Integer Casting in C

Computer Engineering 1

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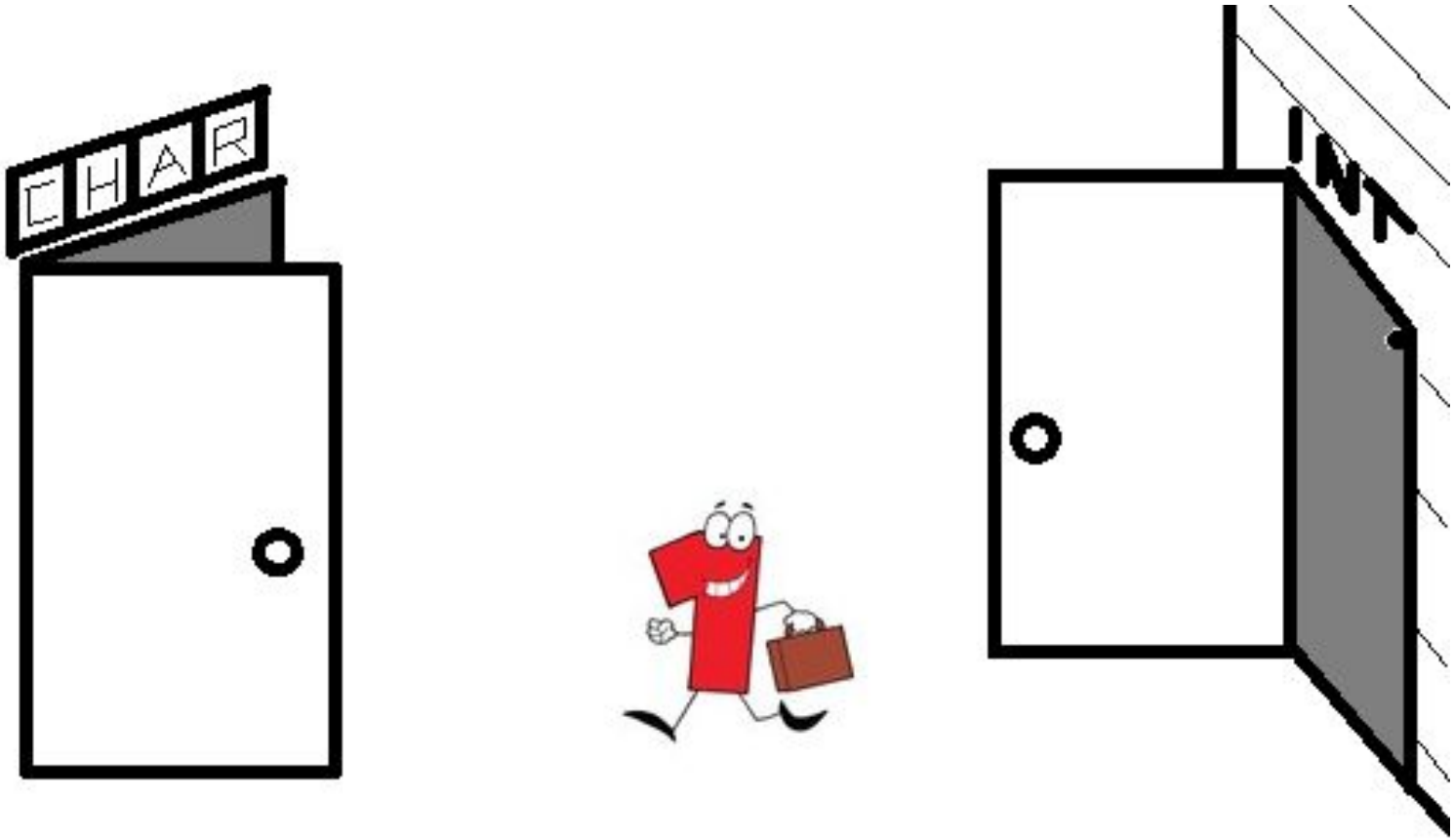
Motivation



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Agenda

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- Type conversion
  - signed ↔ unsigned
  - Extension
  - Truncation

Learning Objectives

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At the end of this lesson you will be able

- to explain the casting of integer types in C
- to apply the assembly instructions associated with casting
- to say how a given memory content is interpreted for different integer types in C
- to give the memory content after storing different C integer types

Integer Casting in C

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- **Integer ranges based on word sizes**

8-bit	hex	unsigned	signed
	0x00	0	0
	...	...	...
	0x7F	127	127
	0x80	128	-128
	...	...	...
	0xFF	255	-1

16-bit	hex	unsigned	signed
	0x0000	0	0
	...	...	...
	0x7FFF	32'767	32'767
	0x8000	32'768	-32'768
	...	...	...
	0xFFFF	65'535	-1

32-bit	hex	unsigned	signed
	0x0000 0000	0	0
	...	...	...
	0x7FFF'FFFF	2'147'483'647	2'147'483'647
	0x8000'0000	2'147'483'648	-2'147'483'648
	...	...	...
	0xFFFF'FFFF	4'294'967'295	-1

Integer Casting in C: Type conversion

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- **signed ←→ unsigned**

`int8_t`	←→	`uint8_t`
`int16_t`	←→	`uint16_t`
`int32_t`	←→	`uint32_t`
`int64_t`	←→	`uint64_t`

- **Extension**

`int_8`	→	`int16_t`	→	`int32_t`	→	`int64_t`	signed
`uint_8`	→	`uint16_t`	→	`uint32_t`	→	`uint64_t`	unsigned

- **Truncation**

`int64_t`	→	`int32_t`	→	`int16_t`	→	`int_8`	signed
`uint64_t`	→	`uint32_t`	→	`uint16_t`	→	`uint_8`	unsigned

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- **signed ←→ unsigned**

signed $-b_3 \cdot 2^3 + b_2 \cdot 2^2 + b_1 \cdot 2^1 + b_0 \cdot 2^0$

unsigned $+b_3 \cdot 2^3 + b_2 \cdot 2^2 + b_1 \cdot 2^1 + b_0 \cdot 2^0$

Casts in **red** area

➔ Small negative numbers turn into large positive numbers

➔ Large positive numbers turn into small negative numbers

binary	unsigned	signed 2' compl.
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	-8
1001	9	-7
1010	10	-6
1011	11	-5
1100	12	-4
1101	13	-3
1110	14	-2
1111	15	-1

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- **Casting**

unsigned	→	signed
signed	→	unsigned

Bit representation stays the same,
but interpretation changes

- **Example 4-Bit**
  - 1011b → Interpretation as unsigned 11d
    → Interpretation as signed -5d

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- **Example 1: signed 8-bit → unsigned 8-bit**
  - Bit representation stays the same, interpretation changes

```
dec    hex    OC     TC = OC + 1
10d    0x0A   0xF5   0xF6
```

c contains 0xF6, interpreted as -10d

```
int8_t c = -10;
uint8_t uc = (uint8_t)c;
```

uc also contains 0xF6, but interpreted as 246d

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- **Example 2: signed 32-bit → unsigned 32-bit**
  - Bit representation stays the same, interpretation changes

dec	hex	OC	TC = OC + 1
9133d	0x0000'23AD	0xFFFF'DC52	0xFFFF'DC53

i contains 0xFFFF'DC53, interpreted as -9133d

```
int32_t i = -9133;
uint32_t ui = (uint32_t)i;
```

ui also contains 0xFFFF'DC53, but interpreted as 4'294'958'163d

Explicit cast is not even required

```
uint32_t ui2 = i;  // implicit cast
```

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- **Example 3: Cast unsigned 32-bit → signed 32-bit**
  - Bit representation stays the same, interpretation changes

dec	hex
4'294'964'632d	0xFFFF'F598

uix contains 0xFFFF'F598,
interpreted as 4'294'964'632

```
uint32_t uix = 4294964632;
int32_t ix = uix;     // implicit cast
```

ix also contains 0xFFFF'F598,
but interpreted as -2664d

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- **If one of the operands is unsigned, C performs an implicit cast for the signed values to unsigned**
  - Example n = 32: signed ∈ [-2'147'483'648 , 2'147'483'647]
  - Can lead to strange results (red lines)

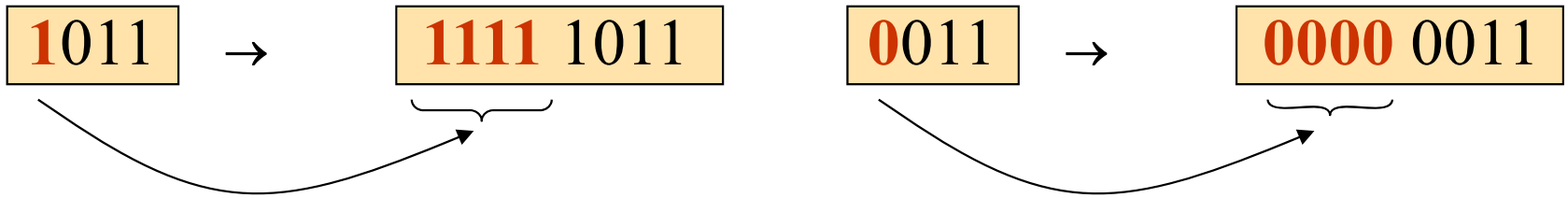
Expression	Type	Evaluation
0 == 0U	unsigned	1
-1 < 0	signed	1
-1 < 0U	unsigned	0
2'147'483'647 > -2'147'483'647 - 1	signed	1
2'147'483'647U > -2'147'483'647 – 1	unsigned	0
2'147'483'647 > (int) 2'147'483'648U	signed	1
-1 > -2	signed	1
(unsigned) -1 > -2	unsigned	1

Examples: R. Bryant, D. O'Hallaron

Integer Casting

- **Extension: 4 Bit → 8 Bit**
  - **Unsigned → Zero Extension**

  - **Signed → Sign Extension**



Integer Casting: Sign Extension

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- **Sign Extension Cortex-M0 (signed values)**
  - Extend word-length without changing value
  - SXTB Extends an 8-bit value to a 32-bit value
  - SXTH Extends a 16-bit value to a 32-bit value
- **Zero Extension Cortex-M0 (unsigned values)**
  - Extend word-length, fill with zeroes
  - UXTB Extends an 8-bit value to a 32-bit value
  - UXTH Extends a 16-bit value to a 32-bit value

Examples

```
SXTB  R3, R10   ; Extract lowest byte of the value in R10,
                ; sign extend it and write the result to R3
UXTH  R2, R3    ; Extract lower two bytes of the value in R3,
                ; zero extend it and write the result to R2
```

Integer Casting: Sign Extension

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- **Example Sign Extension**

```
int16_t sx =  15213;
int32_t ix = (int32_t)sx;

int16_t sy = -15213;
int32_t iy = (int32_t)sy;
```

	dec	hex	bin			
sx	15213	0x3B6D			00111011	01101101
ix	15213	0x0000'3B6D	00000000	00000000	00111011	01101101
sy	-15213	0xC493			11000100	10010011
iy	-15213	0xFFFF'C493	11111111	11111111	11000100	10010011

signed Integer Types: from small to large

→ **Sign bit is copied to the left**

Integer Casting: Truncation

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- **Truncation: Reduce number of digits**
  - Cast cuts the left most digits
- **Unsigned** → modulo Operation

```
uint32_t x = 287962;
uint16_t sx = (uint16_t)x;
uint32_t y = (uint32_t)sx;
```

```
0x000464DA →  287'962
    0x64DA →   25'818
0x000064DA →   25'818
```

- **Signed** → possible change of sign!

```
int32_t x  = 53191;
int16_t sx = (int16_t) x;
int32_t y  = (int32_t) sx;
```

```
0x0000CFC7 →  53'191
    0xCFC7 → -12'345
0xFFFFCFC7 → -12'345
```

Conclusion

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- **Integer Casts**
  - Type Conversions
- **signed – unsigned**
  - Small negative numbers correspond to large positive numbers
- **Extensions**
  - Add additional bits
    - signed sign extension copy sign bit to the left
    - unsigned zero extension fill left bits with zero
- **Truncations**
  - Cut left most digits
    - signed possible change of sign
    - unsigned results in modulo operation