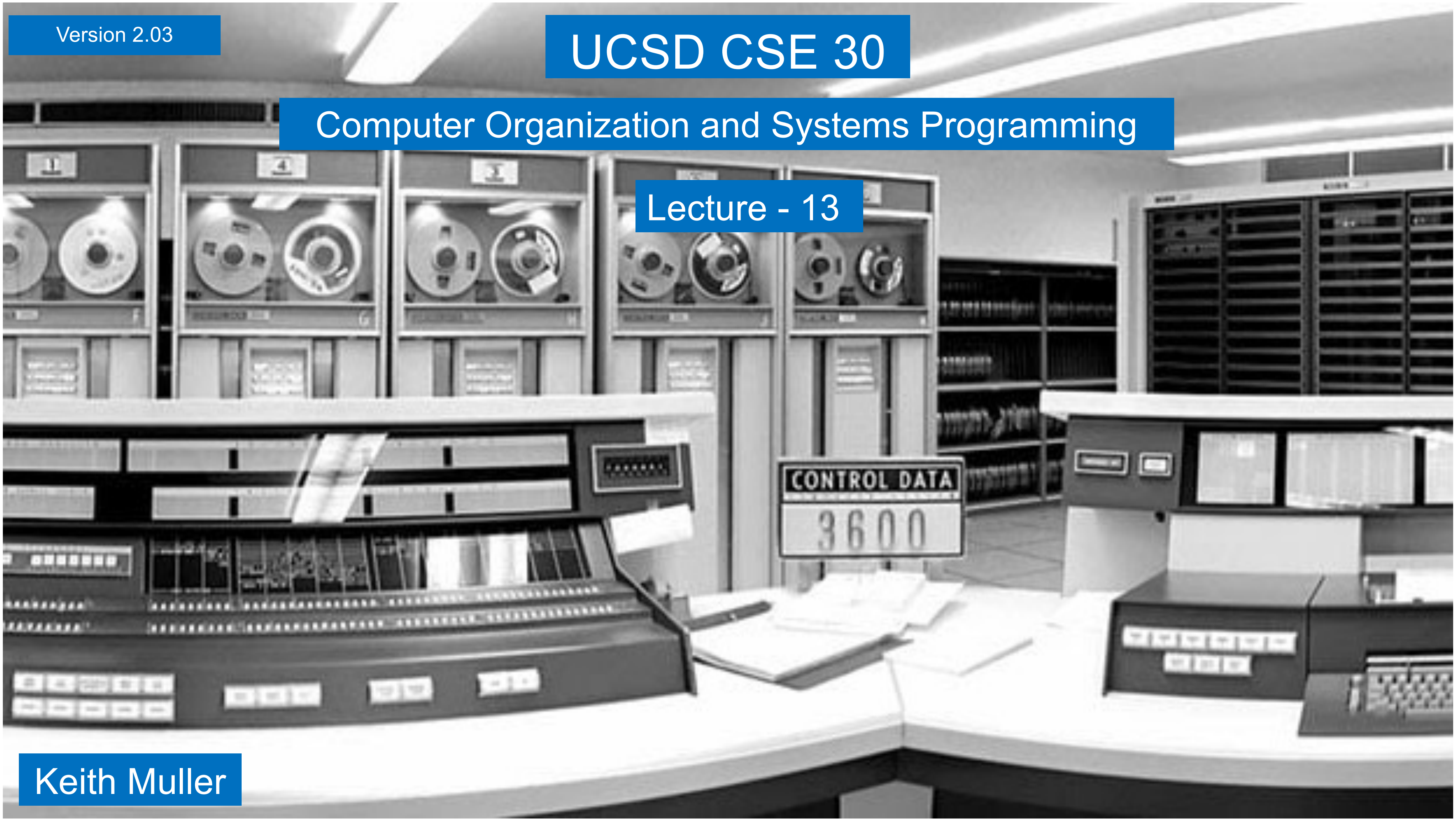
Version 2.03

UCSD CSE 30

Computer Organization and Systems Programming

Lecture - 13

Keith Muller



Program Flow – Counting (For) Loop Version 1

Pre loop setup

Pre-test Loop guard

Post loop update

```
for (r1 = 0; r1 < 10; r1++) {
    /* block */
}
```

A **counting loop** has three parts:

1. Pre-loop setup
2. Pre-test loop guard conditions
3. Post-loop update

Pre loop setup

Pre-test loop guard

Post loop update

```
    mov r1, 0
.Lfor:

    cmp r1, 10
    bge .Lendfr

    // block code

    add r1, r1, 1
    b .Lfor

.Lendfr:
```


x

Program Flow – Counting (For) Loop – Version 2

Pre loop setup | Pre-test Loop guard | Post loop update

```
for (r1 = 0; r1 < 10; r1++) {
    /* block */
}
```

- Alternative:
- move Pre-test loop guard before the loop
- Add post-test loop guard
    - *converts* to *do while*
    - **removes** an **unconditional branch**

Pre-loop setup → `mov r1, 0`

Pre-test loop guard → `cmp r1, 10` / `bge .Lendfr`

Post loop update → `add r1, r1, 1`

Post-test loop guard → `cmp r1, 10` / `blt .Ldo`

```
    mov r1, 0

    cmp r1, 10
    bge .Lendfr

.Ldo:

    // block code

    add r1, r1, 1

    cmp r1, 10
    blt .Ldo

.Lendfr:
```


x

Nested loops

```
for (r3 = 0; r3 < 10; r3++) {
    r0 = 0;

    do {
        r0 = r0 + r1++;
    } while (r1 < 10);

    // fall through
    r2 = r2 + r1;
}
r5 = r0;
```

```
    mov r3, 0
.Lfor:
    cmp r3, 10      // loop guard
    bge .Lendfor

    mov r0, 0

.Ldo:
    add r0, r0, r1
    add r1, r1, 1

    cmp r1, 10   // loop guard
    blt .Ldo

    // fall through
    add r2, r2, r1

    add r3, r3, 1 // loop iteration
    b .Lfor
.Lendfor:
    mov r5, r0
```

- Nest loop blocks as you would in C or Java

x

Keep loops Properly Nested:
Do not branch into the middle of a loop

- It is hard to understand and debug loops when you branch into the middle of a loop
- **Keep loops proper nested**

Do not do the following:

```
.Lloop1:
    add r1, r1, 1
.Lloop2:
    add r2, r2, 1
    add r2, r1, r3
    cmp r1, 10
    blt .Lloop1
    beq .Lend1
    add r3, r3, 1
    cmp r2, 20
    ble .Lloop2
.Lend1:
```

Bad practice: branch into loop body

x

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

`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
```


x

Bitwise Not (vs Boolean Not)

```
in 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	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
```

register r1

register r0

```
mvn   r0, 12

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

0x0c

register r0 0xffff fff3

Bitwise NOT

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

- A **bitwise NOT** operation

0x 0c

imm8 expansion

0x0000000c

bitwise not

0xfffffff3

x

mvn – Copies NOT (~)

mvn	Rd	rot4	imm8
	destination register	constant (immediate value)	

mvn	Rd	Rm
	destination register	source register

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

~ 1100

0011

Bitwise NOT

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
```

invert the bits

copy into 32 bits zero extend

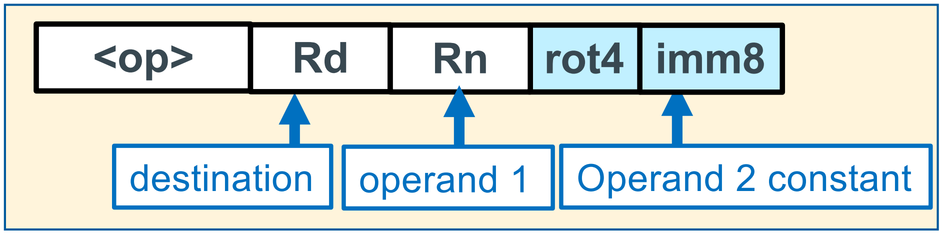
r1 0xfffffffb ← 0x00000004 ← 0x4

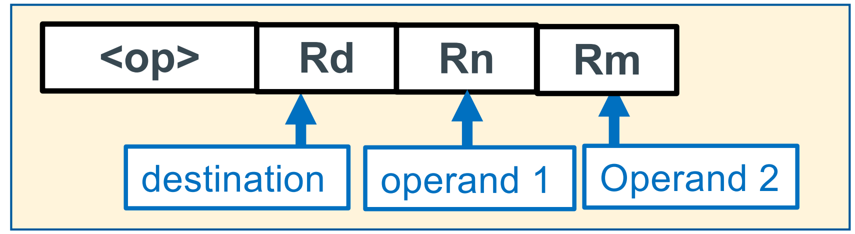
r1 0x55555555 ← 0xaaaaaaaa r5

r1 0x11111111 ← 0x0

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

Bitwise versus C Boolean Operators

Boolean Operators | Bitwise Operators

Meaning	Operator		Operator	Meaning
Boolean AND	a && b		a & b	Bitwise AND
Boolean OR	a || b		a | b	Bitwise OR
Boolean NOT	!b		~b	Bitwise NOT

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

bitwise & versus boolean &&

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

bitwise ~ versus boolean !

```
~0x01 = 0xfffffffe (bitwise)
!0x01 = 0x0 (Booelan)
```


x

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

- 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)`
- `and:` 0 clears the bit, 1 passes bit unchanged `(a = b & c; // in C)`

x

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
```

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
   unchanged              forces to a 0
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
```


x

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
unchanged                 forces to a 0
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
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
}
```

```
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

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)
```

```
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
```


x

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   77: 0111 0111
eor
MASK: r3 0x00 00 00 ff
  unchanged              inverts (flips)
RSLT: r1 0xab ab ab 88   88: 1000 1000
```

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


x

Unsigned Integers (positive numbers) with Fixed # of Bits

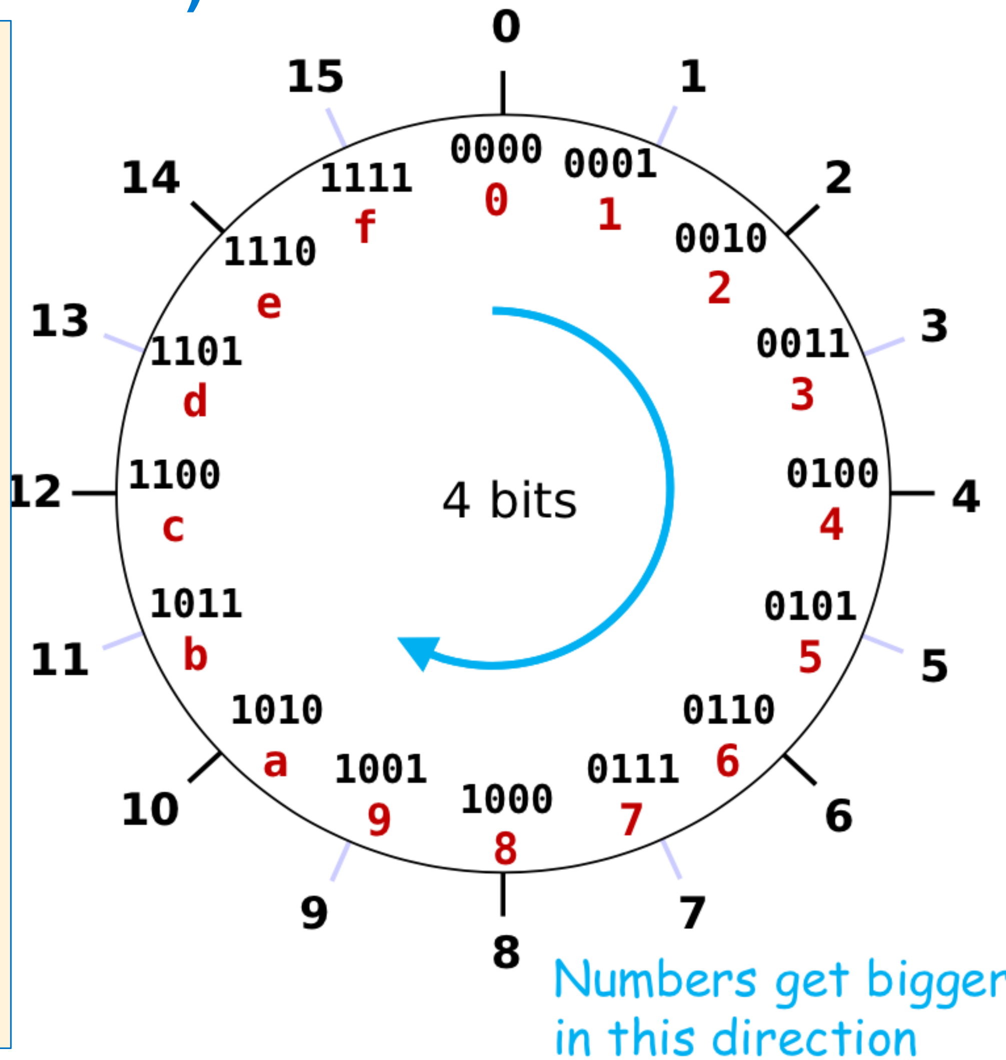
- 4 bits is 2^4 = ONLY 16 distinct values
- **Modular** (C operator: %) or clock math
  - Numbers start at 0 and "wrap around" after 15 and go back to 0
- Keep adding 1

  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



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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
- **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`)

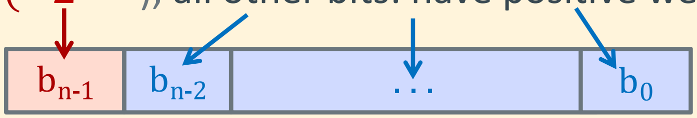
Same "width" (same number of encodings), just shifted in value

x

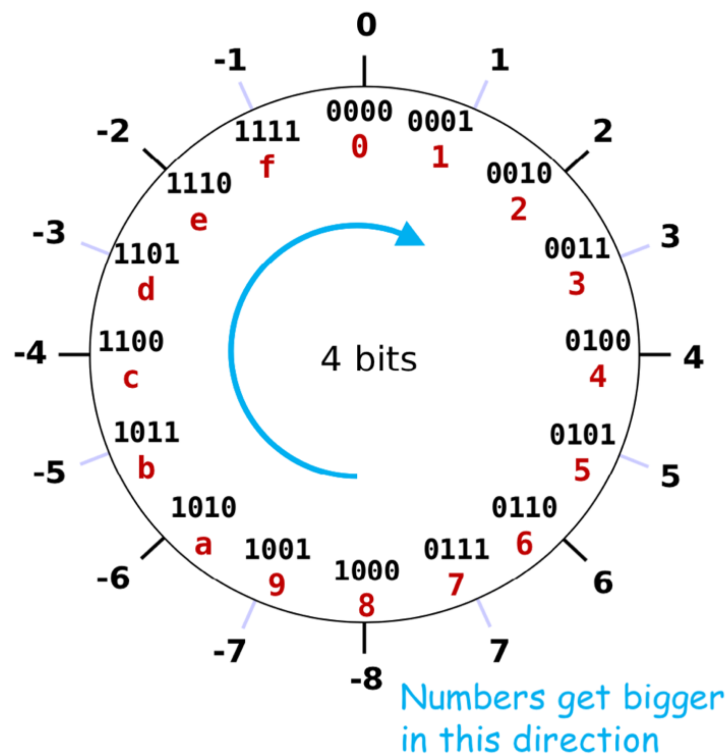
Two's Complement: The MSB Has a *Negative Weight*

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

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**:
    $1\times2^3 + 0\times2^2 + 1\times2^1 + 0\times2^0$ = **10**
  - 1010_2 **two's complement**:
    $-1\times2^3 + 0\times2^2 + 1\times2^1 + 0\times2^0 = -8 + 2 =$ **–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**



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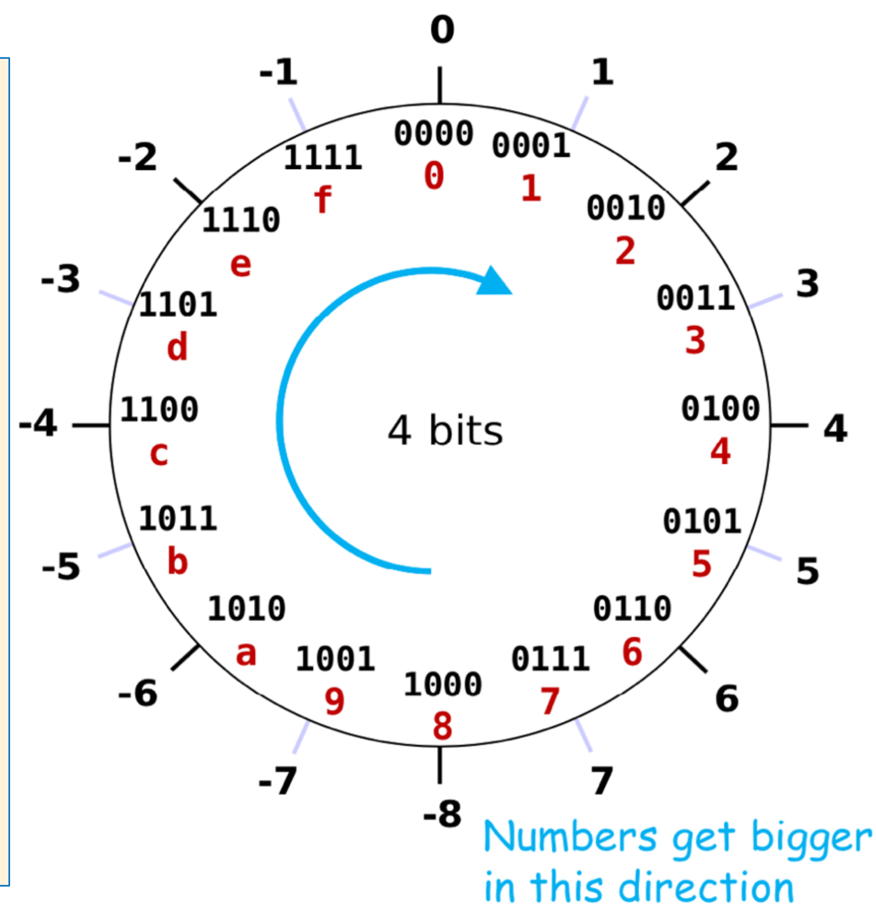
2's Complement Signed Integer Method

- 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!*



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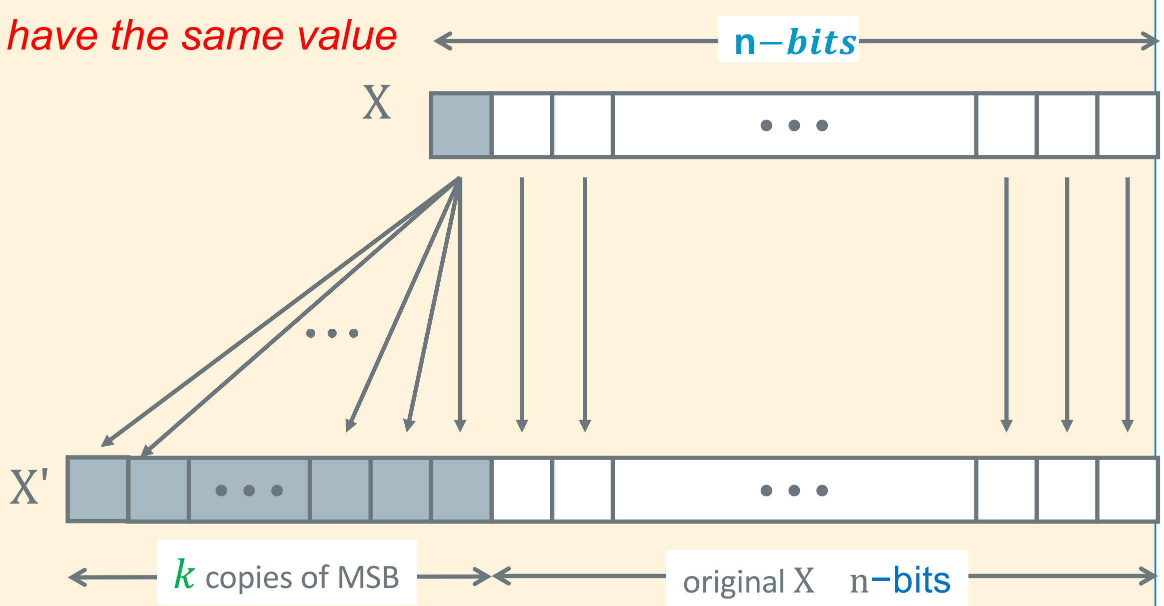
Sign Extension (how type promotion works)

- 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

x

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
```


x

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
```

```
     7 = 00000111
invert = 11111000
add 1  +        1
    -7   11111001
```

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


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;
}
```

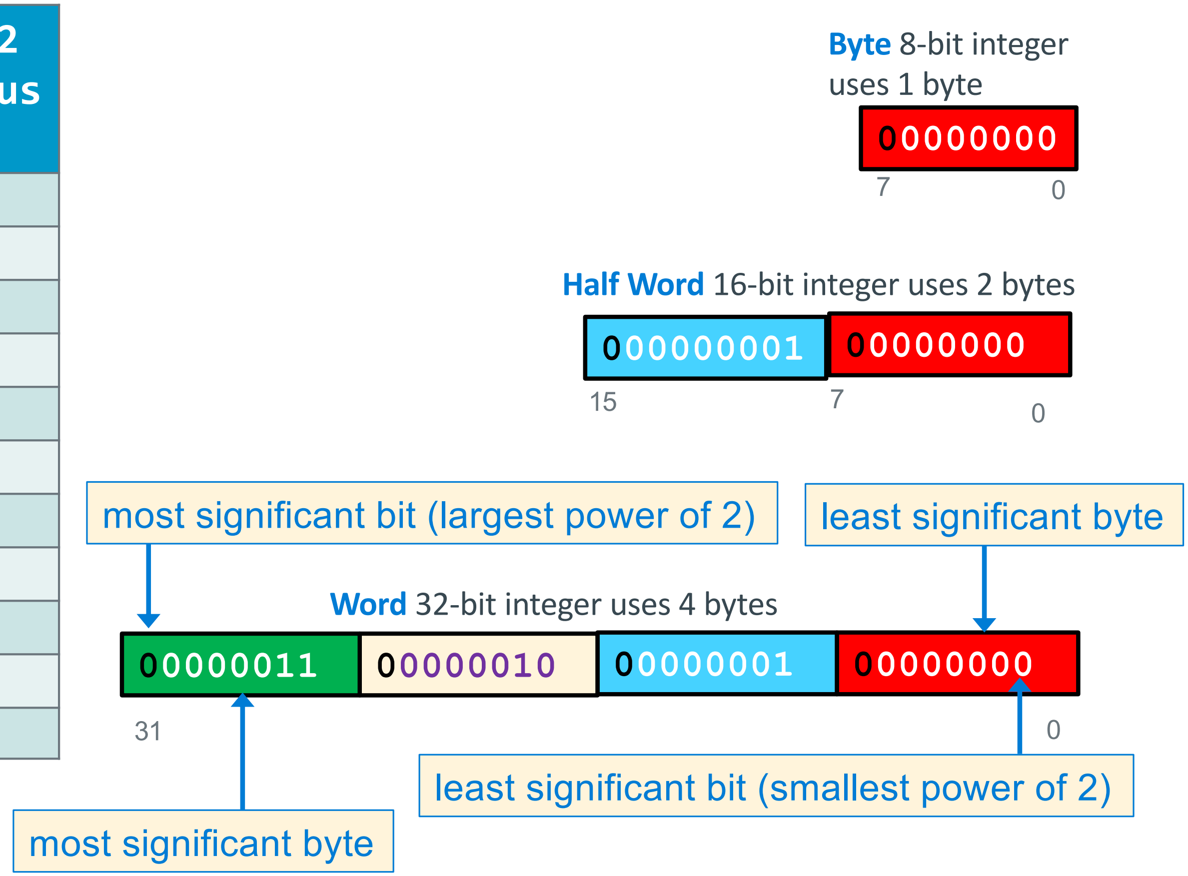
```
%./a.out
c decimal = -1
c = 0xff
i decimal = -1
i = 0xffffffff

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


x

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



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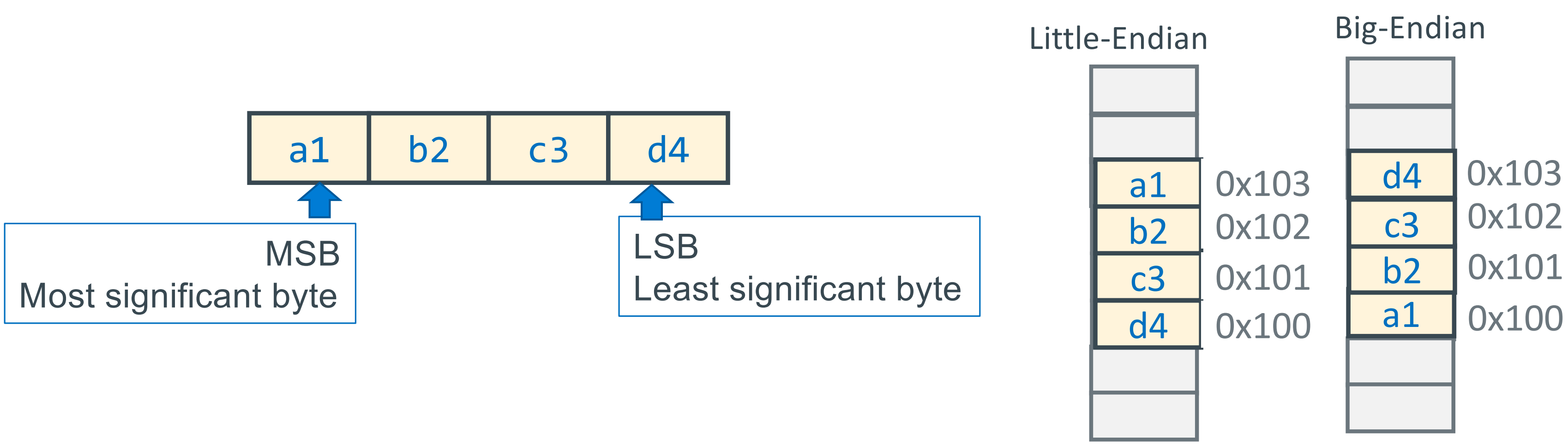
Byte Ordering of Numbers In Memory: Endianness

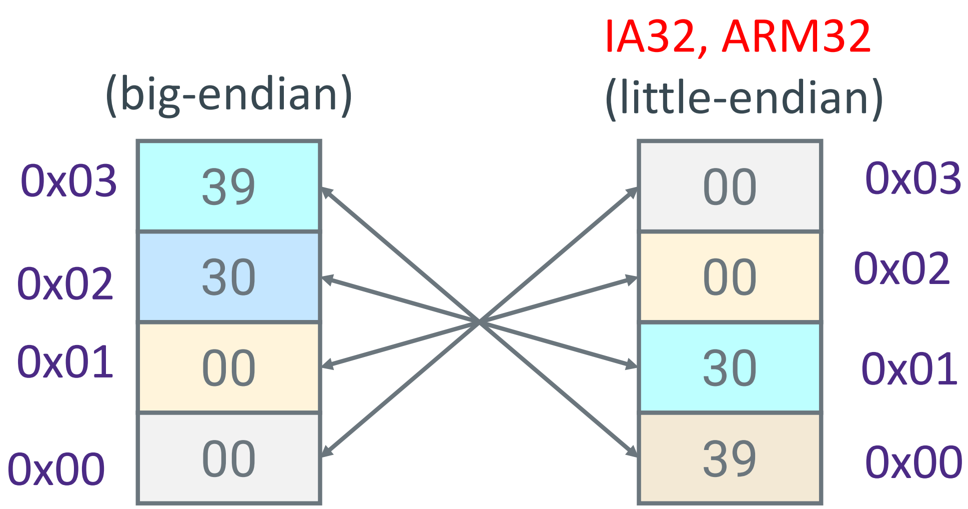
- Two different ways to place multi-byte integers in a byte addressable memory
- Big-endian: Most Significant Byte (“big end”) starts at the *lowest (starting)* address
- Little-endian: Least Significant Byte (“little end”) starts at the *lowest (starting)* address
- Example: 32-bit integer with 4-byte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



Byte Ordering Example

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

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



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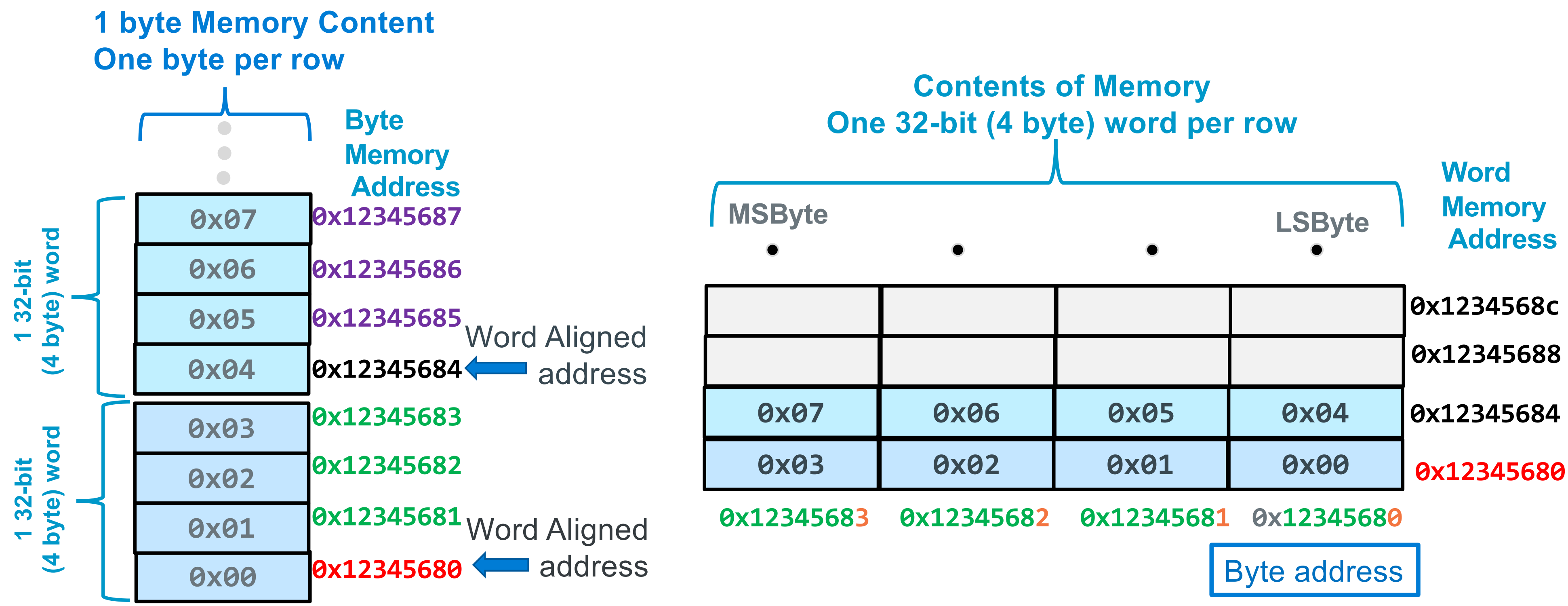
Byte Addressable Memory Shown as 32-bit words



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

x

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

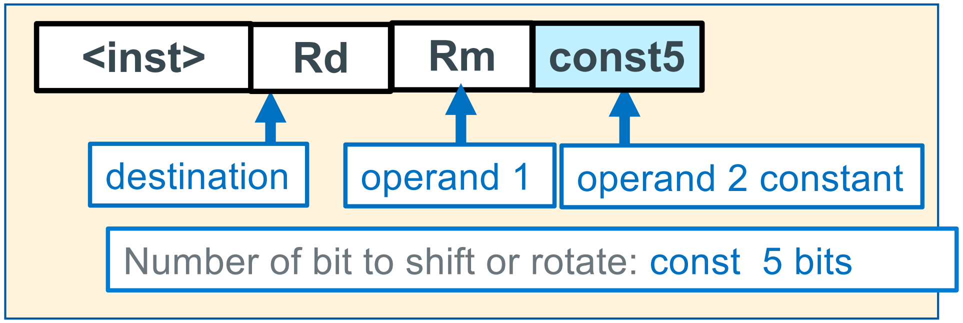
```
#include <stdio.h>
#define SZ 2
int main()
{
    unsigned int foo[SZ] = {0x11223344, 0xaabbccdd};
    unsigned int *iptr = foo;
    unsigned char *chptr = (unsigned char *)foo;


    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;
}
```

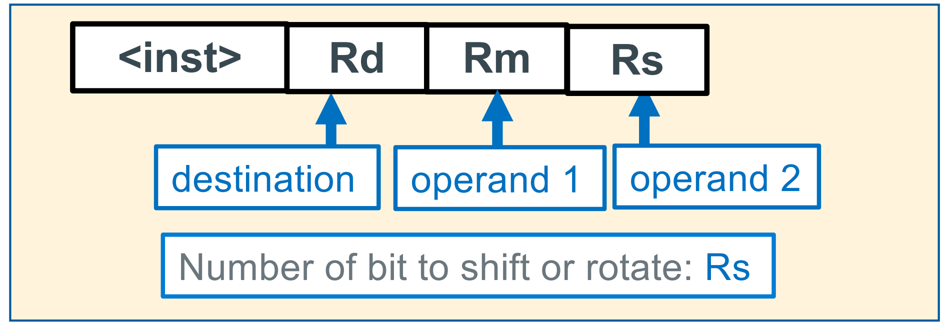
```
kmuller@keithm-pi4:~$ ./a.out
foo[1]: aabbccdd
foo[0]: 11223344
byte 7: aa
byte 6: bb
byte 5: cc
byte 4: dd
byte 3: 11
byte 2: 22
byte 1: 33
byte 0: 44
```

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

x

Shift and Rotate Instructions





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
		$R_d \leftarrow R_m$ << *const5*
		$R_d \leftarrow R_m$ << 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
		$R_d \leftarrow R_m$ >> *const5*
		$R_d \leftarrow R_m$ >> 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
		$R_d \leftarrow R_m$ >> *const5*
		$R_d \leftarrow R_m$ >> 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
		$R_d \leftarrow R_m$ ror *const5*
		$R_d \leftarrow R_m$ ror R_s
			right rotate
			rot: 0 - 31
				

x

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 **Replicating** the most significant bit on left
    - Maintains sign of `x`
- **In Java:** logical shift is **>>>** and arithmetic shift is >>

x

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

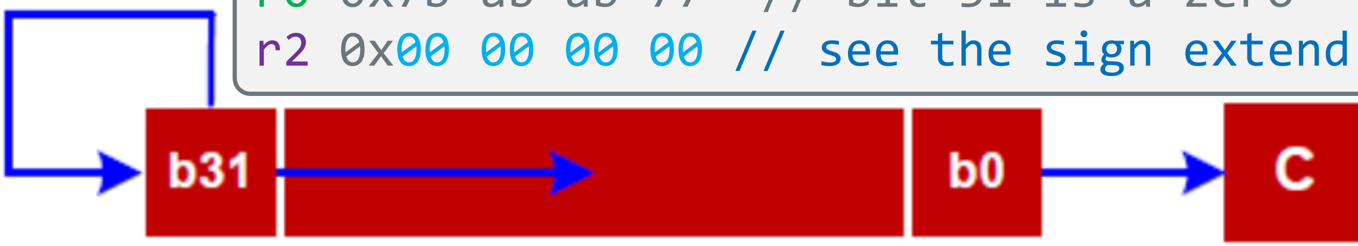
```
int i;
//code
if ((i>>31) == -1) {
  // code neg #
}
```

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


x

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
```



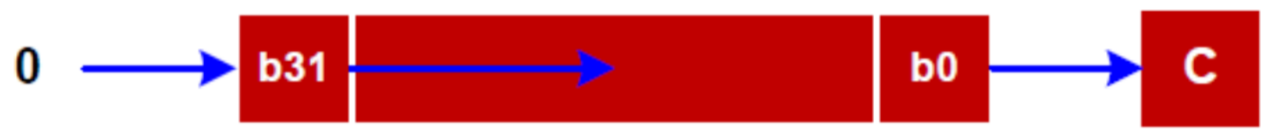
Test for sign
0 if r0 positive

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

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


x

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
```

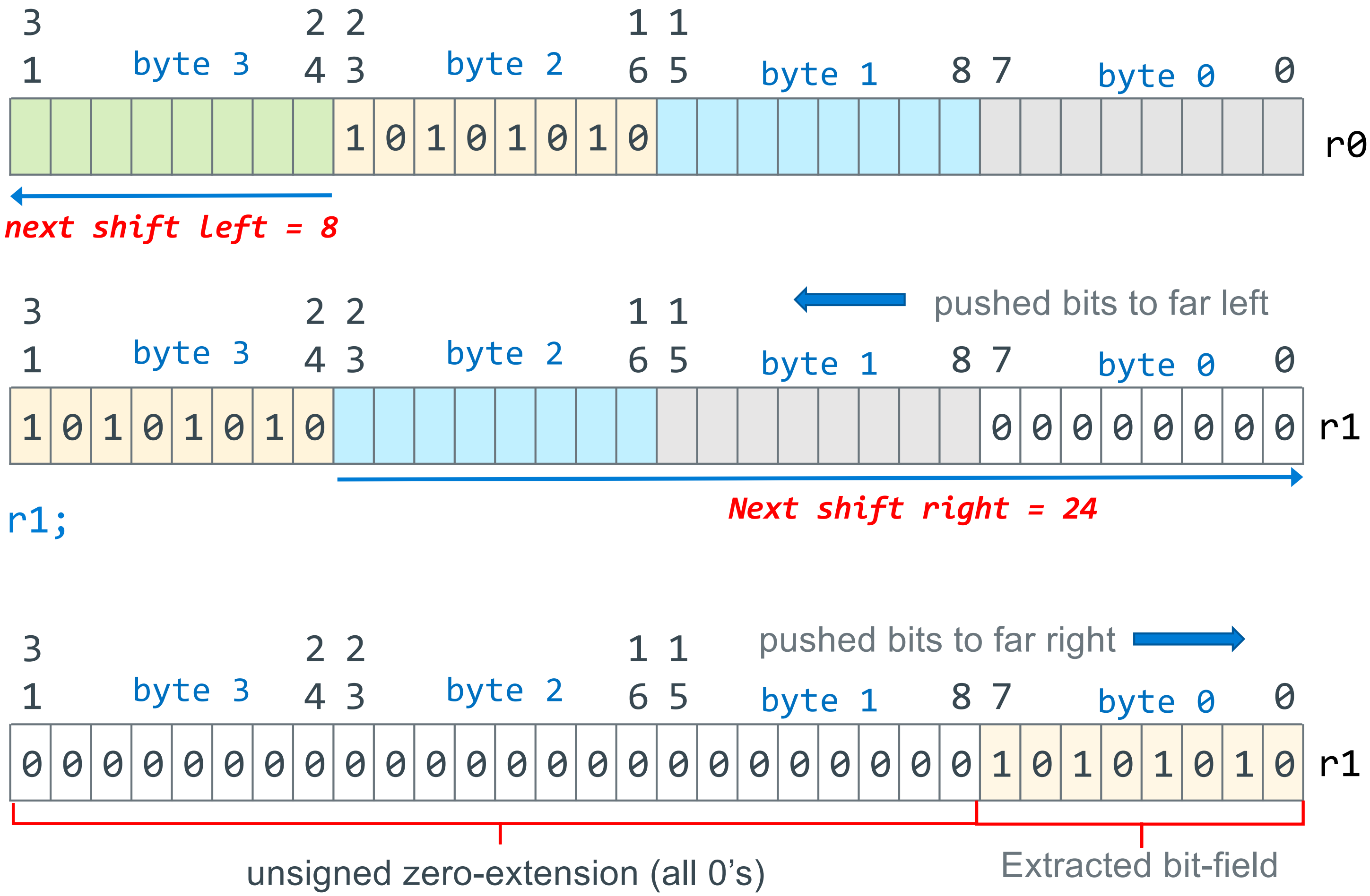

```
ror r2, r0, 8

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


x

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;
```

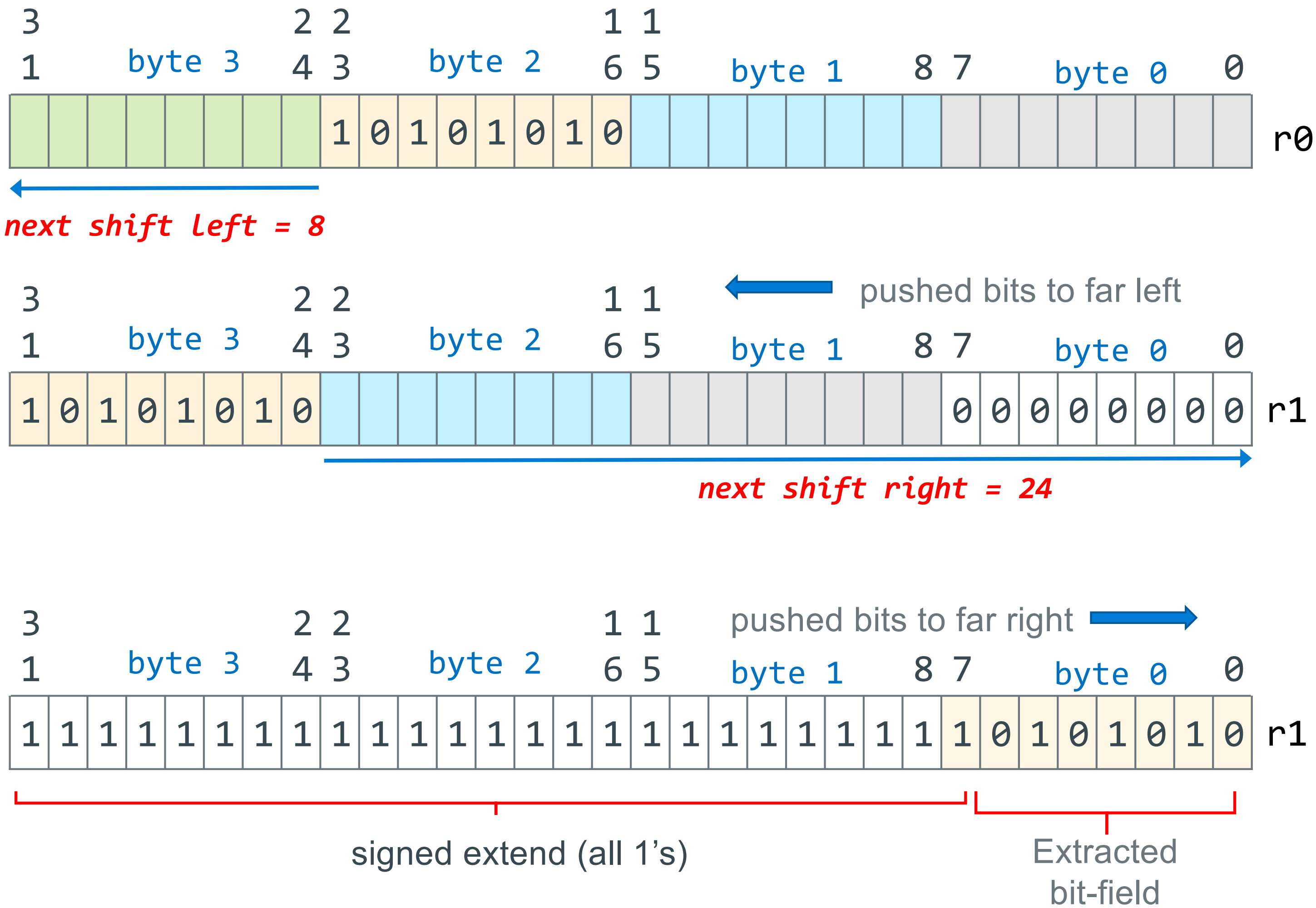

x

Extracting Signed Bitfields

- Move byte 2 in r0 to byte 0 in r1

```
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

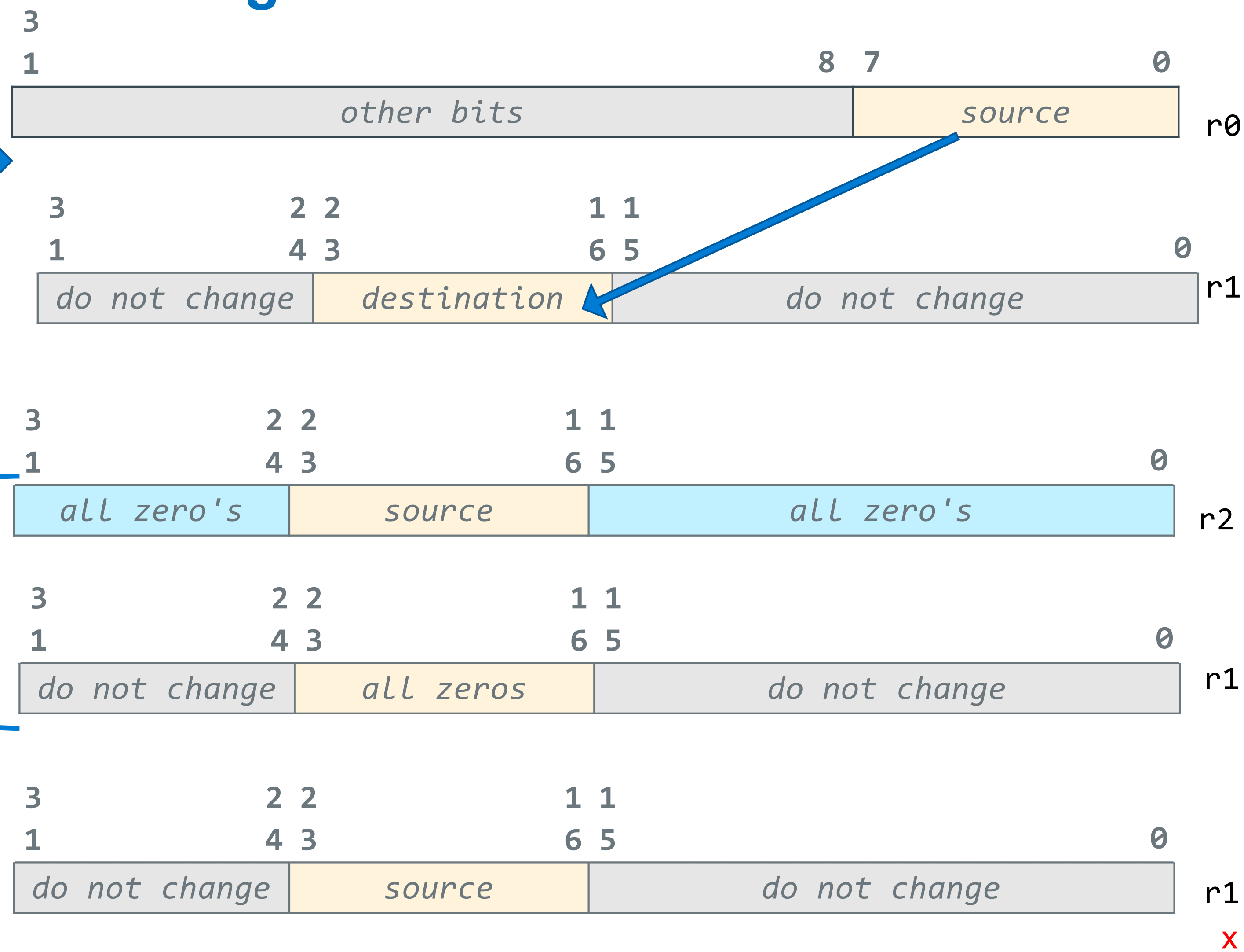
Task: Insert source into destination

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

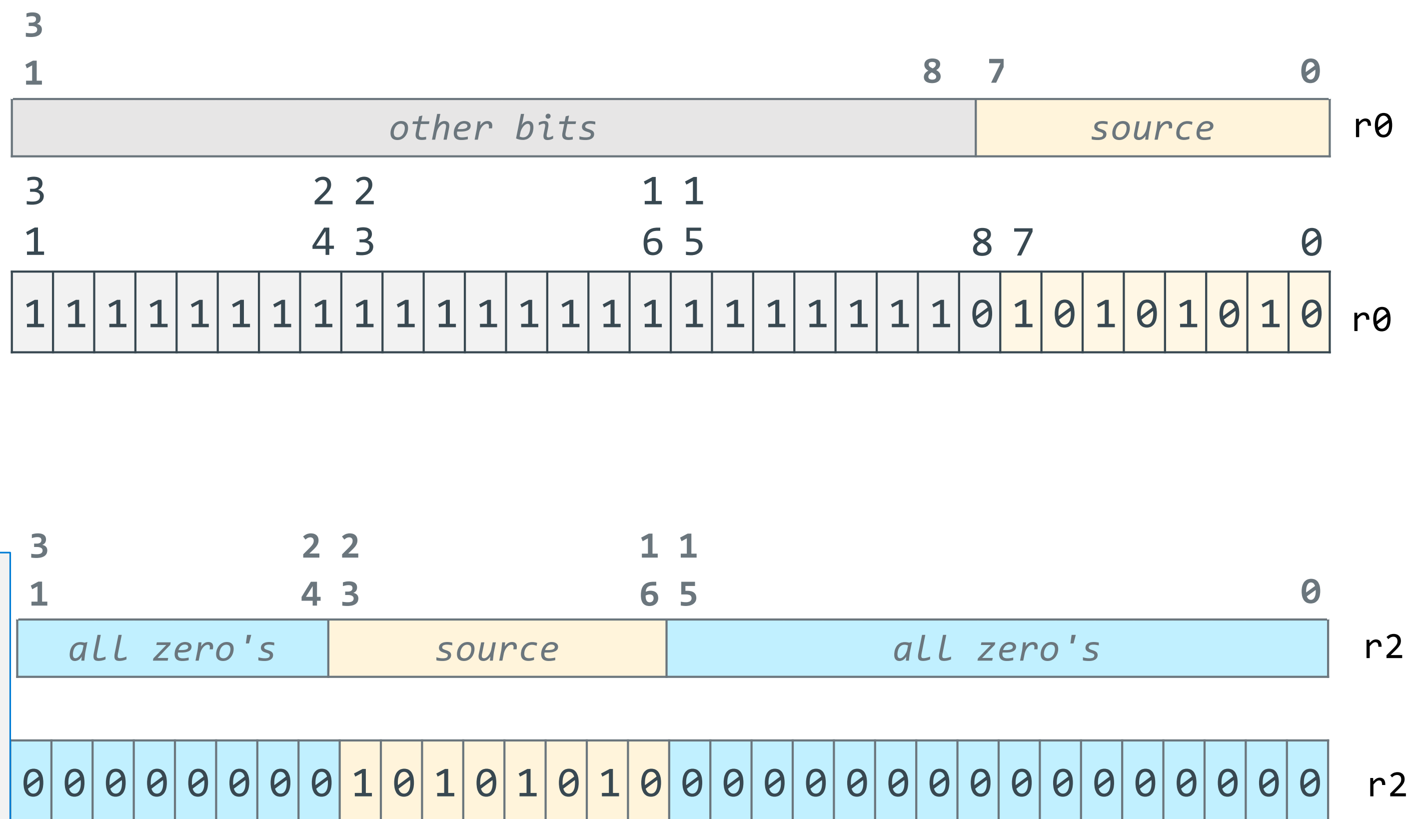
Approach
(1) isolate source field
(2) clear destination field
(3) Bitwise or together

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

results in



Inserting Bitfields – Isolating the Source Field



isolate source field

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

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


x

Inserting Bitfields – Clearing the Destination Field

31 … 24	23 … 16	15 … 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

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

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

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

31 … 24	23 … 16	15 … 0	
do not change	*all zeros*	*do not change*	r1

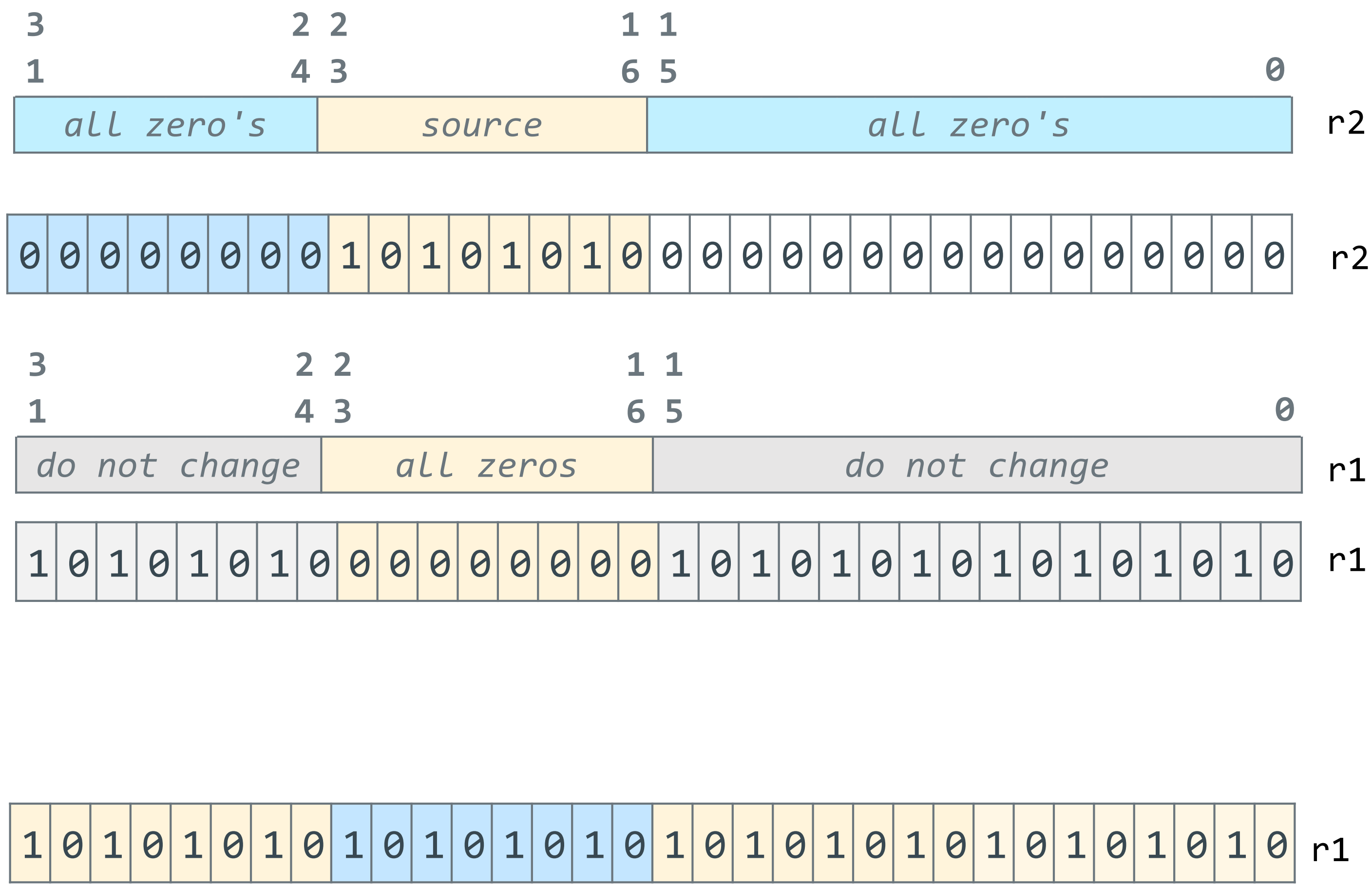
1 0 1 0 1 0 1 0	0 0 0 0 0 0 0 0	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0	r1

x

Inserting Bitfields –
Combining Isolated Source and Cleared Destination

```
isolated source
```

```
field cleared in
destination
```




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

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

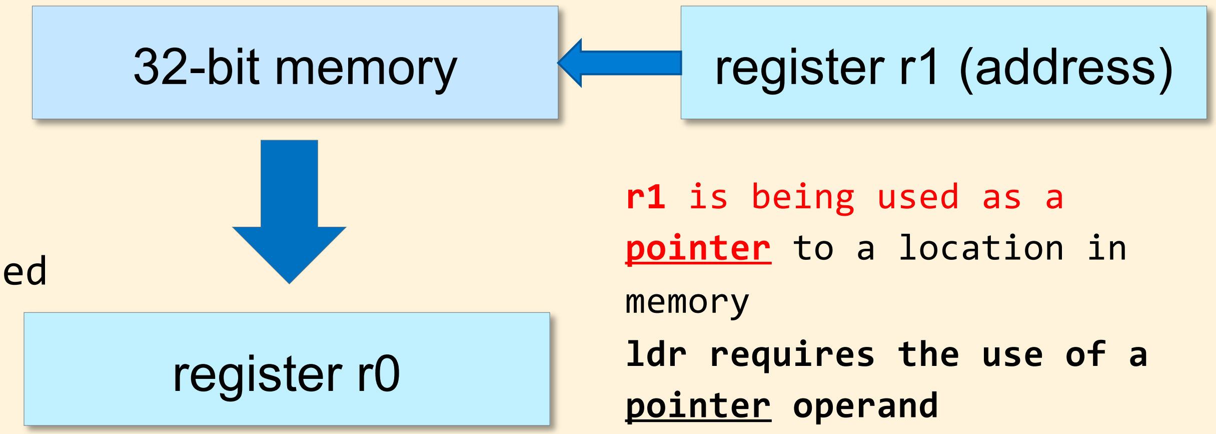
0 0 0 0 0 0 0 0	*source*	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Keep these bits	0 0 0 0 0 0 0 0	Keep these bits

x

Load/Store: Register Base Addressing

```
ldr r0, [r1]
```

Copies a 32-bit word from the memory location whose address is contained in r1 (r1 is a pointer) into register r0



r1 is being used as a **pointer** to a location in memory

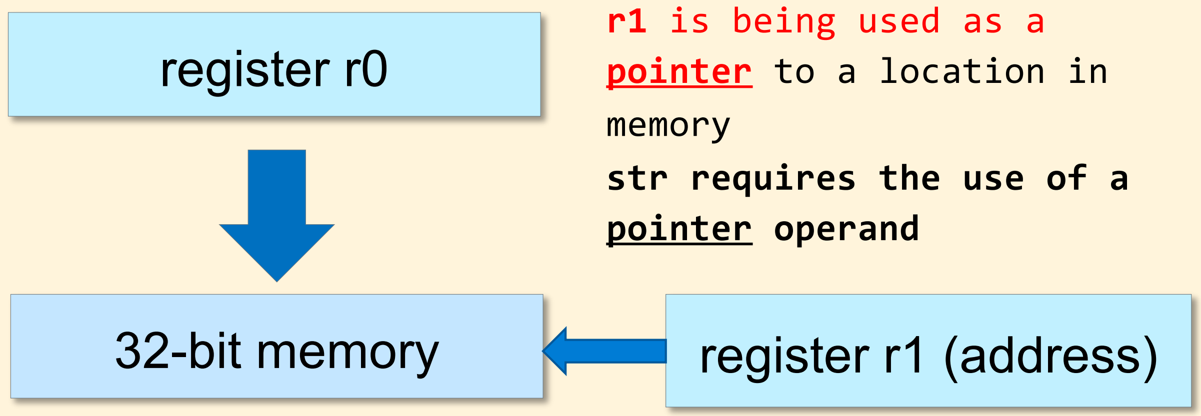
ldr requires the use of a pointer operand

```
str   r0, [r1]
```

Copies all 32 bits of the value held in register r0 to the 32-bit memory location contained in register r1 (r1 pointer)

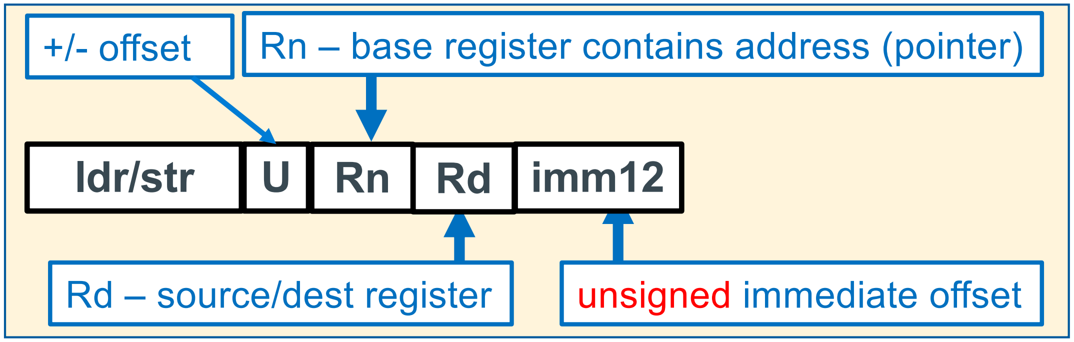
r1 is being used as a **pointer** to a location in memory

str requires the use of a pointer operand



x

LDR/STR – Base Register + Immediate Offset Addressing

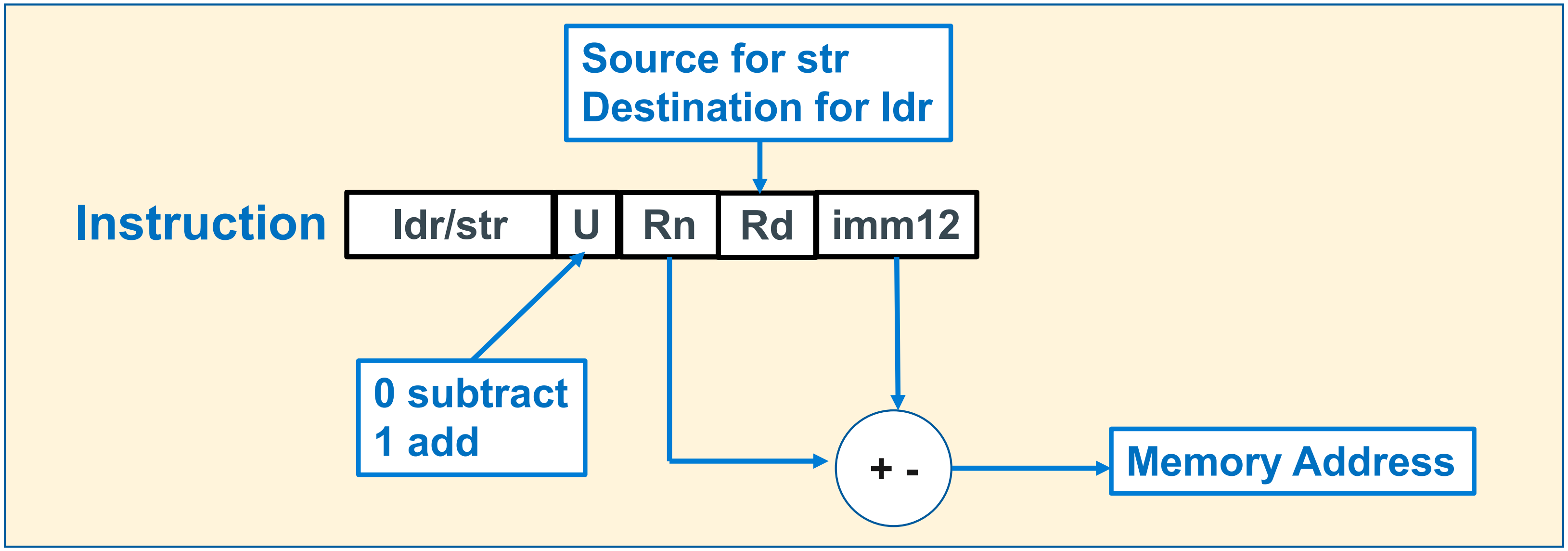


- **Register Base Addressing**:
  - Pointer Address: Rn; source/destination data: Rd
  - **Unsigned pointer address** in stored in the base register
- **Register Base + immediate offset Addressing:**
  - Pointer Address = register content + immediate offset
  - Unsigned offset integer immediate value (bytes) is added or subtracted (U bit above says to add or subtract) from the pointer address in the base register

```
ldr/str  Rd,  [Rn, +- imm12] // base register pointer + offset  imm12 in bytes
                             -4095 <= imm12 <= 4095 (bytes)
ldr/str  Rd,  [Rn]           // base register pointer + 0 offset (imm12 is 0)
```


x

ldr/str Register Base and Register + Immediate Offset Addressing

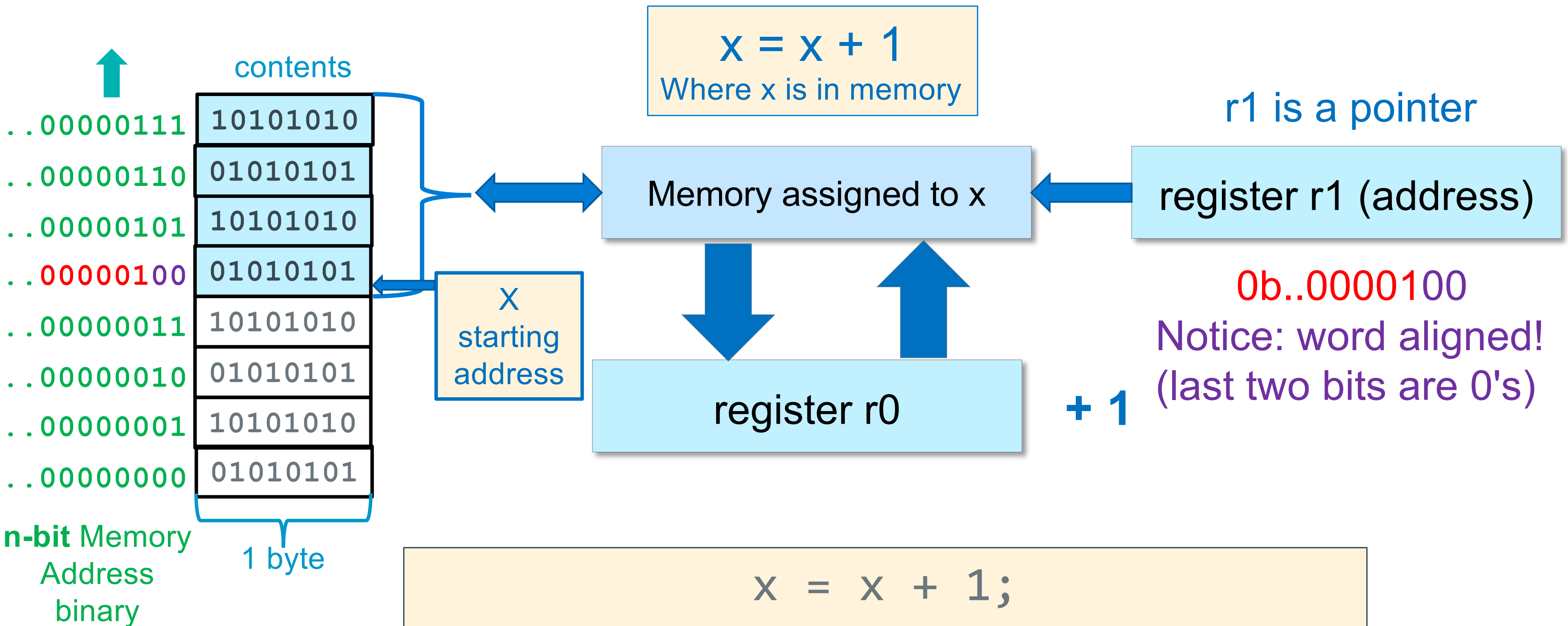


Syntax	Address	Examples

`ldr/str Rd, [Rn +/- constant]` constant is in bytes	Rn + or – constant
	same
		`ldr r0, [r5,100]`
		`str r1, [r5, 0]`
		`str r1, [r5]`

x

Example Base Register Addressing Load – Modify – Store




```
x = x + 1;
ldr r0, [r1]          // r0 = *r1 (read x)
add r0, r0, 1         // r0 = r0 + 1 (x++)
str r0, [r1]          // *r1 = r0 write x
```


x

Loading and Storing: Variations List

- Load and store have variations that move 8-bits, 16-bits and 32-bits
- Load into a register with less than 32-bits will set the upper bits not filled from memory differently depending on which variation of the load instruction is used
- Store will only select the lower 8-bit, lower 16-bits or all 32-bits of the register to copy to memory, register contents are not altered

Instruction	Meaning	Sign Extension	Memory Address Requirement
`ldrsb`	load signed byte	sign extension	none (any byte)
`ldrb`	load unsigned byte	zero fill (extension)	none (any byte)
`ldrsh`	load signed halfword	sign extension	halfword (2-byte aligned)
`ldrh`	load unsigned halfword	zero fill (extension)	halfword (2-byte aligned)
`ldr`	load word	---	word (4-byte aligned)
`strb`	store low byte (bits 0-7)	---	none (any byte)
`strh`	store halfword (bits 0-15)	---	halfword (2-byte aligned)
`str`	store word (bits 0-31)	---	word (4-byte aligned)

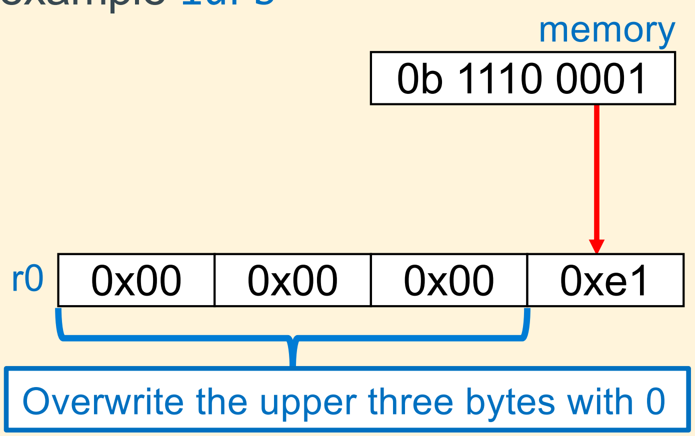
x

Loading 32-bit Registers From Memory Variables < 32-Bits Wide

Unsigned

Zero-Extend: Add leading 0's

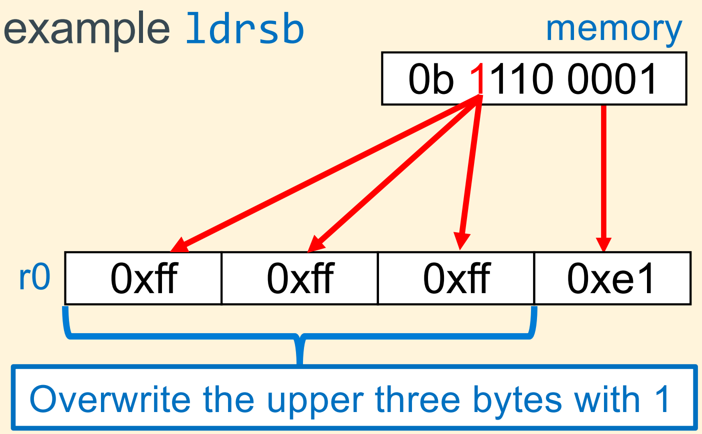
example `ldrb`



Signed (2's complement)

Sign-Extend: Replicate sign bit

example `ldrsb`

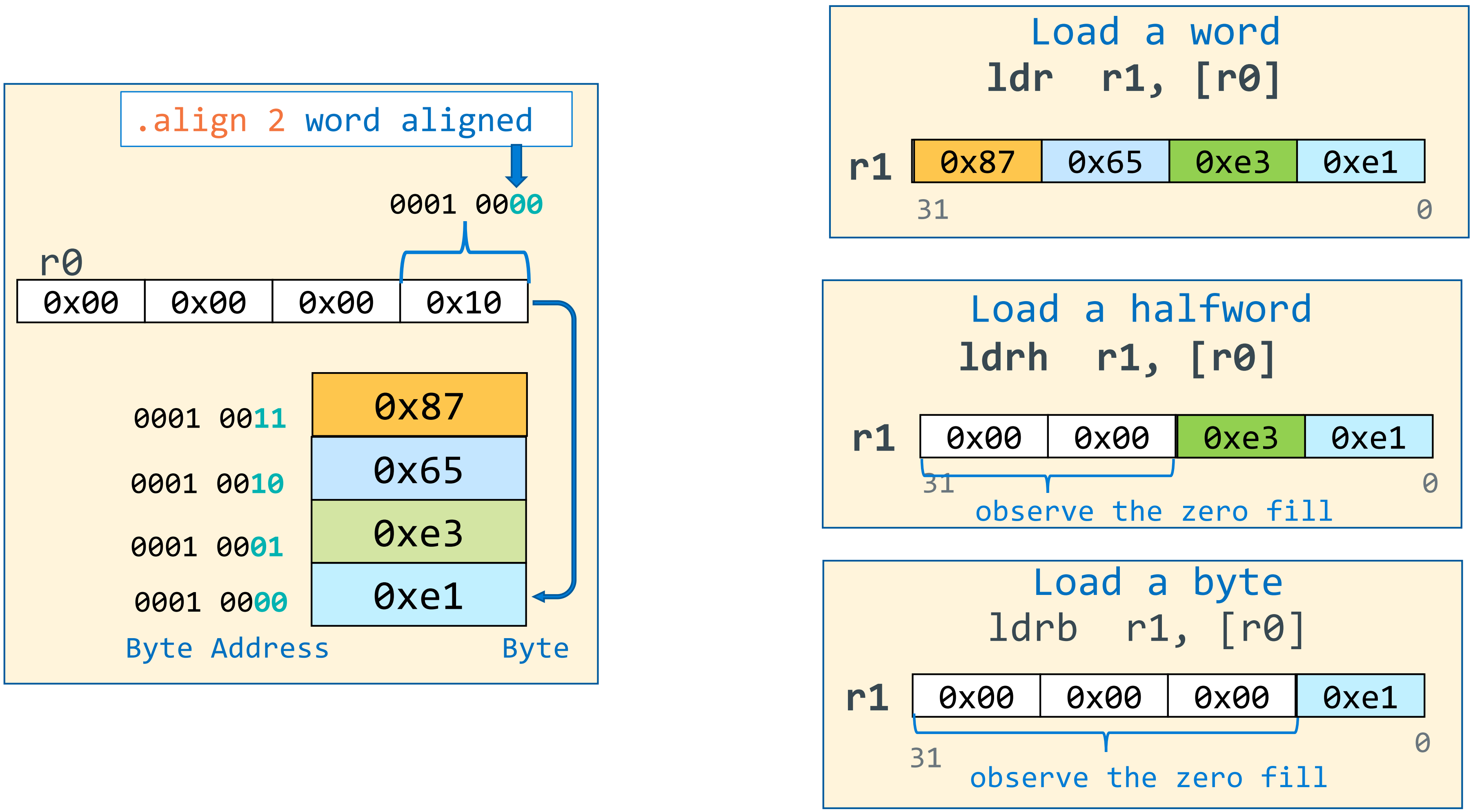


Instructions that zero-extend:
ldrb, ldrh

Instructions that sign-extend:
ldrsb, ldrsh

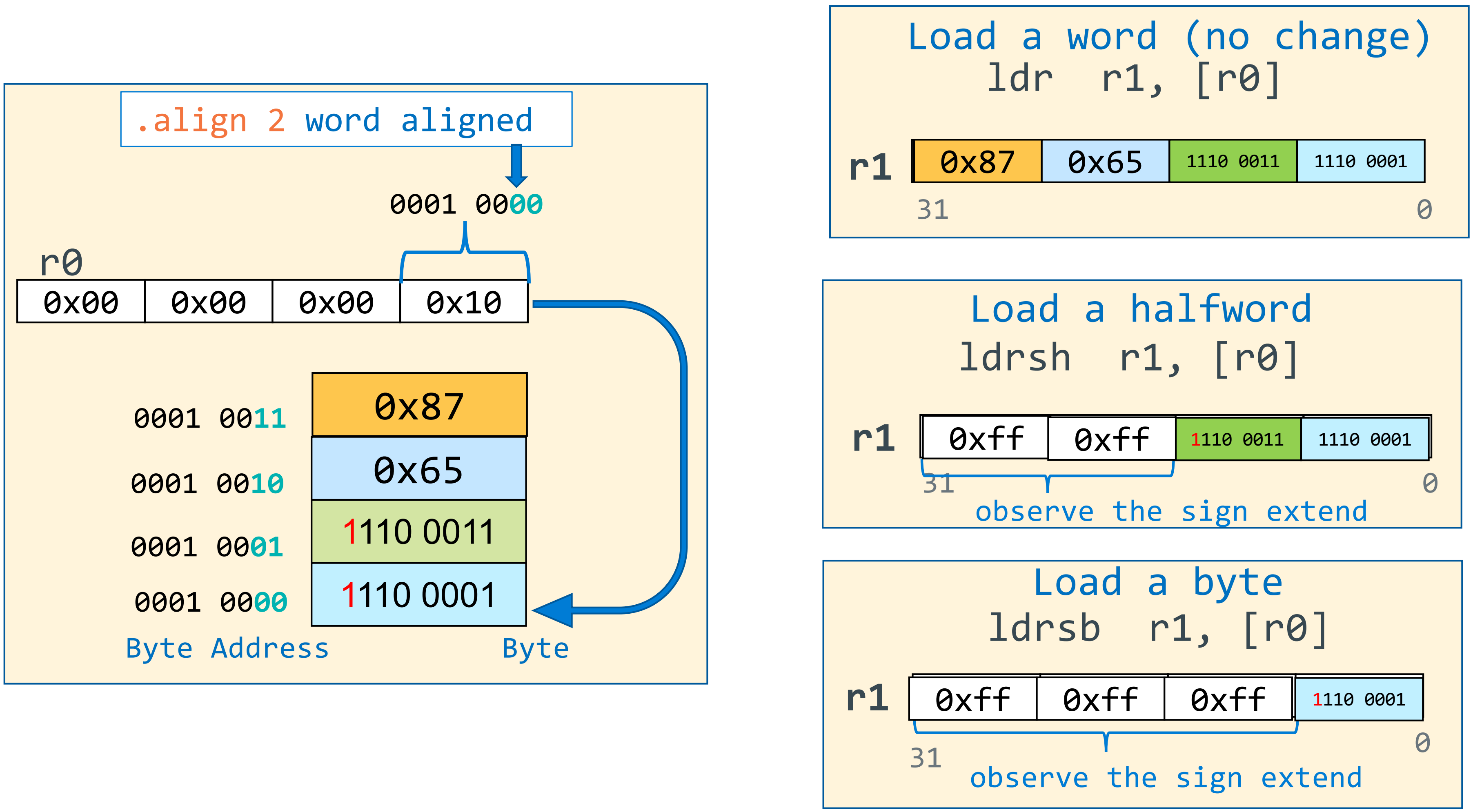
x

Load a Byte, Half-word, Word

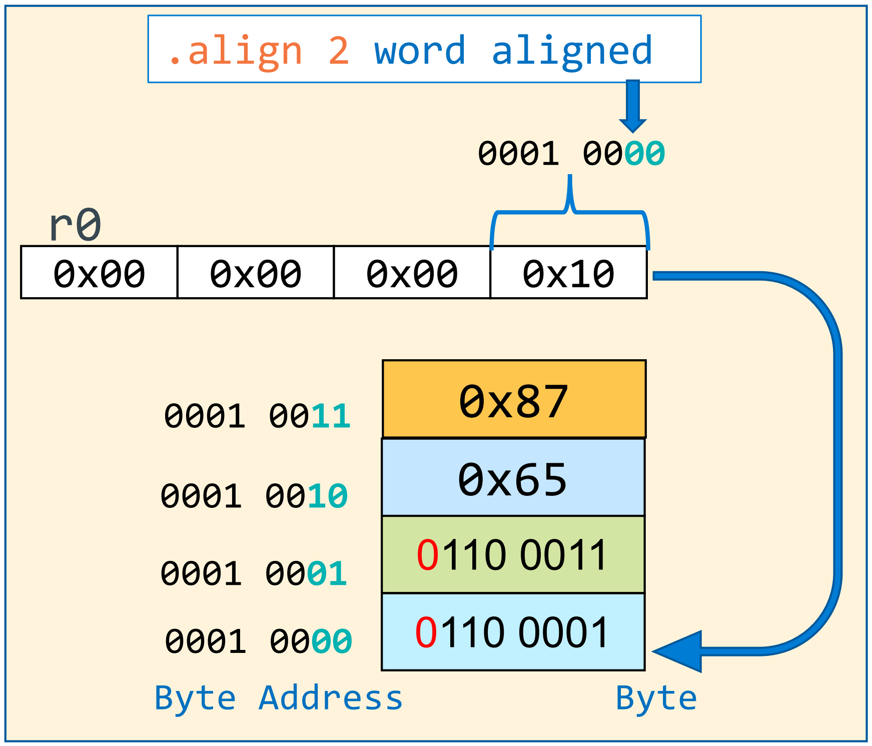


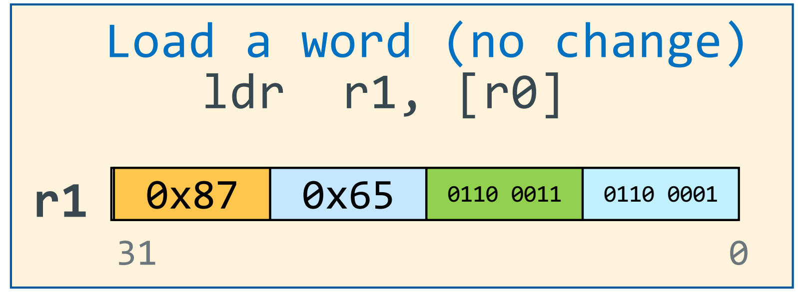
x

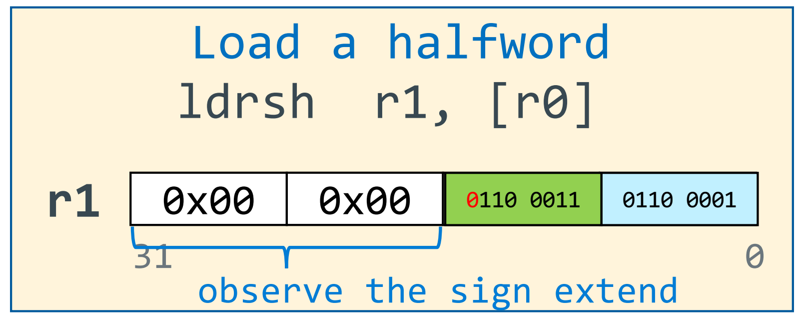
Signed Load a Byte, Half-word, Word

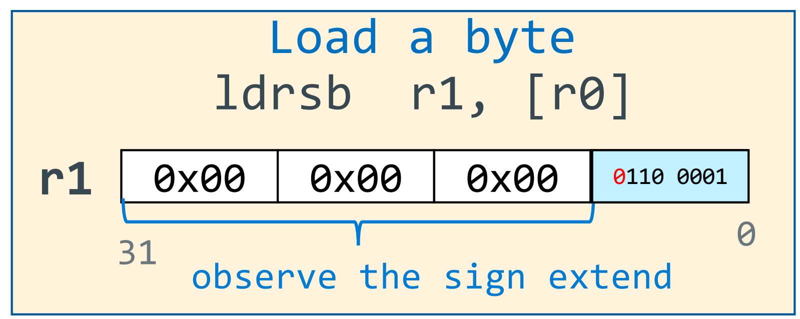


Signed Load a Byte, Half-word, Word



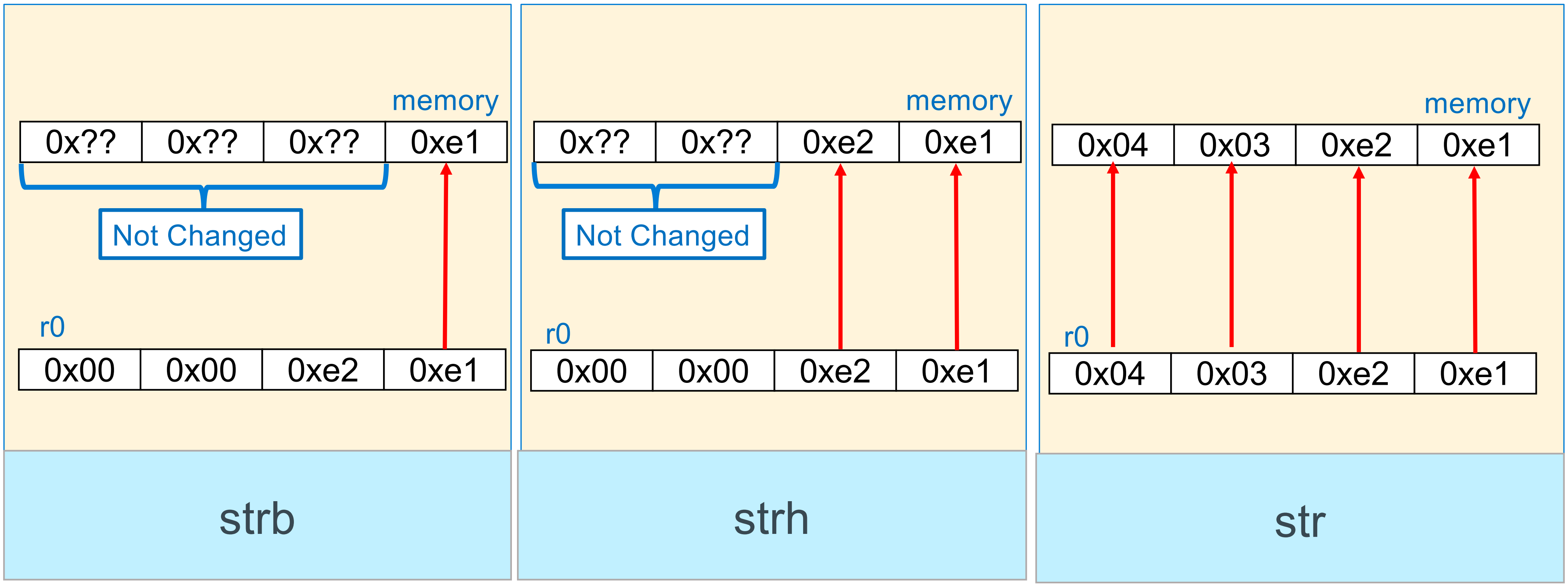






x

Storing 32-bit Registers To Memory 8-bit, 16-bit, 32-bit



x

Store a Byte, Half-word, Word

initial value in r0

0x20	0x00	0x00	0x00

Store a byte

```
strb  r1, [r0]
```

r1

31			0
0x87	0x65	0xe3	0xe1

Byte Address	Byte
0x20000003	0x33
0x20000002	0x22
0x20000001	0x11
0x20000000	0xe1

observe other bytes NOT altered

Store a halfword

```
strh r1, [r0]
```

r1

31			0
0x87	0x65	0xe3	0xe1

Byte Address	Byte
0x20000003	0x33
0x20000002	0x22
0x20000001	0xe3
0x20000000	0xe1

Store a word

```
str  r1, [r0]
```

r1

31			0
0x87	0x65	0xe3	0xe1

Byte Address	Byte
0x20000003	0x87
0x20000002	0x65
0x20000001	0xe3
0x20000000	0xe1

x