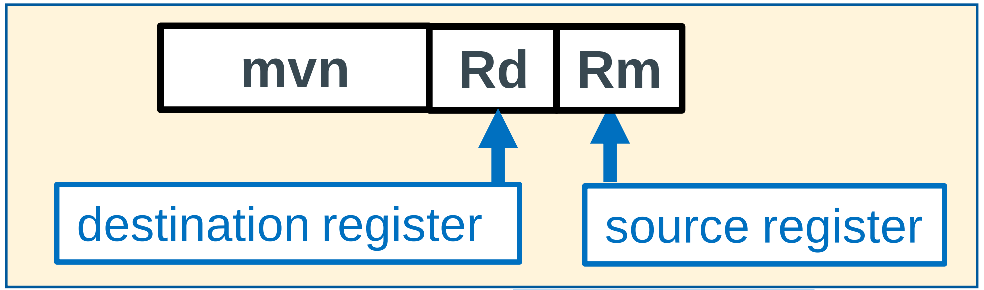
- A **bitwise NOT** operation



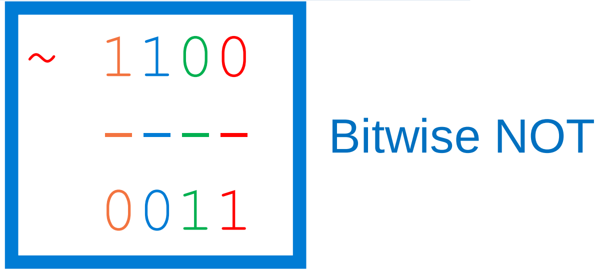
x

mvn – Copies NOT (~)





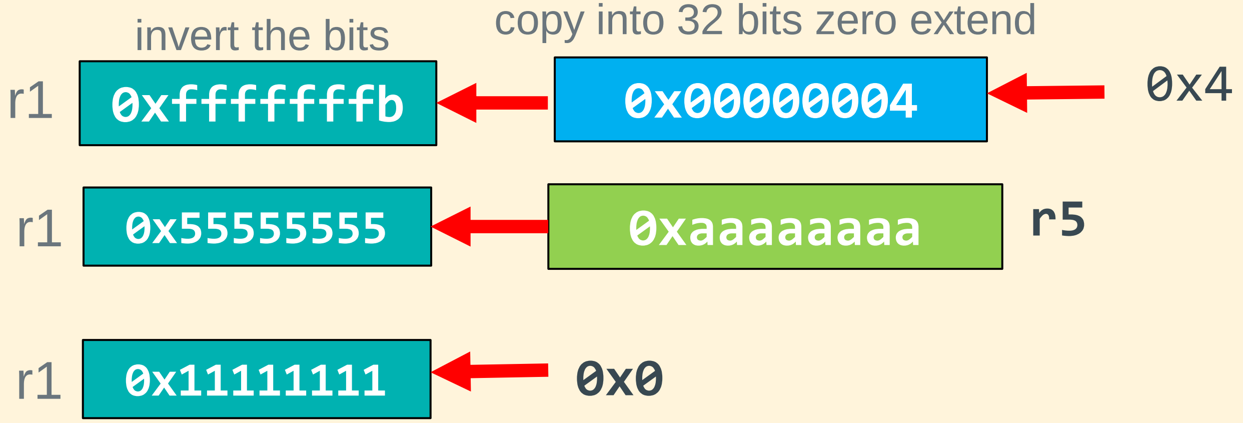
```
mvn  Rd, constant   // Rd = constant
mvn  Rd,  Rm        // Rd = Rm
```



bitwise NOT operation. Immediate (constant) version copies to 32-bit register, then does a bitwise NOT

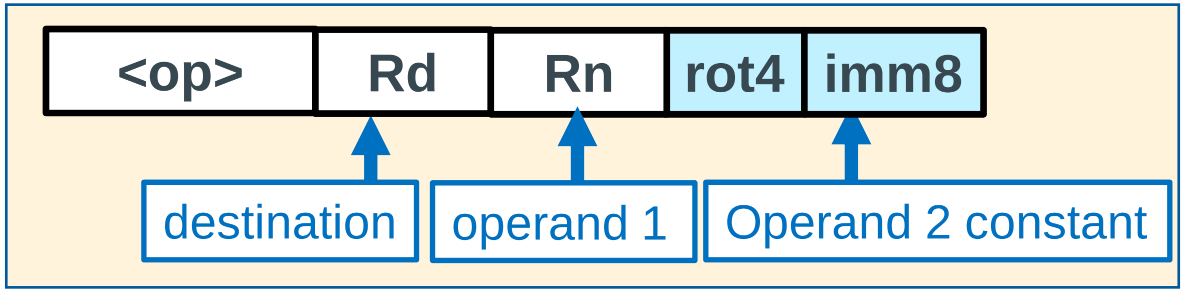
imm8	extended imm8	inverted imm8	signed base 10
0x00	0x00 00 00 00	0xff ff ff ff	-1
0xff	0x00 00 00 ff	0xff ff ff 00	-256

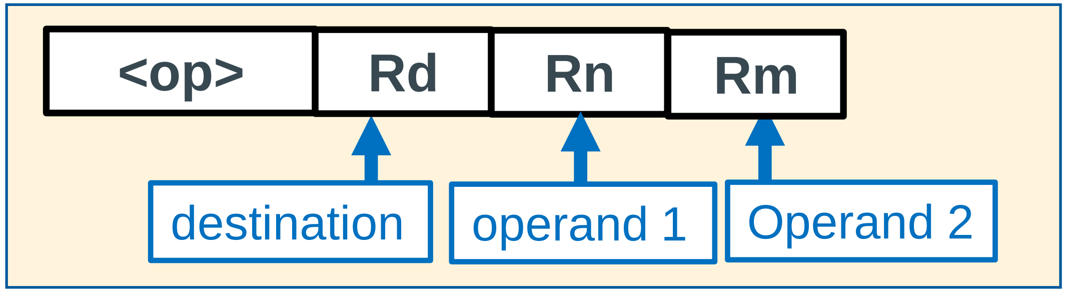
```
mvn    r1, 4          // x = ~4
mvn    r1, r5        // x = ~y in C


mvn    r1, 0         // x = -1
```



x

Bitwise Instructions





```
<op>  Rd,  Rn, constant   // Rd = Rn <op> constant
<op>  Rd,  constant       // Rd = Rd <op> constant
<op>  Rd,  Rn,  Rm        // Rd = Rn <op> Rm
```

Bytes: 0 <= imm8 <= 255 + values from "rotating" rot 4 bits

Bitwise <op> description	C Syntax	*Arm <op> Syntax Op2: either register or constant value*	*Operation*
Bitwise **AND**	a & b	and R_d, R_n, Op2	R_d = R_n & Op2
Bitwise **OR**	a | b	orr R_d, R_n, Op2	R_d = R_n | Op2
Exclusive **OR**	a ^ b	eor R_d, R_n, Op2	R_d = R_n ^ Op2
Bitwise **NOT**	a = ~b	mvn R_d, R_n	R_d = ~R_n

X

Bitwise versus C Boolean Operators

bool x=true;

int y=x;

Boolean Operators

Meaning	*Operator*
Boolean AND	a && b
Boolean OR	a || b
Boolean NOT	!b

Bitwise Operators

Operator	*Meaning*
a & b	Bitwise AND
a | b	Bitwise OR
~b	Bitwise NOT

Boolean operators **act on the entire value not the individual bits**

bitwise & **versus** **boolean &&**

```
        0x10  &    0x01  = 0x00  (bitwise)
a =     0x10 T &&  0x01 T = 0x01 T (Boolean)
```

0001 0000

& 0000 0001

& 0 0

bitwise ~ **versus** **boolean !**

```
        ~0x01 = 0xfffffffe (bitwise)

        !0x01 = 0x0 (Booelan)
```

0x10

The act (operation) of *Masking*

a =	a_7	a_6	a_5	a_4	a_3	a_2	a_1	a_0
	<op>	<op>	<op>	<op>	<op>	<op>	<op>	<op>
b =	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0
result =	c_7	c_6	c_5	c_4	c_3	c_2	c_1	c_0

a : 1 0
eor ^ : 1 1
0 1

- Bit masks access/modify specific bits in memory
- Masking act of applying a mask to a value with a specific op:
- `orr:` 0 passes bit unchanged, 1 sets bit to 1 `(a = b | c; // in C)`
- `eor:` 0 passes bit unchanged, 1 inverts the bit `(a = b ^ c; // in C)` flip
- `and:` 0 clears the bit, 1 passes bit unchanged `(a = b & c; // in C)`

Mask on

force bits to 1 "**mask on**" operation

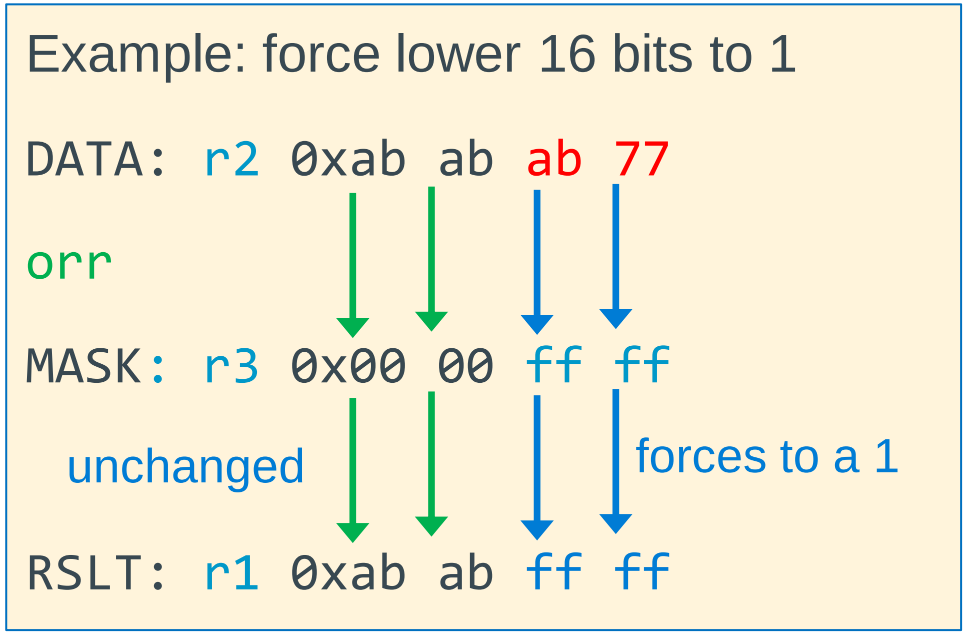
- 1 to **set a bit to 1**
- 0 to let a **bit through unchanged**

```
orr  r1, r2, r3

r1 = r2 | r3; // in C
```

r2: 0xabcd1234

ldr r1, =0xDF0000F0

orr r0, r2, r1



Example: force lower 16 bits to 1

```
DATA: r2 0xab ab ab 77
orr
MASK: r3 0x00 00 ff ff
  unchanged          forces to a 1
RSLT: r1 0xab ab ff ff
```

Example: force lower 8 bits to 1

```
DATA: r2 0xab ab ab 77

orr   r1 , r2, 0xff

r1 = r2 | 0xff; // in C

RSLT: r1 0xab ab ff ff
```

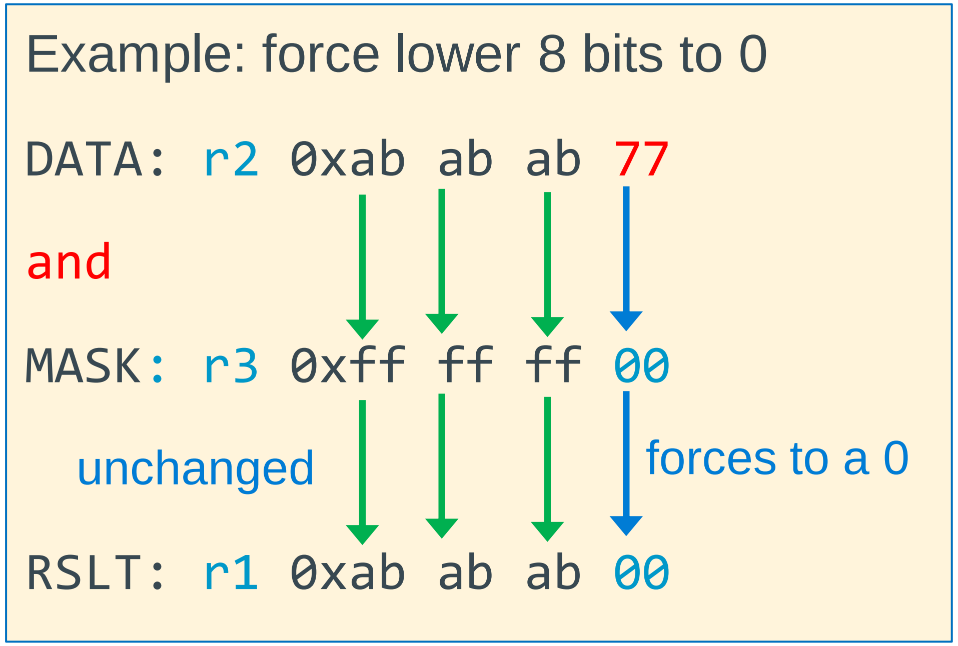
x

Mask off

force bits to 0 "**mask off**" operation

- 0 to **set a bit to 0** ("clears the bit")
- 1 to let a **bit through unchanged**

```
and  r1, r2, r3

r1 = r2 & r3; // in C
```



Example: force lower 8 bits to 0

```
DATA: r2 0xab ab ab 77

and

MASK: r3 0xff ff ff 00

RSLT: r1 0xab ab ab 00
```

Example: force lower 8 bits to 0

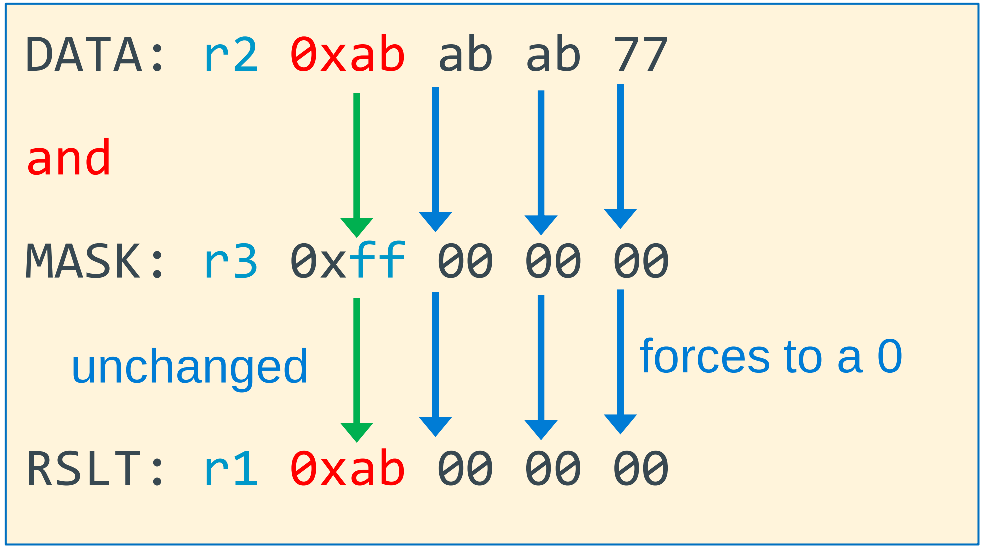
```
DATA: r2 0xab ab ab 77

and r1  r2, 0xffffff00

r1 = r2 & 0xffffff00; // in C

RSLT: r1 0xab ab ab 00
```

Extracting (Isolate) a Field of Bits with a mask

extract top 8 bits of r2 into r1

- 0 to **set a bit to 0** ("clears the bit")
- 1 to let a **bit through unchanged**

```
    and  r1, r2, r3
```



```
DATA: r2 0xab ab ab 77
and
MASK: r3 0xff 00 00 00
RSLT: r1 0xab 00 00 00
```

extract top 8 bits of r2 into r1

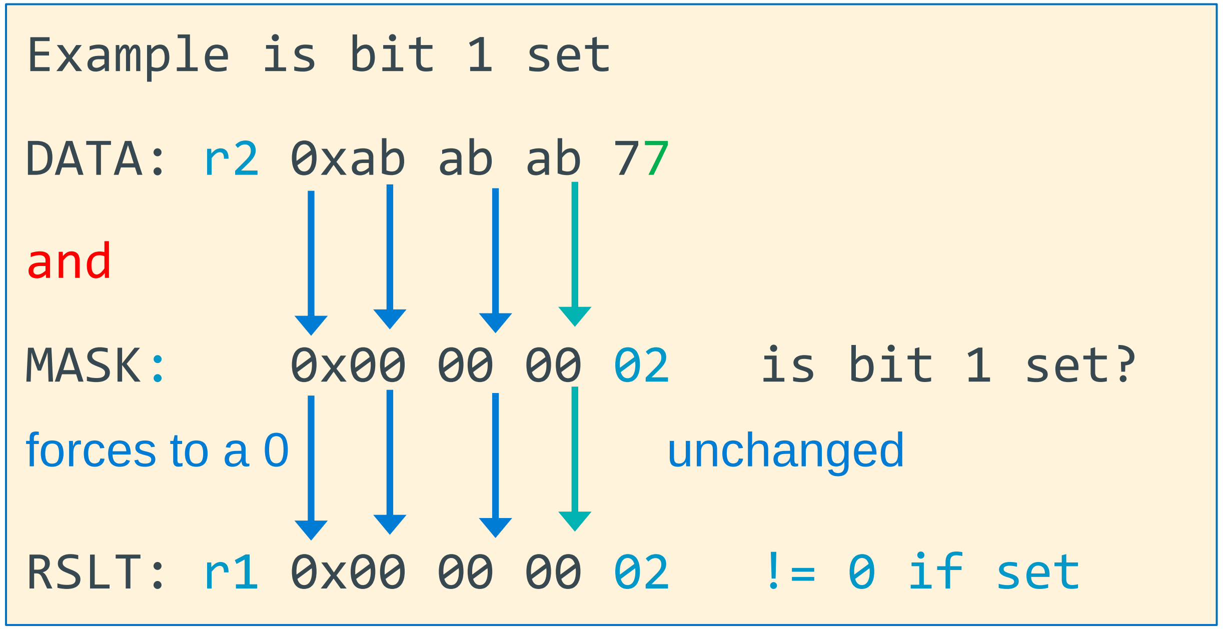
```
DATA: r2 0xab ab ab 77

and  r1, r2, 0xff000000

RSLT: r1 0xab 00 00 00

r1 = r2 & 0xff000000;  // in C
```

Finding if a bit is set

query the status of a bit "**bit status**" operation

- 0 to **set a bit to 0** ("clears the bit")
- 1 to let a **bit through unchanged**

```
        and  r1, r2, 0x02

        cmp r1, 0

        beq .Lendif

        // code for is set

.Lendif:
```



```
Example is bit 1 set

DATA: r2 0xab ab ab 77

and

MASK:    0x00 00 00 02   is bit 1 set?

forces to a 0                 unchanged

RSLT: r1 0x00 00 00 02   != 0 if set
```

```
unsigned int r1, r2;
// code                -- · 0 0010
r1 = r2 & 0x02
if  (r1 != 0) {
    // code for is set
}
```

```
unsigned int r2;
// code
if ((r2 & 0x02) != 0) {
    // code for is set
}
```

x

Even/Odd

Even or odd, check LSB (same as mod %2)

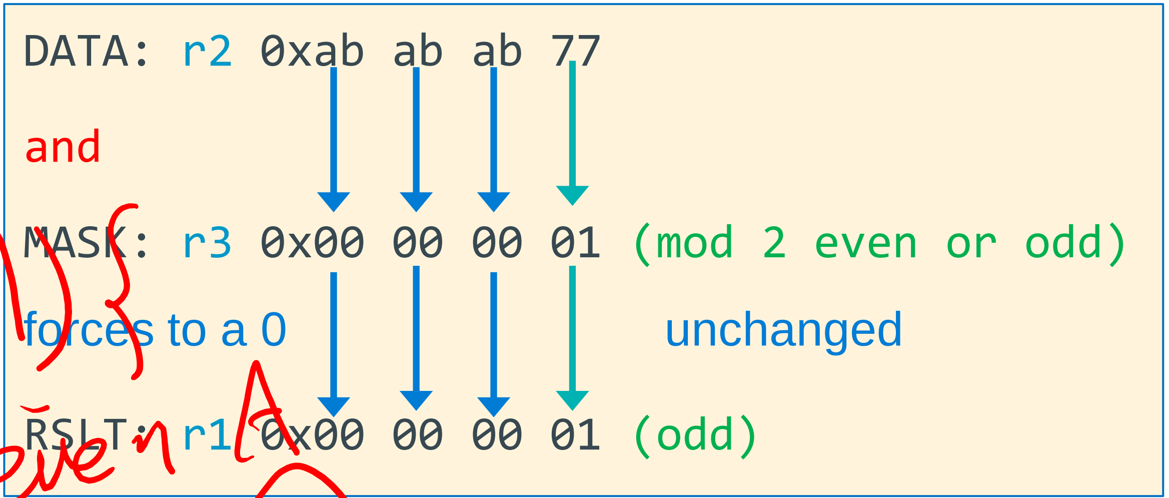
```
check LSB (bit 0) if set then odd, else even
       and  r1, r2, 0x01
       cmp  r1, 0x01
       bne .Lendif
       // code for handling odd numbers
.Lendif:
```

```
   unsigned int r2;
   // code
   if ((r2 & 0x01) != 0) {
       // code for handling odd numbers
   }
```

if(x & 1) {

// even

} // odd



```
DATA: r2 0xab ab ab 77
and
MASK: r3 0x00 00 00 01 (mod 2 even or odd)
forces to a 0                unchanged
RSLT: r1 0x00 00 00 01 (odd)
```

A

B

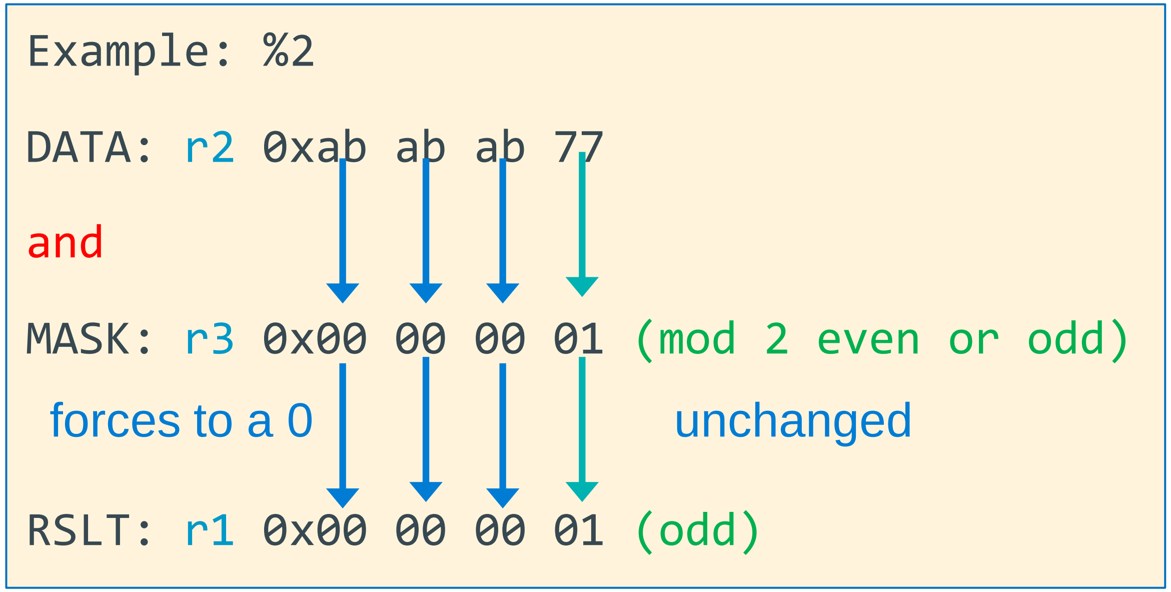
x

MOD %<power of 2>

remainder (mod): num % d where num ≥ 0 and d = 2^k

mask = 2^k -1 so for mod 16, mask = 16 -1 = 15

```
and  r1, r2, r3
```

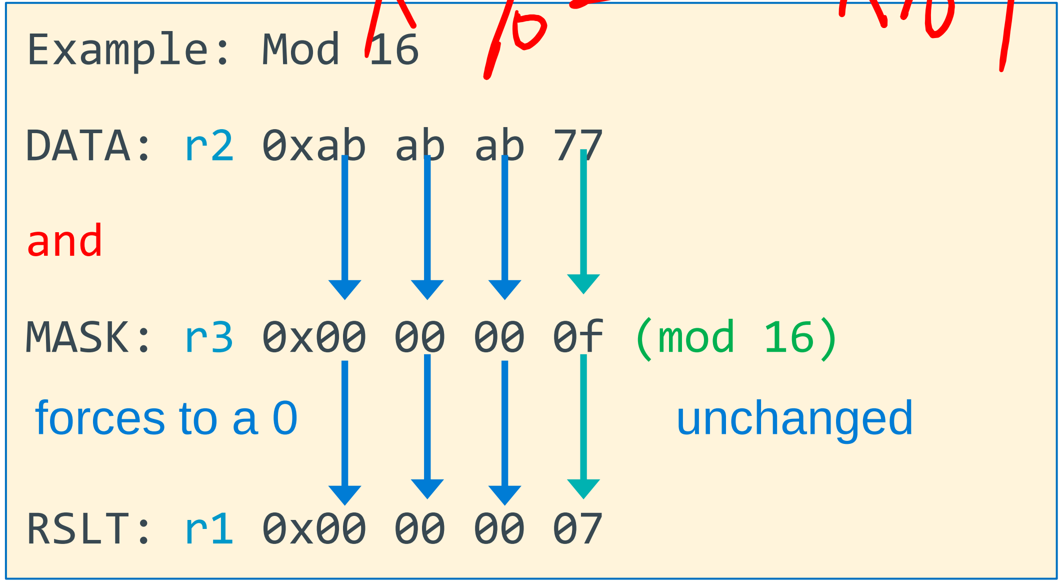


```
Example: %2

DATA: r2 0xab ab ab 77

and

MASK: r3 0x00 00 00 01 (mod 2 even or odd)
```

forces to a 0 unchanged

```
RSLT: r1 0x00 00 00 01 (odd)
```

x %2 x%4



```
Example: Mod 16

DATA: r2 0xab ab ab 77

and

MASK: r3 0x00 00 00 0f (mod 16)
```

forces to a 0 unchanged

```
RSLT: r1 0x00 00 00 07
```

Flipping bits: bit toggle
Used in PA7/PA8

invert (*flip*) bits "**bit toggle**" operation

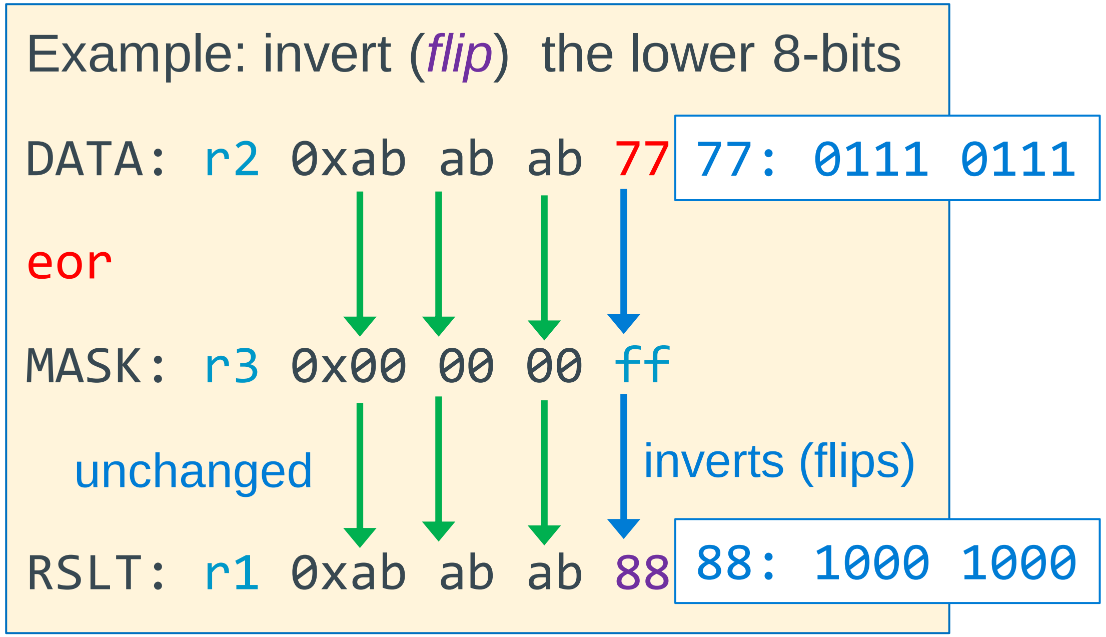
- 1 **will flip the bit**
- 0 to let a **bit through**

```
eor   r1, r2, r3
```

- Observation: When applied twice, it returns the original value (symmetric encoding)
- With a mask of all 1's is a 1's compliment

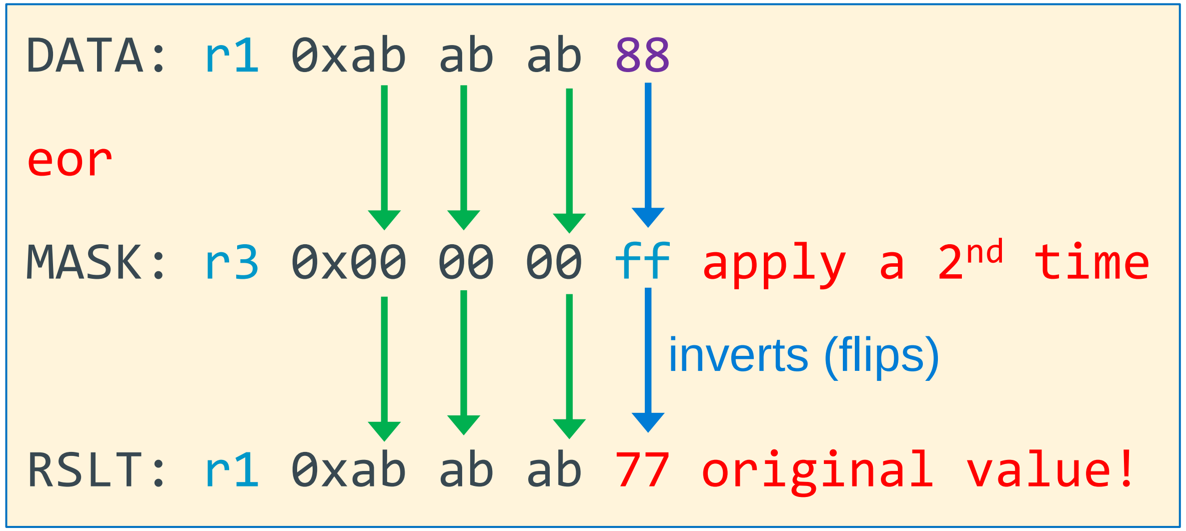
```
Example: flip the lower 8-bits

    eor  r1, r2, 0xff
```

```
unsigned int r1, r2;

r1 = r2 ^ 0xff;
```



Example: invert (*flip*) the lower 8-bits

```
DATA: r2 0xab ab ab 77
eor
MASK: r3 0x00 00 00 ff
RSLT: r1 0xab ab ab 88
```



```
DATA: r1 0xab ab ab 88
eor
MASK: r3 0x00 00 00 ff apply a 2nd time
RSLT: r1 0xab ab ab 77 original value!
```

Unsigned Integers (positive numbers) with Fixed # of Bits

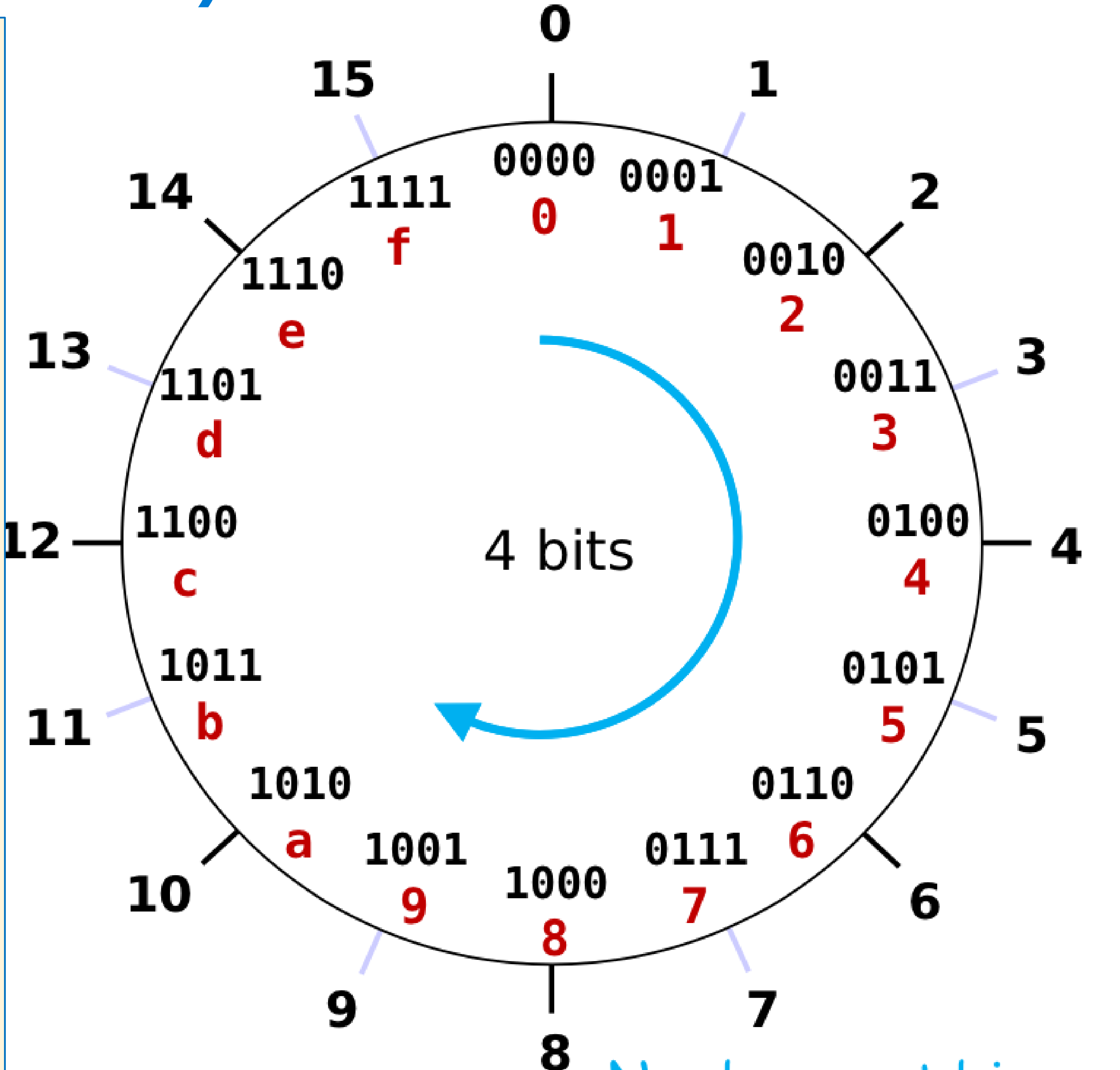
- 4 bits is 2^4 = ONLY 16 distinct values
- Modular (C operator: %) or clock math
  - Numbers start at 0 and “wrap around” after 15 and go back to 0
- Keep adding 1

  wraps (clockwise)

  0000 -> 0001 … -> 1111 -> 0000
- Keep subtracting 1

  wraps (counter-clockwise)

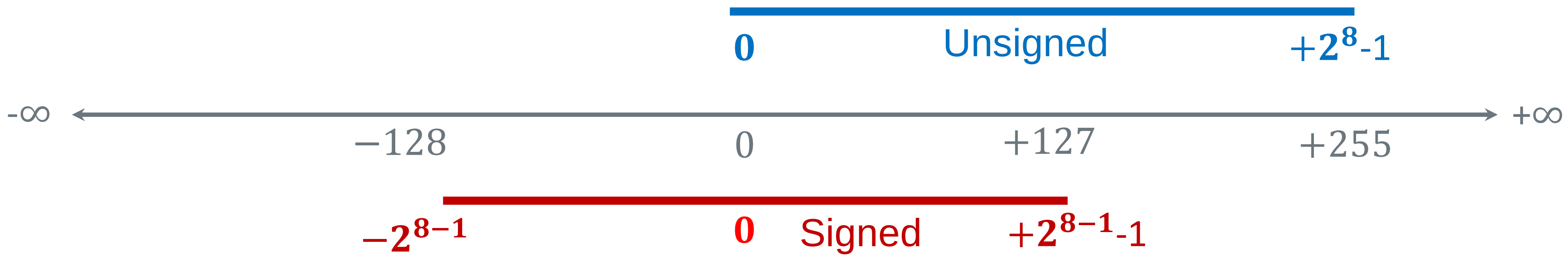
  1111 -> 1110 … -> 0000 -> 1111
- Addition and subtraction use normal "carry" and "borrow" rules, just operate in binary



Numbers get bigger in this direction

Problem: How to Encode Both Positive and Negative Integers

- How do we represent the negative numbers within a fixed number of bits?
  - Allocate some bit patterns to negative and others to positive numbers (and zero)
- 2^n distinct bit patterns to encode positive and negative values
- **Unsigned values:** $0 \ldots 2^n - 1$ ← -1 comes from counting 0 as a "positive" number (n: 4 0 - - - 15)
- **Signed values:** $-2^{n-1} \ldots 2^{n-1} - 1$ (dividing the range in ~ half including 0)
- **On a number line (below):** 8-bit integers – signed and unsigned (*e.g.*, `char in C`)

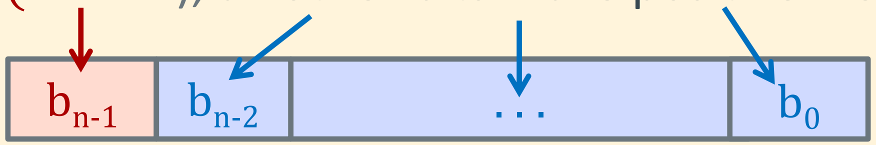


Same “width” (same number of encodings), just shifted in value

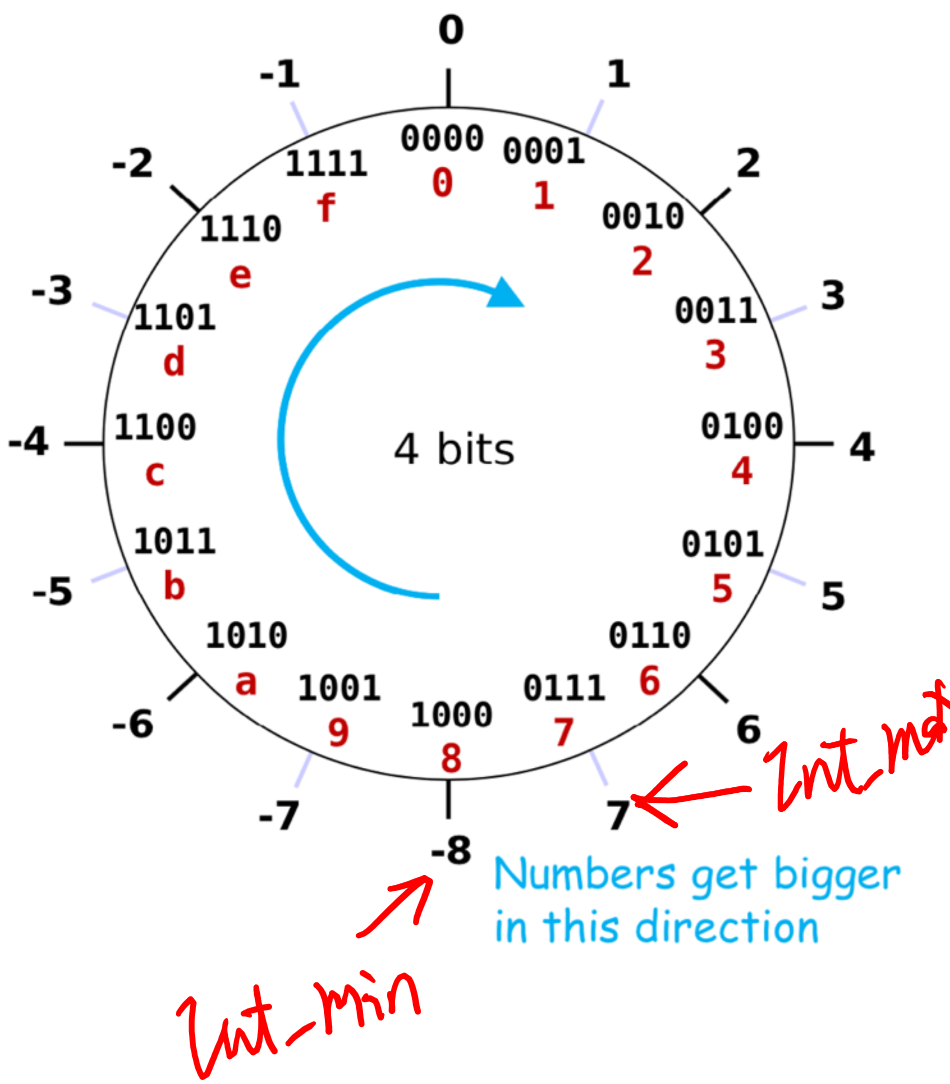
Two's Complement: The MSB Has a *Negative Weight*

$$2's\ Comp = -b_{n-1}2^{n-1} + b_{n-2}2^{n-2} + \ldots + b_1 2^1 + b_0 2^0$$

b_{n-1} weight is (-2^{n-1}), all other bits: have positive weights $(+2^i)$



- 4-bit ($w = 4$) weight $= -2^{4-1} = -2^3 = -8$
  - 1010_2 **unsigned**:
    $1\text{x}2^3 + 0\text{x}2^2 + 1\text{x}2^1 + 0\text{x}2^0 =$ **10**
  - 1010_2 **two's complement**:
    $-1\text{x}2^3 + 0\text{x}2^2 + 1\text{x}2^1 + 0\text{x}2^0 = -8 + 2 =$ **–6**
  - -8 in **two's complement:**
    $1000_2 = -2^3 + 0 = -8$
  - -1 in **two's complement:**
    $1111_2 = -2^3 + (2^3 - 1) = -8 + 7 =$ **-1**



Int_ma

Numbers get bigger in this direction

Int_min

x

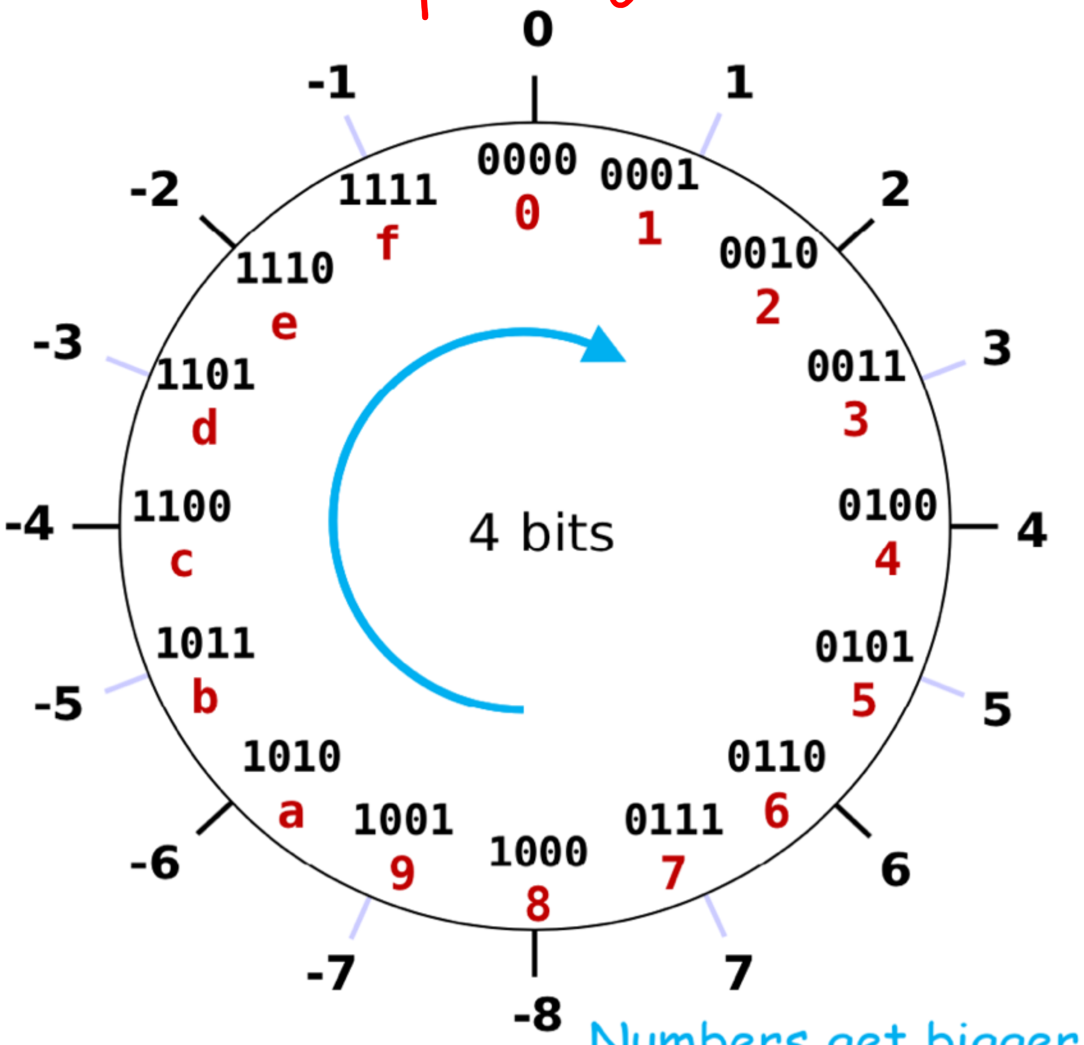
2's Complement Signed Integer Method

flip every bit +1

- Positive numbers encoded same as unsigned numbers
- All negative values have a one in the leftmost bit
- All positive values have a zero in the leftmost bit
  - This implies that 0 is a positive value
- Only one zero
- **For n bits, Number range is $-(2^{n-1})$ to $+(2^{n-1}$ - 1)**
  - Negative values "go 1 further" than the positive values
- Example: the range for 8 bits:

  -128, -127, .. 0, .. 126, **+127**
- Example the range for 32 bits:

  -2147483648 .. 0, .. **+2147483647**
- *Arithmetic is the same as with unsigned binary!*



Numbers get bigger in this direction

Sign Extension (how type promotion works)

- Sometimes you need to work with integers encoded with different number of bits

8 bits (char) -> (16 bits) **`short`** -> (32 bits) **`int`**

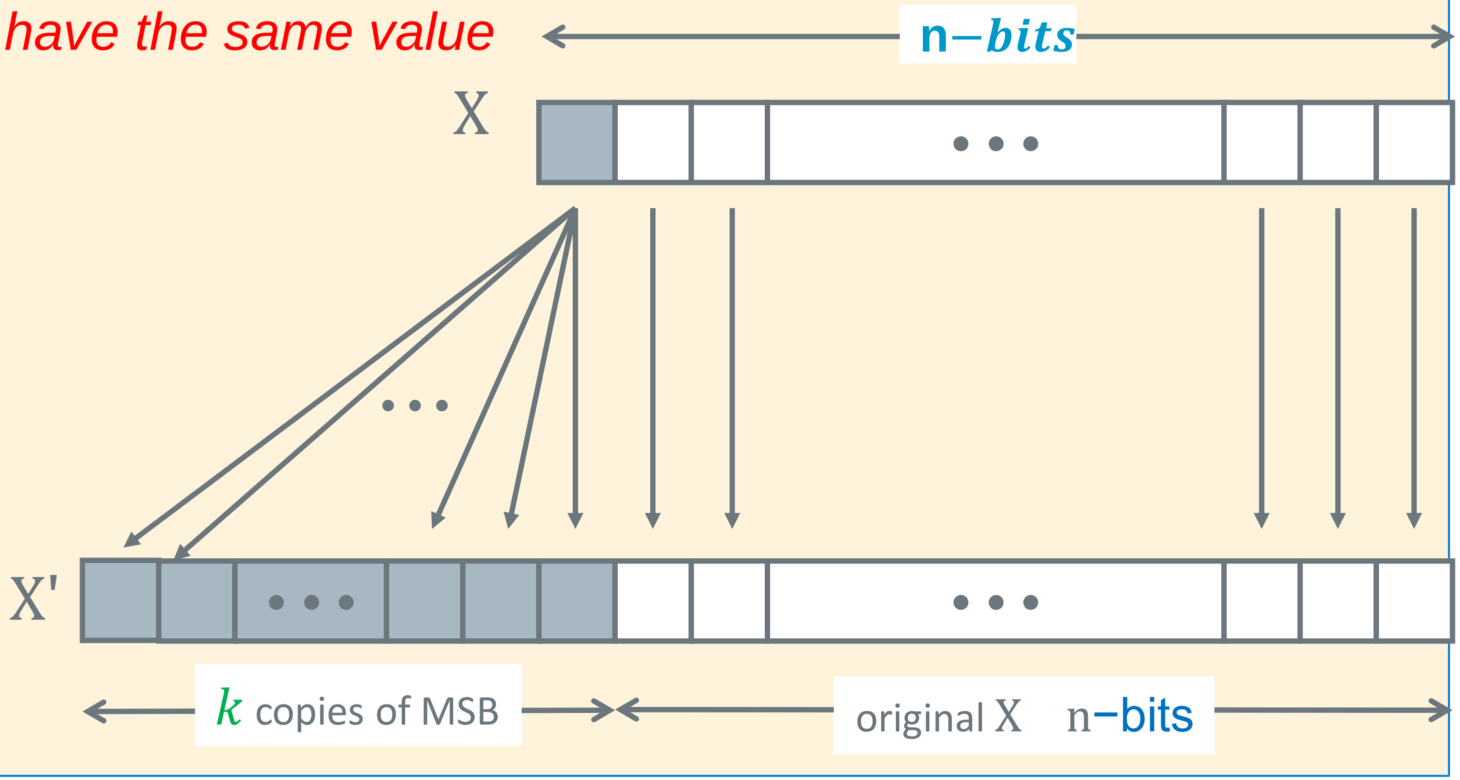
- **Sign extension increases the number of bits: n-bit** wide signed integer X, ***EXPANDS*** to a ***wider*** n−bit + k-bit signed integer X' where *both have the same value*

Unsigned

- Just add leading zeroes to the left side

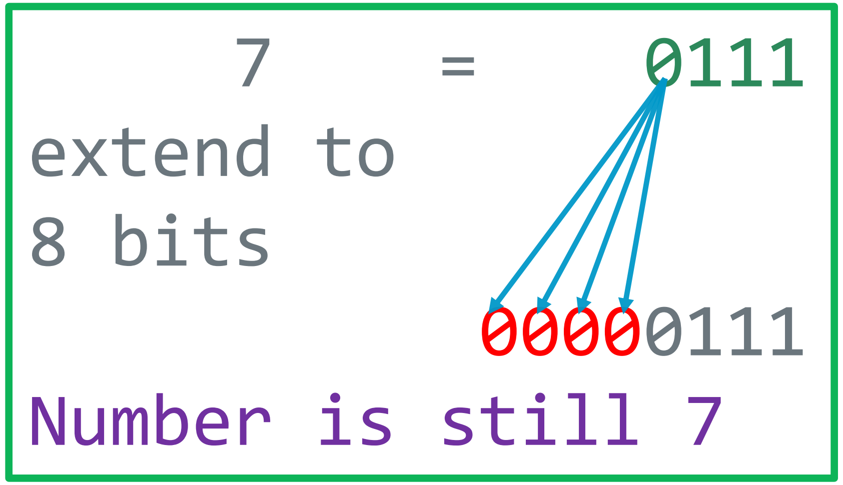
Two's Complement Signed:

- If positive, add leading zeroes on the left
  - Observe: Positive stay positive
- If negative, add leading ones on the left
  - Observe: Negative stays negative

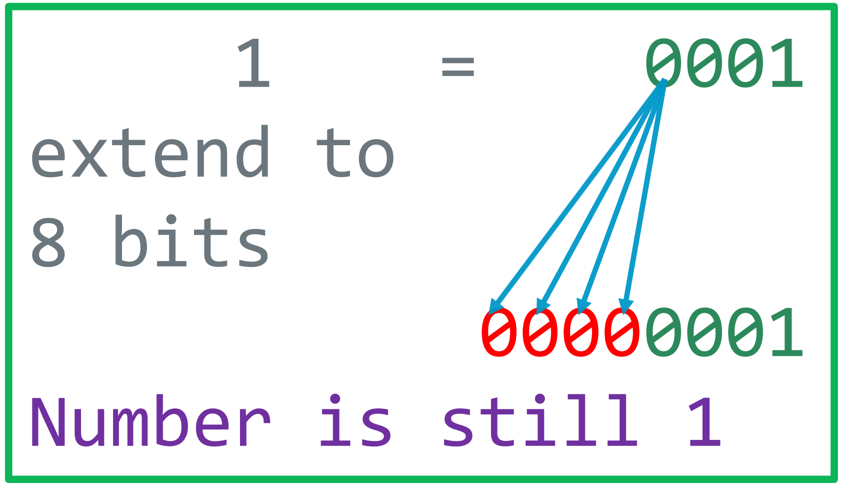


Example: Two’s Complement Sign or bit Extension - 1

- Adding 0's in front of a positive numbers does not change its value



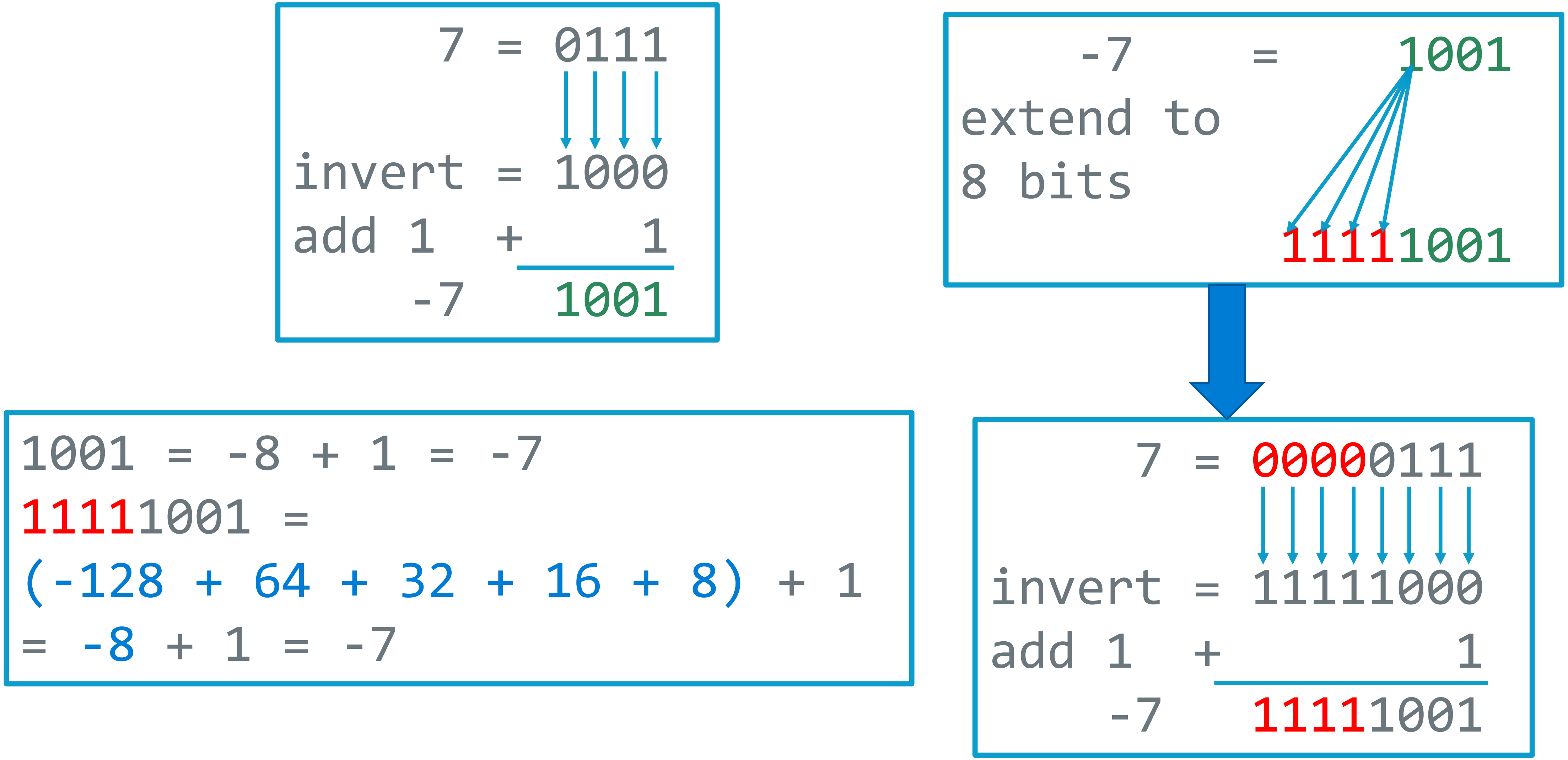
```
    7     =    0111
extend to
8 bits
           00000111
Number is still 7
```



```
    1     =    0001
extend to
8 bits
           00000001
Number is still 1
```

Example: Two’s Complement Sign or bit Extension -2

- Adding 1's if front of a negative number does not change its value



```
     7 = 0111

invert = 1000
add 1  +    1
    -7   1001
```

```
  -7     =    1001
extend to
8 bits
            11111001
```

```
1001 = -8 + 1 = -7
11111001 =
(-128 + 64 + 32 + 16 + 8) + 1
= -8 + 1 = -7
```

```
     7 = 00000111

invert = 11111000
add 1  +        1
    -7   11111001
```

x

Sign Extension in C: Type casts

- Convert from smaller to larger integral data types
- C and Java automatically performs sign extension
- Example (on pi-cluster with 32-bit int)

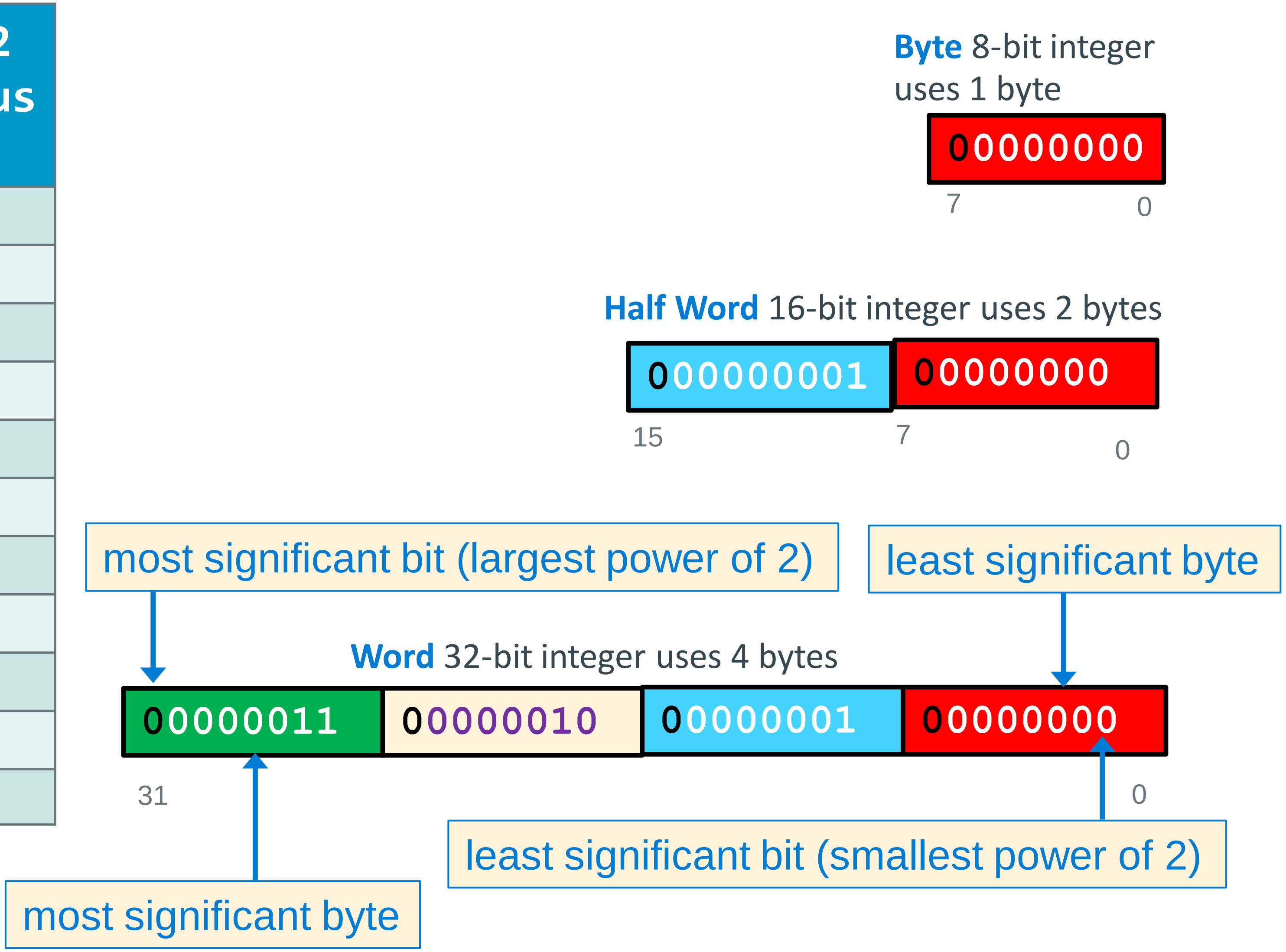
```
#include <stdlib.h>
#include <stdio.h>
int main(void)
{
    signed char c = -1;
    signed int i = c;
    unsigned char d = 1;
    unsigned int j = d;
    printf("c decimal = %hd\n", c);
    printf("c = 0x%hhx\n", c);
    printf("i decimal = %d\n", i);
    printf("i = 0x%x\n", i);
    printf("\nd decimal = %hd\n", d);
    printf("d = 0x%hhx\n", d);
    printf("j decimal = %d\n", j);
    printf("j = 0x%x\n", j);
    return EXIT_SUCCESS;
}
```

```
%./a.out
c decimal = -1
c = 0xff
i decimal = -1
i = 0xffffffff

d decimal = 1
d = 0x1
j decimal = 1
j = 0x1
```

Different Type of Numbers each have a Fixed # of Bits

Spanning one or more contiguous bytes of memory

C Data Type	AArch-32 contiguous Bytes
char (arm unsigned)	1
short int	2
unsigned short int	2
int	4
unsigned int	4
long int	4
long long int	8
float	4
double	8
long double	8
pointer *	4

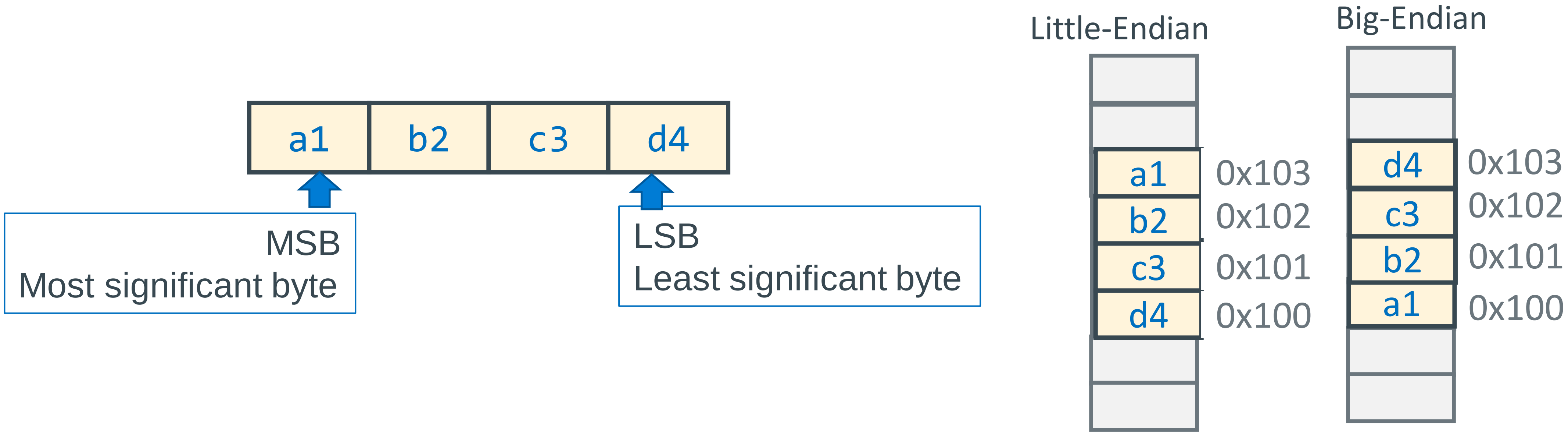


Byte 8-bit integer uses 1 byte
00000000
7
0
Half Word 16-bit integer uses 2 bytes
00000001
00000000
15
7
0
most significant bit (largest power of 2)
least significant byte
Word 32-bit integer uses 4 bytes
00000011
00000010
00000001
00000000
31
0
least significant bit (smallest power of 2)
most significant byte

X

Byte Ordering of Numbers In Memory: Endianness

- Two different ways to place multi-byte integers in a byte addressable memory
- Big-endian: Most Significant Byte ("big end") starts at the *lowest (starting)* address
- Little-endian: Least Significant Byte ("little end") starts at the *lowest (starting)* address
- Example: 32-bit integer with 4-byte data



x

Byte Ordering Example

only in RAM

```
Decimal:   12345
Binary:     0011   0000   0011   1001
Hex:           3      0      3      9
```

0x 00003039

mov r0, r1; //

```
int x = 12345;
// or x = 0x00003039;   // show all 32 bits
```

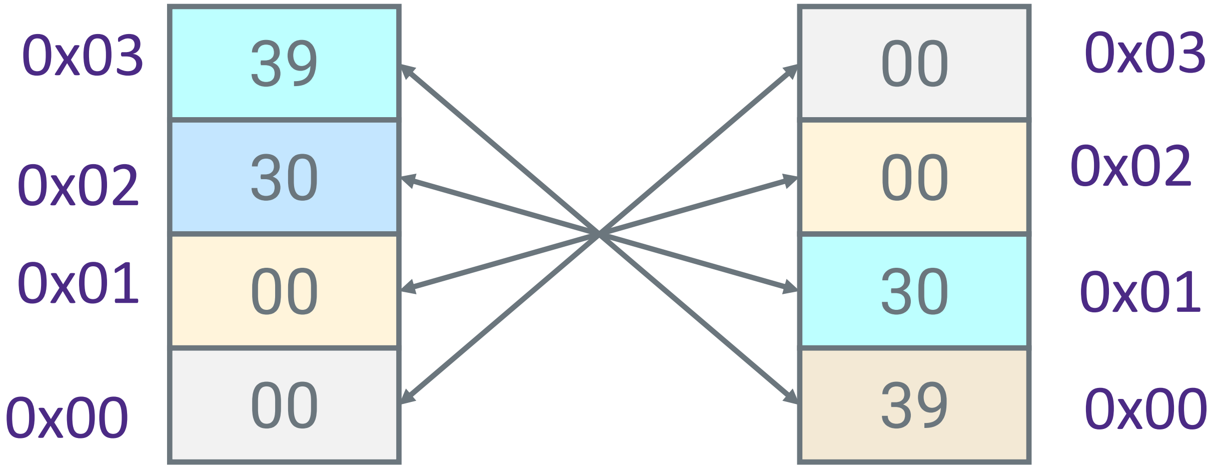
00	00	30	39

MSB LSB

(big-endian)

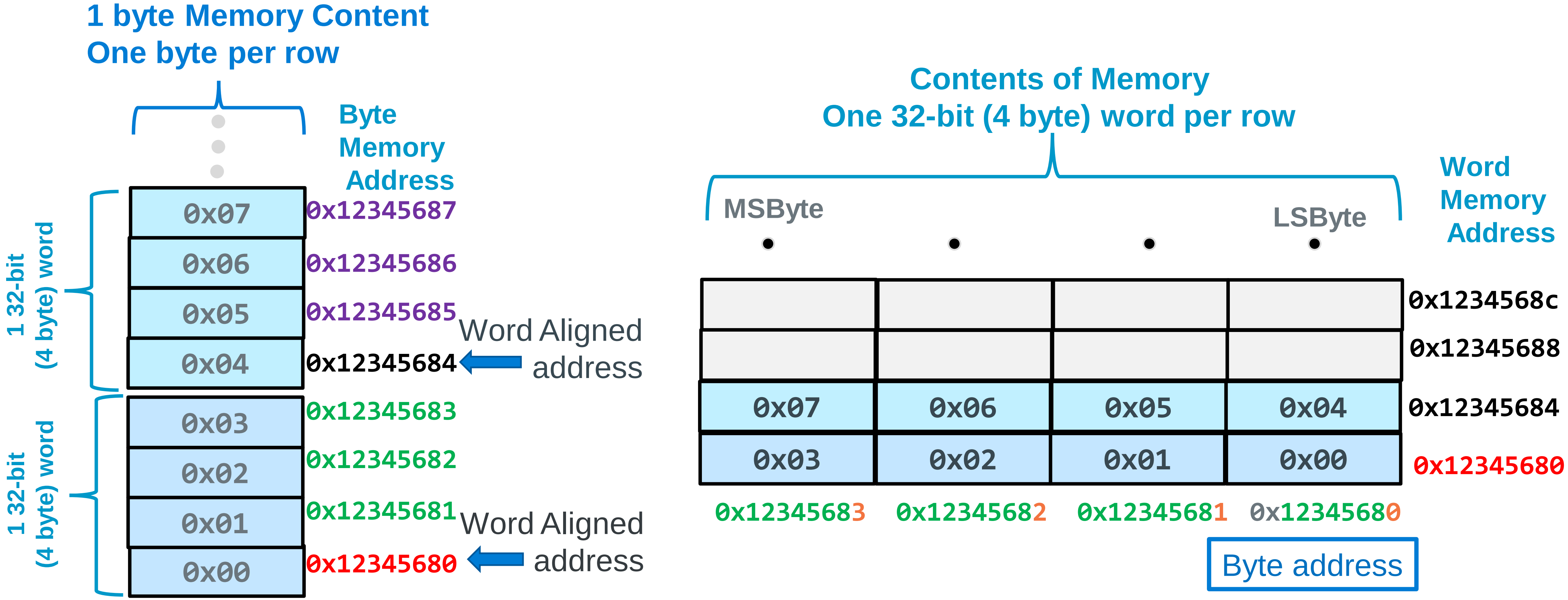
IA32, ARM32

(little-endian)



	big-endian	little-endian	
0x03	39	00	0x03
0x02	30	00	0x02
0x01	00	30	0x01
0x00	00	39	0x00

Byte Addressable Memory Shown as 32-bit words



1 byte Memory Content
One byte per row

	Byte Memory Address
0x07	0x12345687
0x06	0x12345686
0x05	0x12345685
0x04	0x12345684
0x03	0x12345683
0x02	0x12345682
0x01	0x12345681
0x00	0x12345680

1 32-bit (4 byte) word

1 32-bit (4 byte) word

Word Aligned address

Word Aligned address

Contents of Memory
One 32-bit (4 byte) word per row

MSByte			LSByte	Word Memory Address
				0x1234568c
				0x12345688
0x07	0x06	0x05	0x04	0x12345684
0x03	0x02	0x01	0x00	0x12345680
0x12345683	0x12345682	0x12345681	0x12345680	

Byte address

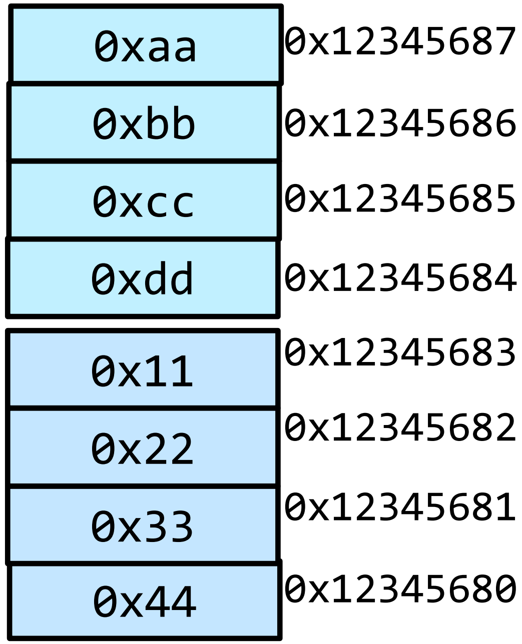
Observation
32-bit aligned addresses
rightmost 2 bits of the address are always 0

X

Using pointers to examine byte order (on pi-cluster)

```
#include <stdio.h>
#define SZ 2
int main()
{
    unsigned int foo[SZ] = {0x11223344, 0xaabbccdd};
    unsigned int *iptr = foo;
    unsigned char *chptr = (unsigned char *)foo;


    for (int i = SZ-1; i >=  0; i--)
        printf("foo[%d]: %x\n", i, *(iptr + i));

    for (int i = sizeof(foo)-1; i >= 0; i--)
        printf("byte %d: %x\n", i, (unsigned int)*(chptr + i));
    return 0;
}
```

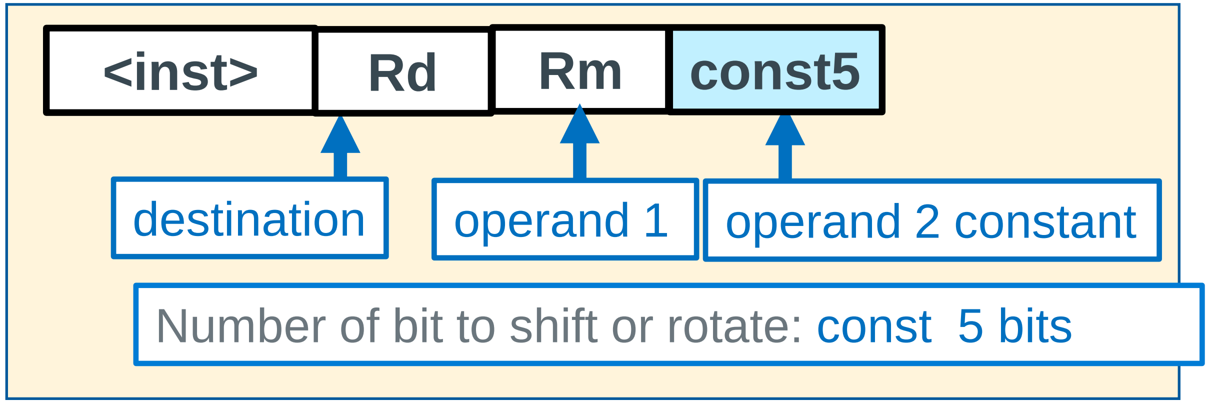
```
kmuller@keithm-pi4:~$ ./a.out
foo[1]: aabbccdd
foo[0]: 11223344
byte 7: aa
byte 6: bb
byte 5: cc
byte 4: dd
byte 3: 11
byte 2: 22
byte 1: 33
byte 0: 44
```



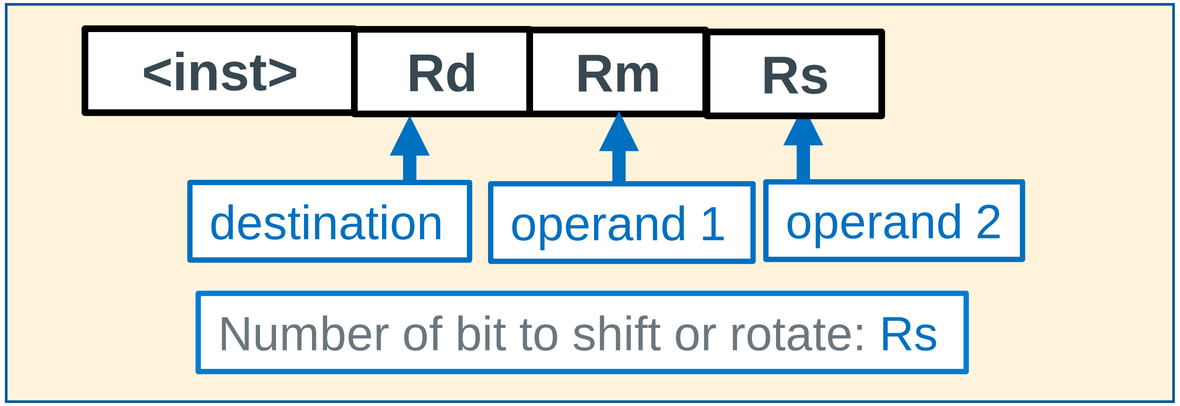
0xaa	0x12345687
0xbb	0x12345686
0xcc	0x12345685
0xdd	0x12345684
0x11	0x12345683
0x22	0x12345682
0x33	0x12345681
0x44	0x12345680

X

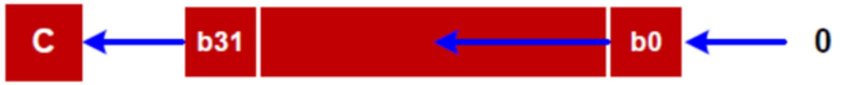
Shift and Rotate Instructions

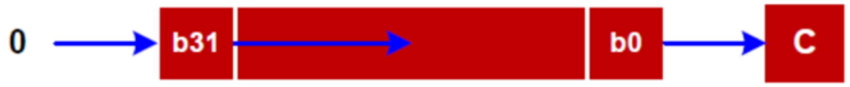


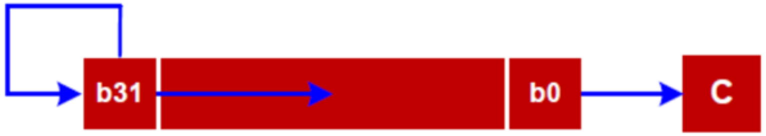
Number of bit to shift or rotate: const 5 bits

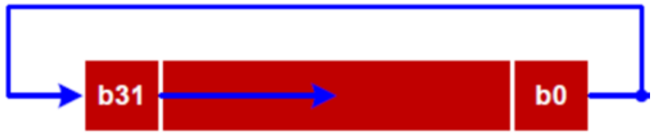


Number of bit to shift or rotate: Rs

Instruction	*Syntax*	*Operation*	*Notes*	*Diagram*
Logical Shift Left int x; or unsigned int x x << n;	lsl R_d, R_m, *const5* lsl R_d, R_m, R_s	R_d ← R_m << *const5* R_d ← R_m << R_s	Zero fills shift: 0 - 31	

Logical Shift Right
unsigned int x;
x >> n;
	lsr R_d, R_m, *const5*
	lsr R_d, R_m, R_s
		R_d ← R_m >> *const5*
		R_d ← R_m >> R_s
			Zero fills
			shift: 1 – 32
				

Arithmetic Shift Right
int x;
x >> n;
	asr R_d, R_m, *const5*
	asr R_d, R_m, R_s
		R_d ← R_m >> *const5*
		R_d ← R_m >> R_s
			Sign extends
			shift: 1 - 32
				

Rotate Right
unsigned int x;
x = (x>>n)|(x<<(32-n));
	ror R_d, R_m, *const5*
	ror R_d, R_m, R_s
		R_d ← R_m ror *const5*
		R_d ← R_m ror R_s
			right rotate
			rot: 0 - 31
				

Shift Operations in C

- n is number of bits to shift a variable x of width w bits
- Shifts by `n < 0` or `n ≥ w` are *undefined*
- Left shift (`x << N`) – **Multiplies by 2^N**
  - Shift N bits left, Fill with `0`s on right
- **In C:** behavior of >> is determined by compiler
  - gcc: it depends on data type of `x` (signed/unsigned)
- Right shift (`x >> N`) - **Divides by 2^N**
  - Logical shift (for unsigned variables)
    - Shift N bits right, Fill with 0s on left
  - Arithmetic shift (for signed variables) – Sign Extension
    - Shift N bits right while **<u>Replicating</u>** the most significant bit on left
    - Maintains sign of `x`
- **In Java:** logical shift is **>>>** and arithmetic shift is >>

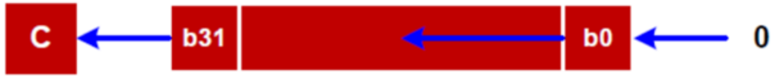
unsigned int x =7;

x>>2// logical

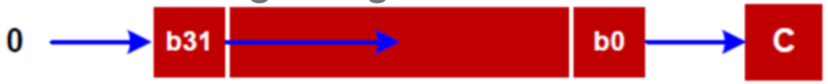
intx =7;

x>>2 :// arithmetic

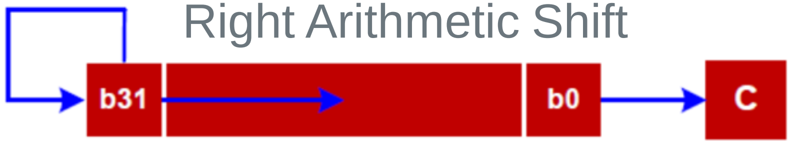
Left Shift



Right logical Shift

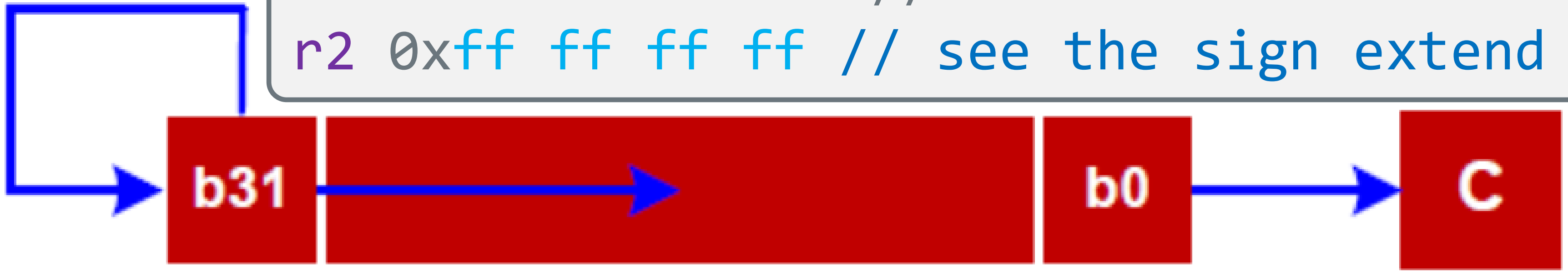


Right Arithmetic Shift



Arithmetic Shift Right Example: Testing Sign

```
asr r2, r0, 31

r0 0xab ab ab 77  // bit 31 is a one
r2 0xff ff ff ff // see the sign extend
```



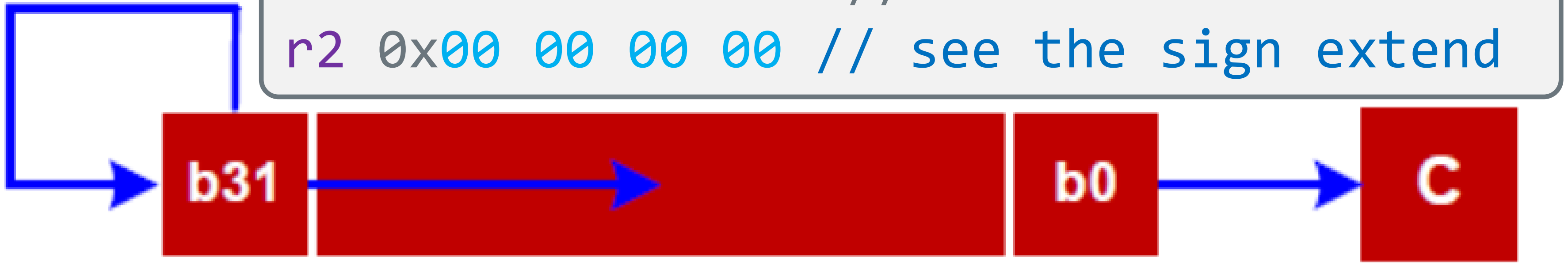
Test for sign
-1 if r0 negative

```
int i;
//code
if ((i>>31) == -1) {
  // code neg #
}
```

```
  asr r2, r0, 31
  cmp r2, -1
  bne .Lendif
  //code neg #
.Lendif:
```

Arithmetic Shift Right Example: Testing SIgn

```
asr r2, r0, 31

r0 0x7b ab ab 77  // bit 31 is a zero
r2 0x00 00 00 00 // see the sign extend
```

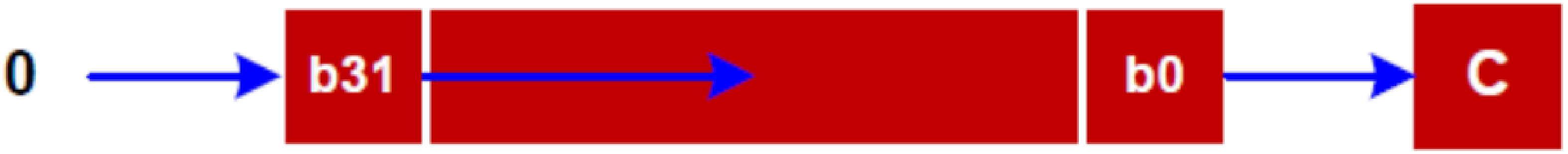


```
int i;
//code
if ((i>>31) == 0) {
  // code pos #
}
```

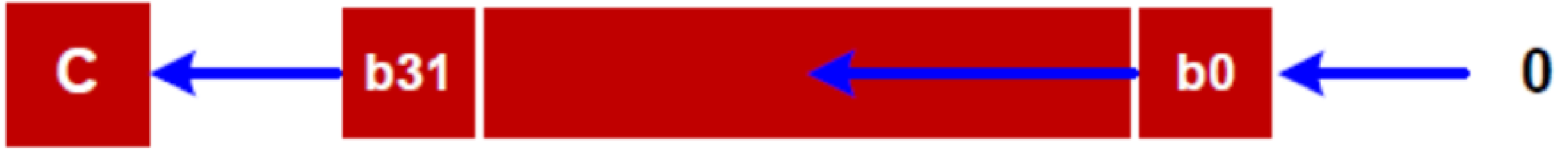
Test for sign
0 if r0 positive

```
  asr r2, r0, 31
  cmp r2, 0
  bne .Lendif
  //code positive #
.Lendif:
```

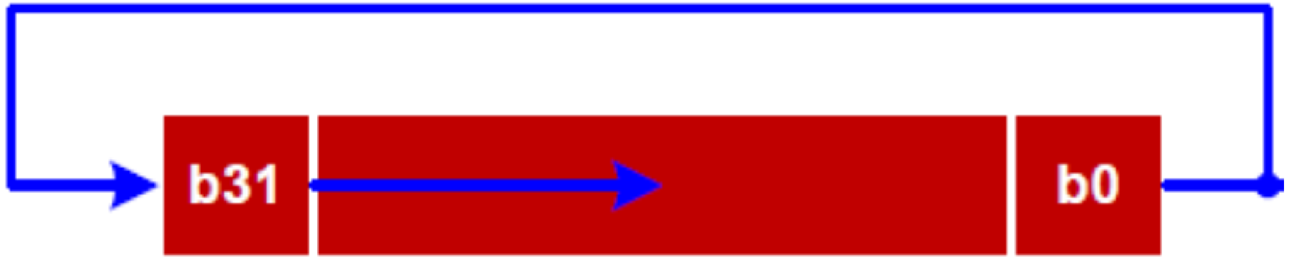
Logical Shift & Rotate Operations



```
lsr r2, r0, 8

r0 0xab ab ab 77
r2 0x00 ab ab ab
```



```
lsl r2, r0, 8

r0 0xab ab ab 77
r2 0xab ab 77 00
```

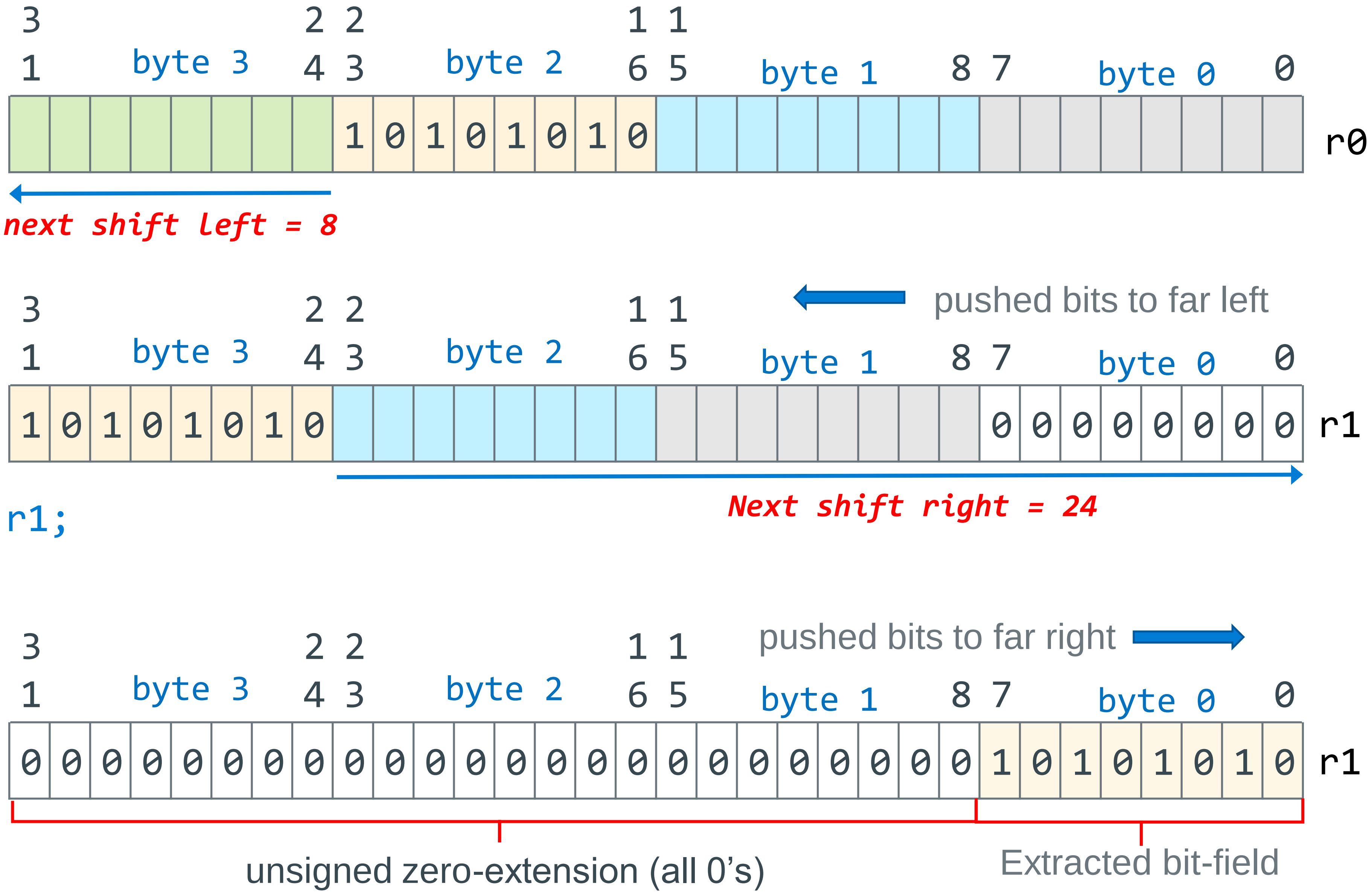


```
ror r2, r0, 8

r0 0xab ab ab 77
r2 0x77 ab ab ab
```

Extracting/Isolating Unsigned Bitfields

Hint: Useful for PA7

- Move byte 2 in r0 to byte 0 in r1



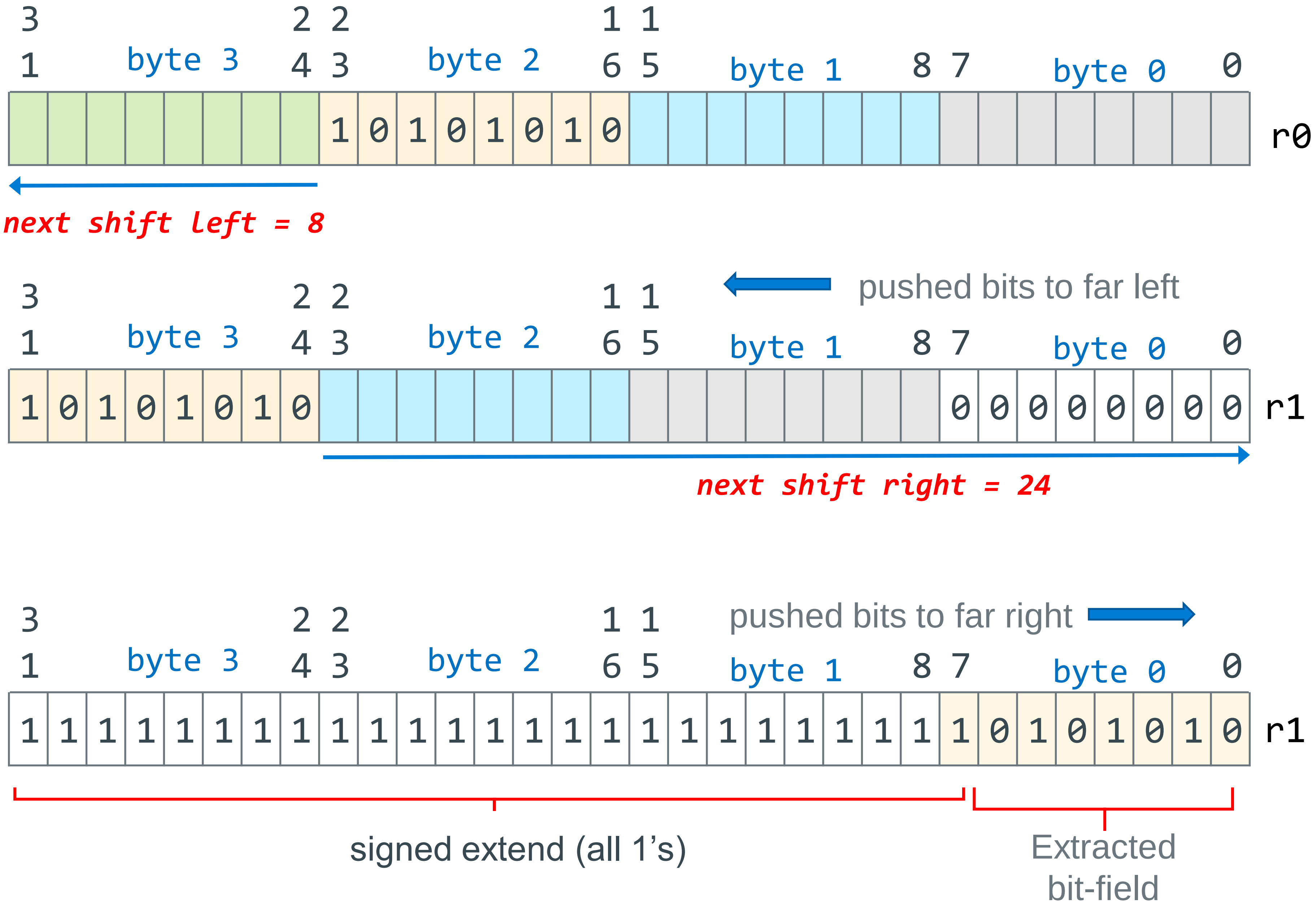
```
lsl  r1, r0, 8
```

```
unsigned int r0,r1;
r1 = r0 << 8;
```

```
lsr  r1, r1, 24
r1 = r1 >> 24;
```

Extracting Signed Bitfields

- Move byte 2 in r0 to byte 0 in r1



r0: `_ _ _ _ _ _ _ _ 1 0 1 0 1 0 1 0 _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _`

r1: `1 0 1 0 1 0 1 0 _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ 0 0 0 0 0 0 0 0`

r1: `1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 0 1 0 1 0`

```
lsl  r1, r0, 8
int r0,r1;
r1 = r0 << 8;
```

```
asr  r1, r1, 24
r1 = r1 >> 24;
```

X

Inserting Bitfields – Inserting Source Field into Destination Field

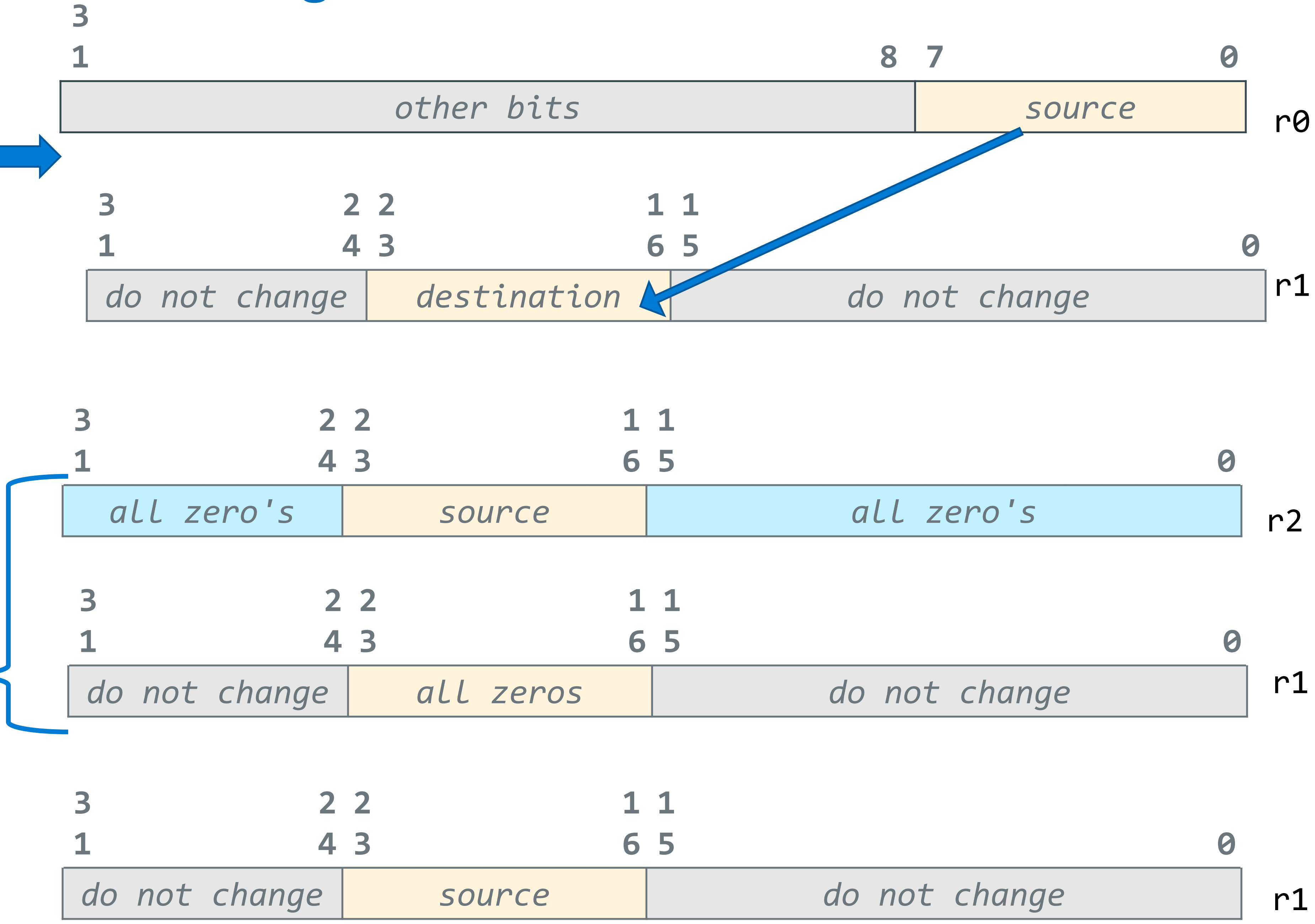
Task: Insert source into destination

a	b	a | b
0	0	0
0	1	1
1	0	1
1	1	1

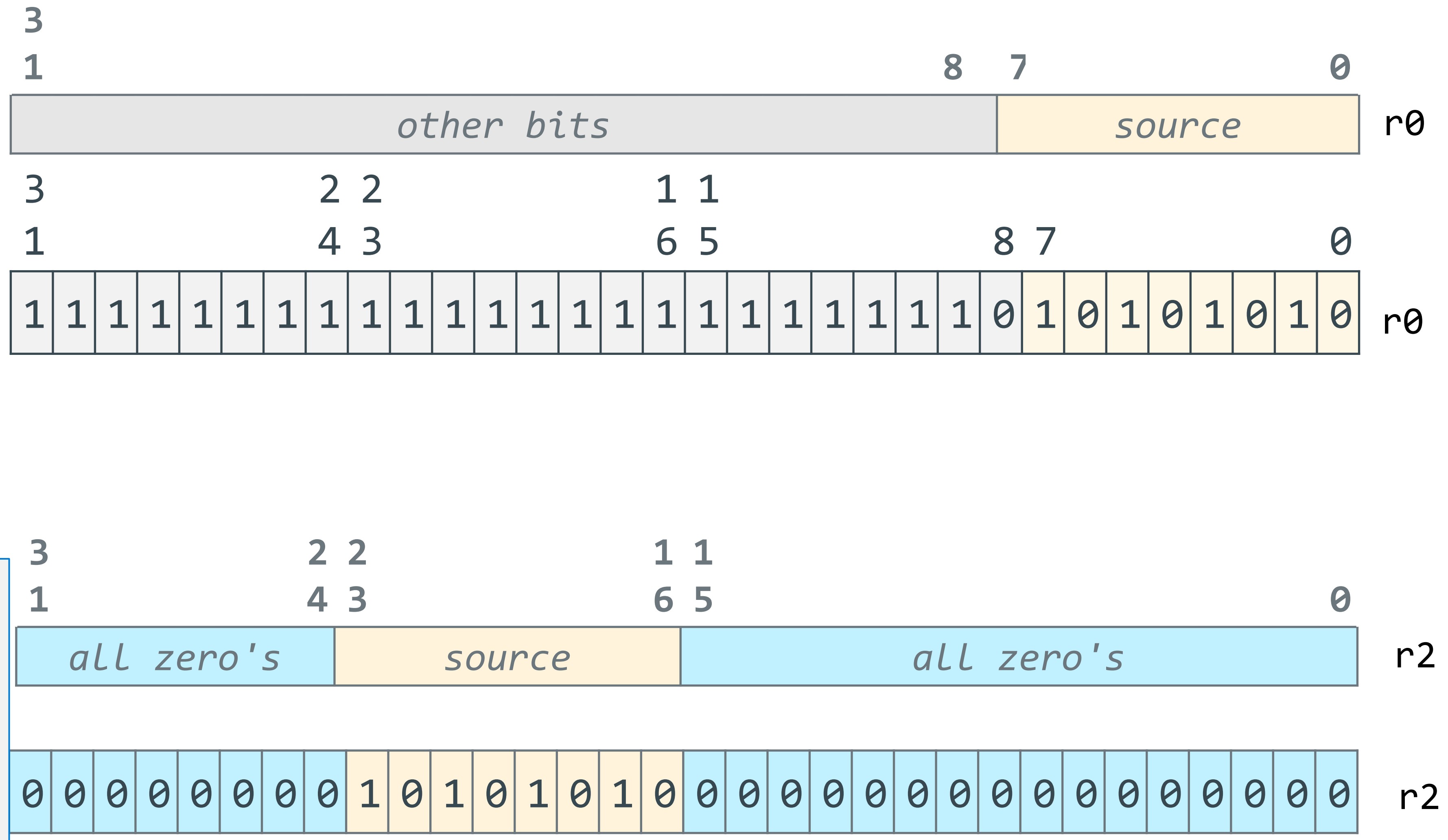
Approach
(1) isolate source field
(2) clear destination field
(3) Bitwise or together

```
orr    r1, r1, r2
r1 =   r1 | r2;
```

results in



Inserting Bitfields – Isolating the Source Field

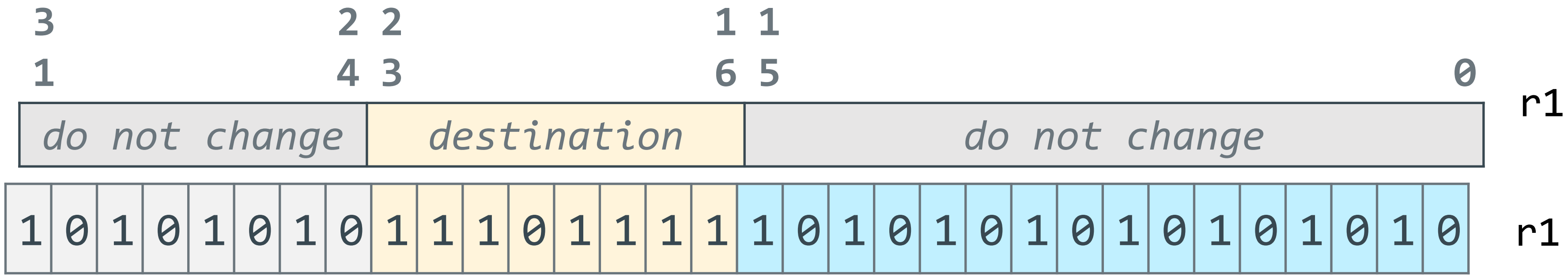


r0: 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 0 1 0 1 0 1 0

r2: 0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

```
isolate source field

lsl    r2, r0, 24
lsr    r2, r2, 8

r2 = r0 << 24;
r2 = r2 >> 8;
```

Inserting Bitfields – Clearing the Destination Field

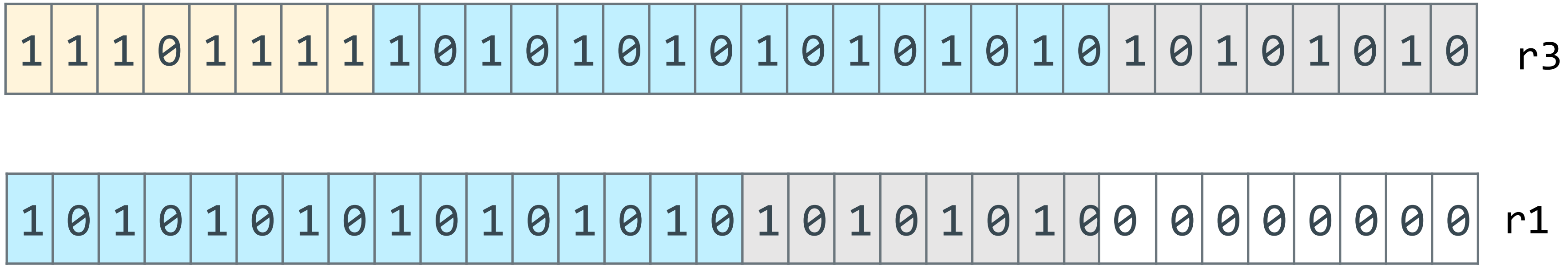


3 1   2 4   2 3   1 6   1 5   0

do not change | *destination* | *do not change*   r1

1 0 1 0 1 0 1 0 1 1 1 0 1 1 1 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0   r1

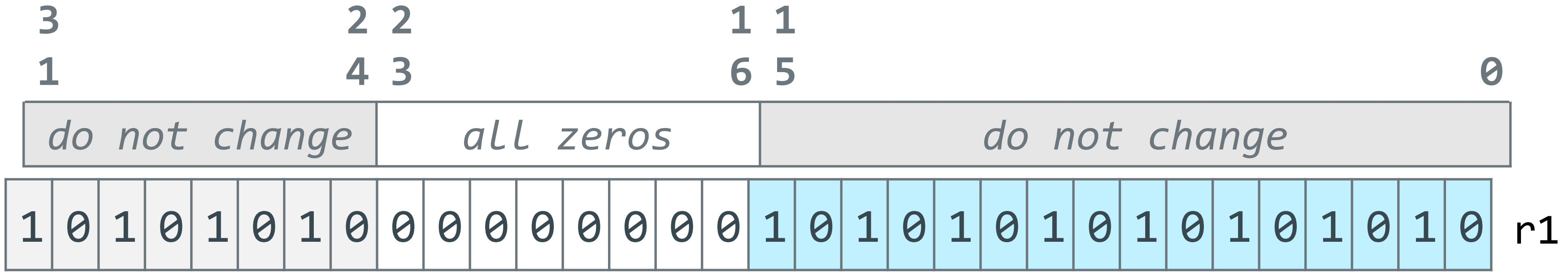
```
clear the
destination field
ror    r1, r1, 24
r1=(r1>>24)|(r1<<8);
```



1 1 1 0 1 1 1 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0   r3

1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0   r1

```
lsl    r1, r1, 8
r1 = r1 << 8;
```



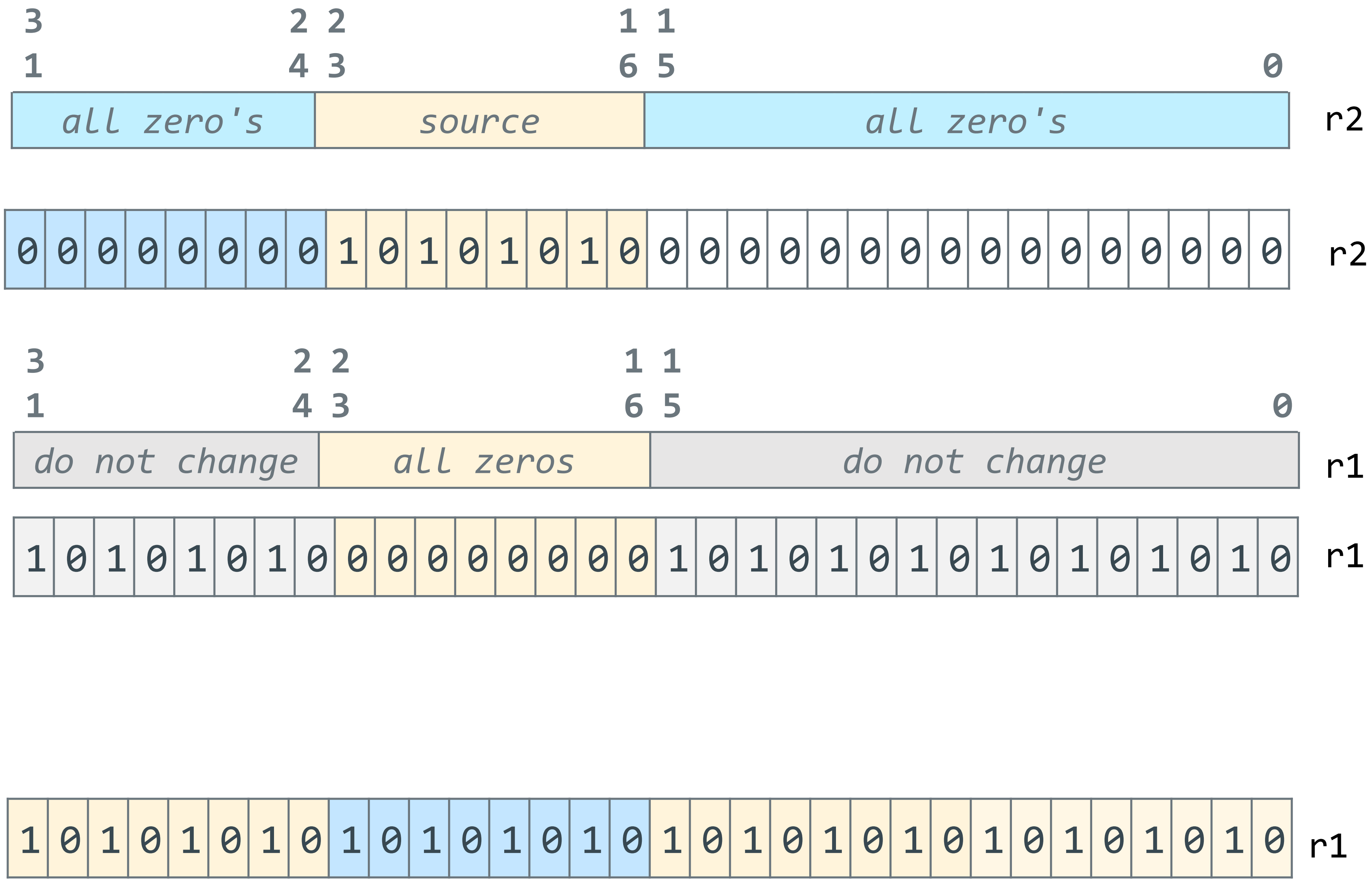
3 1   2 4   2 3   1 6   1 5   0

do not change | *all zeros* | *do not change*

1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0   r1

```
ror    r1, r1, 16
r1= (r1>>16)|(r1<<16);
```

Inserting Bitfields –
Combining Isolated Source and Cleared Destination



isolated source

31 24 23 16 15 0

all zero's	source	all zero's	r2

0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 r2

field cleared in destination

31 24 23 16 15 0

do not change	all zeros	do not change	r1

1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 r1

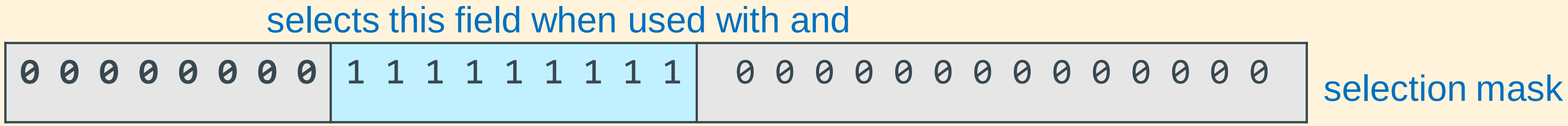
inserted field

```
orr    r1, r1, r0
r1 = r1 | r0;
```

1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 r1

Masking Summary

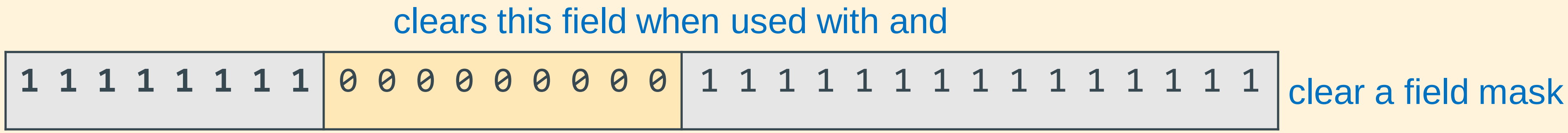
Select a field: Use `and` with a mask of one's surrounded by zero's to select the bits that have a 1 in the mask, all other bits will be set to zero


selects this field when used with and

0 0 0 0 0 0 0 0 | 1 1 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0

selection mask

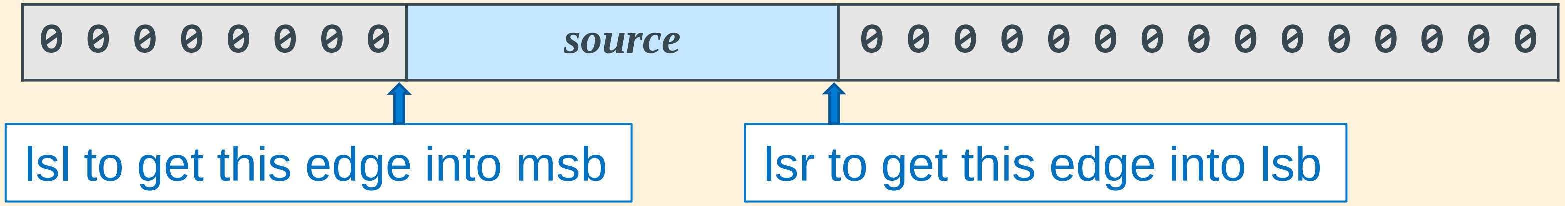
Clear a field: Use `and` with a mask of zero's surrounded by one's to select the bits that have a 1 in the mask, all other bits will be set to zero


clears this field when used with and

1 1 1 1 1 1 1 1 | 0 0 0 0 0 0 0 0 0 | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

clear a field mask

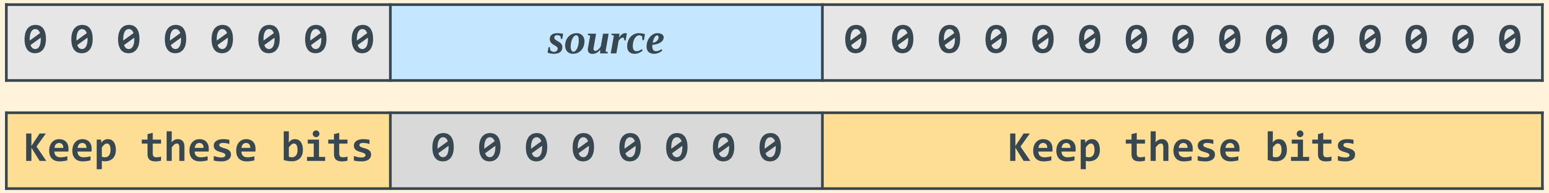
Isolate a field: Use `lsr, lsl, rot` to get a field surrounded by zeros


0 0 0 0 0 0 0 0 | *source* | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

lsl to get this edge into msb

lsr to get this edge into lsb

Insert a field: Use `orr` with fields surrounded by zeros


0 0 0 0 0 0 0 0 | *source* | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Keep these bits | 0 0 0 0 0 0 0 0 | Keep these bits