Computer Systems

CS107

Cynthia Lee

Today's Topics

LAST TIME:
- Number representation
  - Integer representation
  - Signed numbers with two's complement

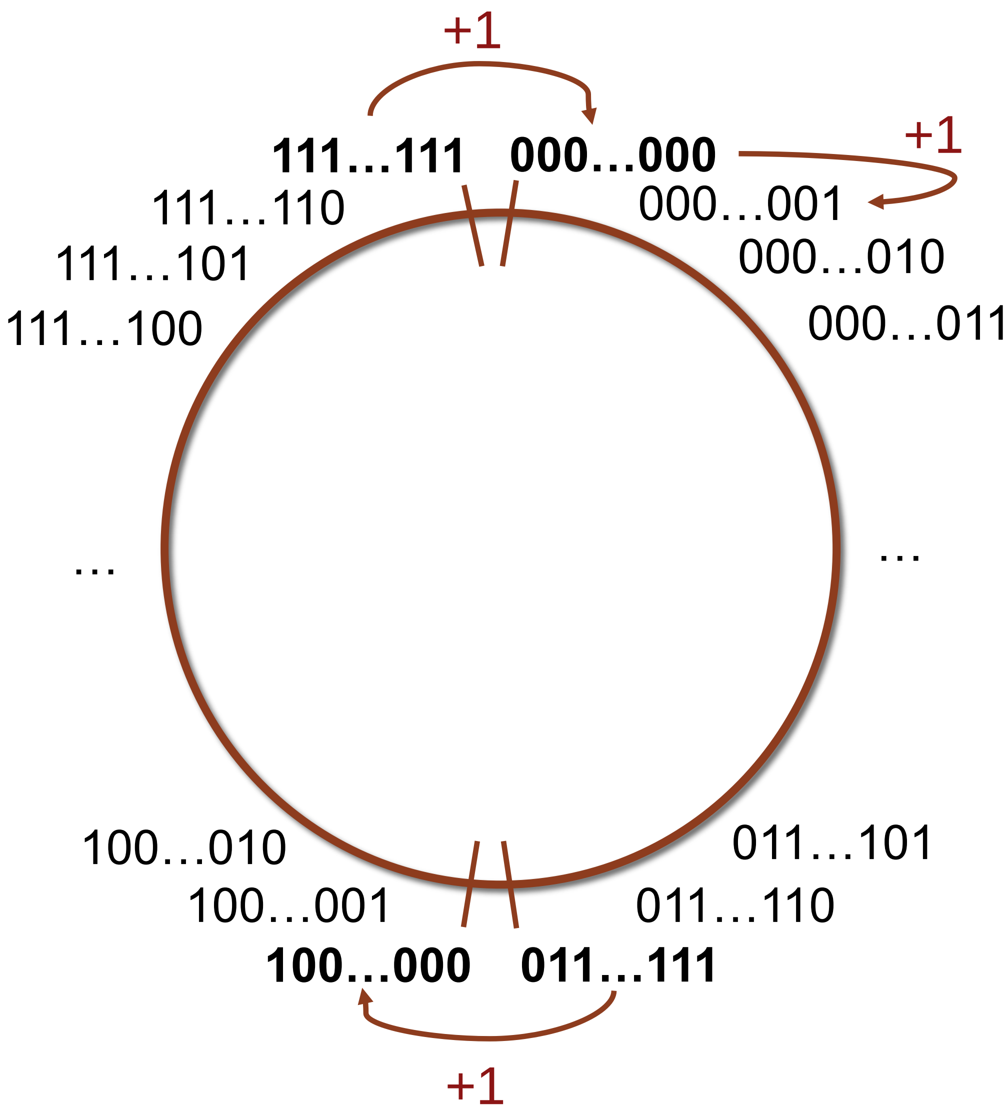
THIS TIME:
- Number representation
  - The integer number line for signed and unsigned
  - Overflow and underflow
  - Comparison, extension and truncation in signed and unsigned
  - Bitwise operations and bit sets

COMING UP:
- Today is last day of topics that will be included on next week's midterm
  - Practice exams and topics list are up now

Reasoning about signed and unsigned

Integer Representation

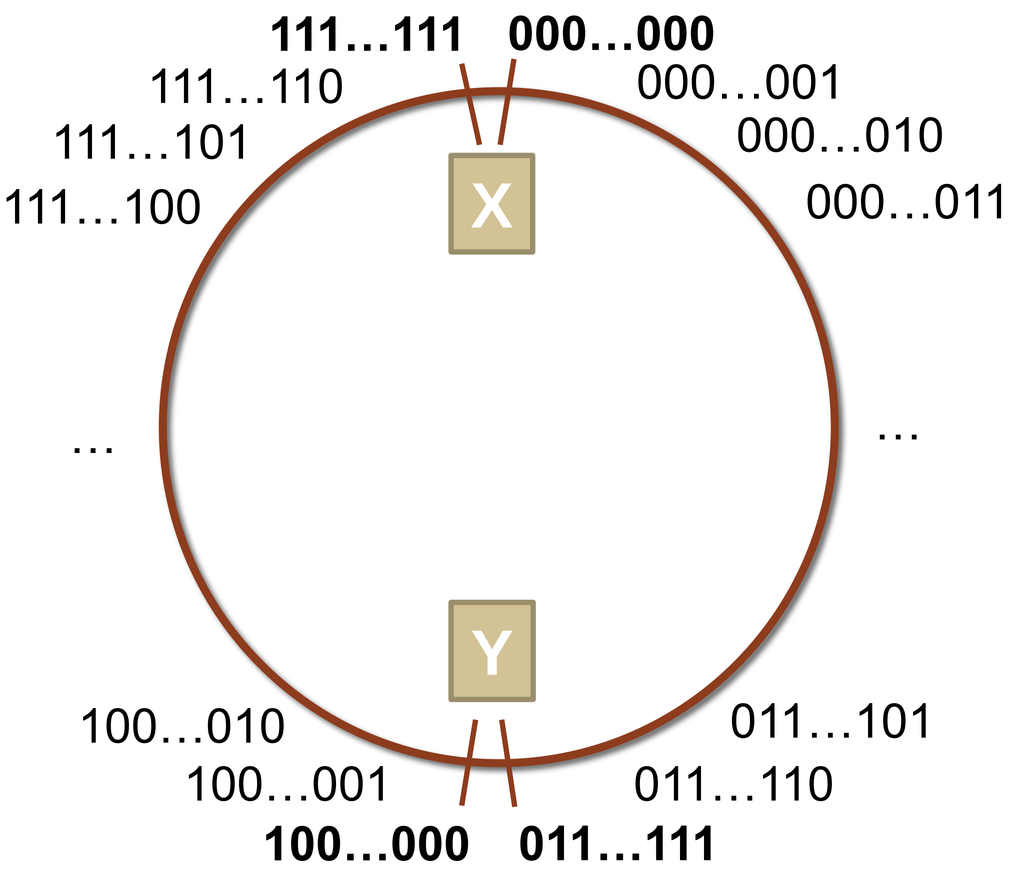
(assume binary values shown are all 32 bits)



Signed and unsigned numbers

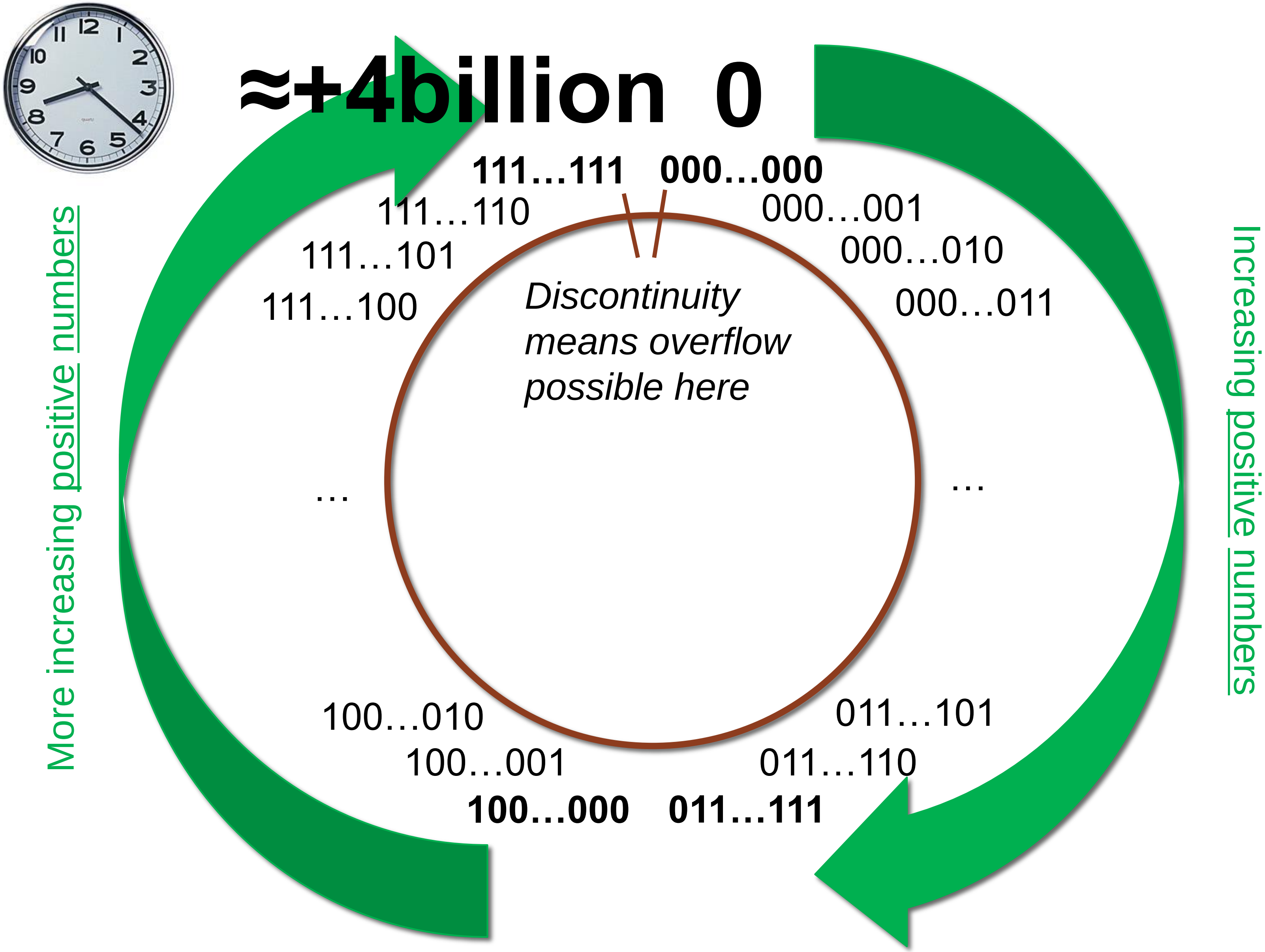
At which points can overflow occur for signed and unsigned int?
(assume binary values shown are all 32 bits)

A. Signed and unsigned can both overflow at points X and Y
B. Signed can overflow at X, unsigned at Y
C. Signed can overflow at Y, unsigned at X
D. Signed can overflow at X and Y, unsigned only at X
E. Other



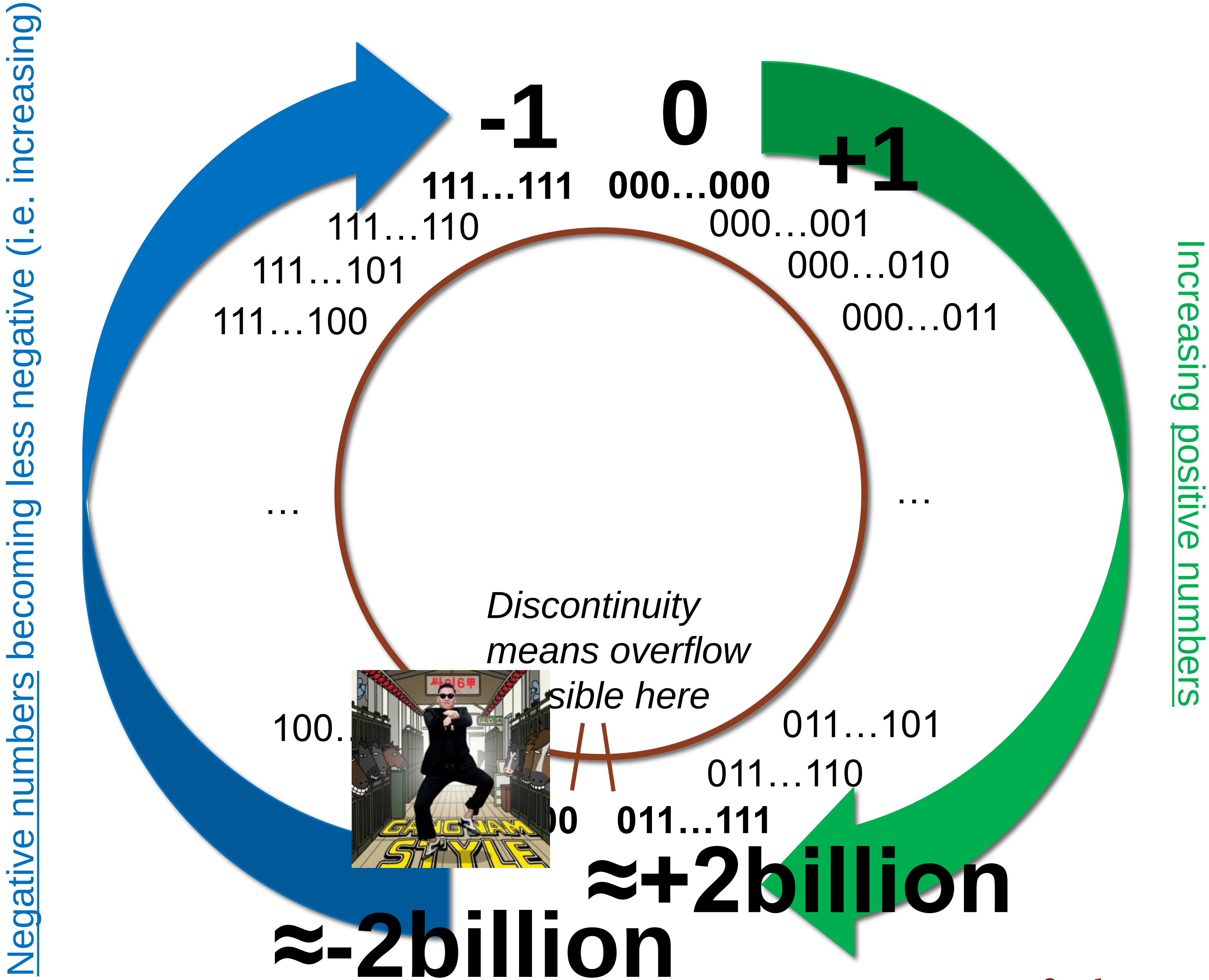
UNSIGNED integers

(assume binary values shown are all 32 bits)



SIGNED integers

(assume binary values shown are all 32 bits)



Comparison operators in signed and unsigned numbers

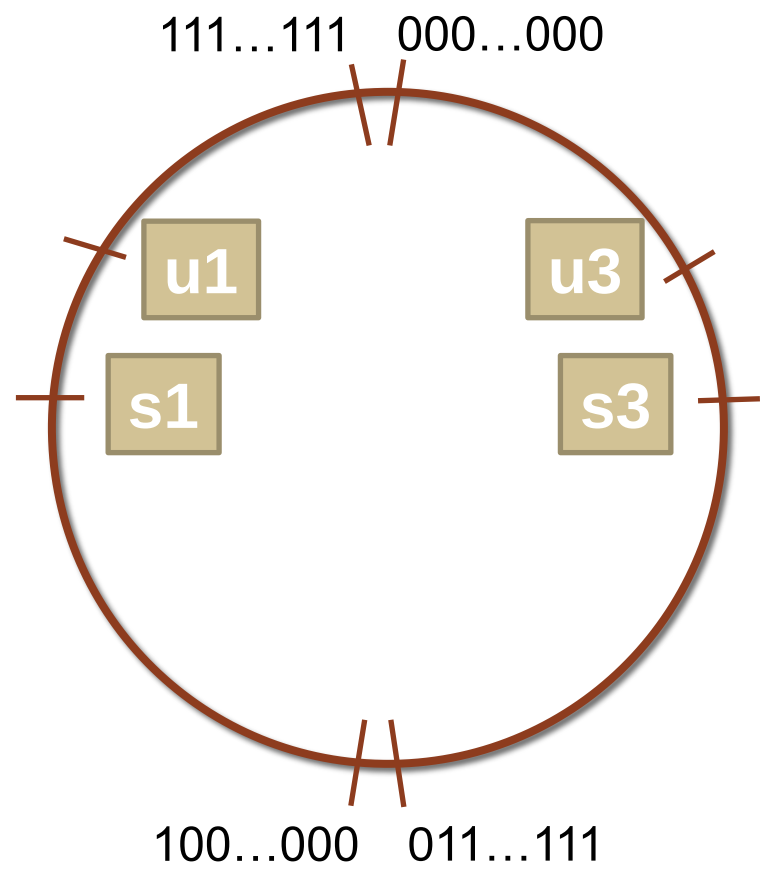
```
int             s1, s2, s3;
unsigned int    u1, u2, u3;
```

Are the following statements true?
(assume that variables are set to values that place them in the spots shown)

- `s3 > u3` Easy: true
- `s1 > s3` Easy: false
- `u1 > u3` Easy: true
- `s1 > u3` Hmmm!??!

C just needs to choose one or the other scheme to dominate. It chooses…drumroll…
unsigned!

So this is **TRUE**.

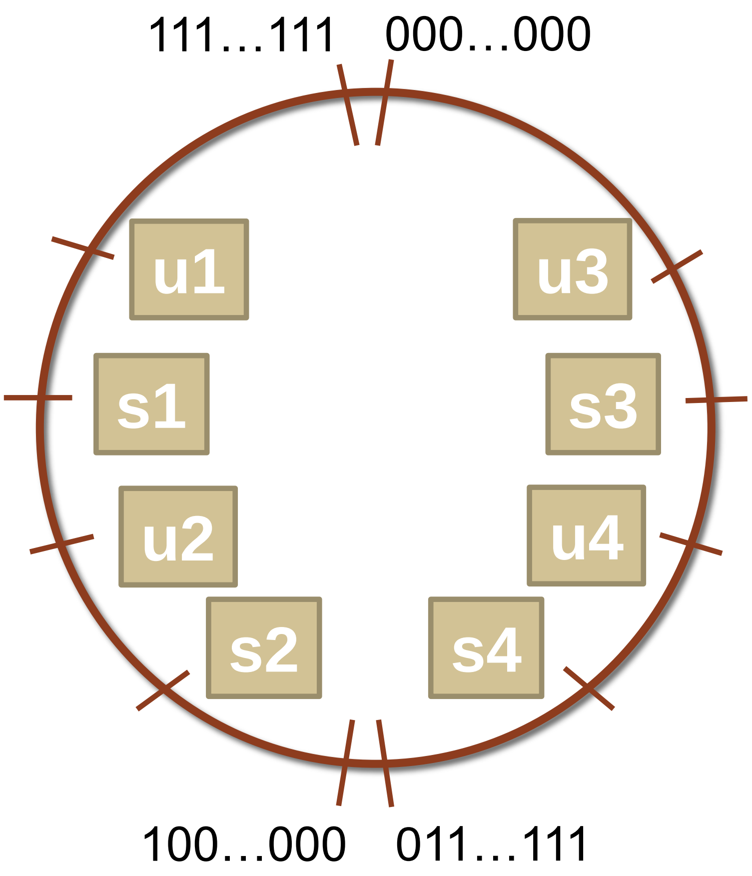


HOME SELF-TEST:
Comparison operators in signed and unsigned numbers

```
int            s1, s2, s3, s4;
unsigned int   u1, u2, u3, u4;
```

Which many of the following statements are true? *(assume that variables are set to values that place them in the spots shown)*

- `s3 > u3`
- `u2 > u4`
- `s2 > s4`
- `s1 > s2`
- `u1 > u2`
- `s1 > u3`



Type truncation in the char/short/int/long family

```
int           i1 = 0x8000007F; // = -2147483521
int           i2 = 0x000000FF; // = 255
char          s1 = i1;         // = 0x7F = 127
char          s2 = i2;         // = 0xFF = -1
unsigned char u1 = i1;         // = 0x7F = 127
unsigned char u2 = i2;         // = 0xFF = 255
```

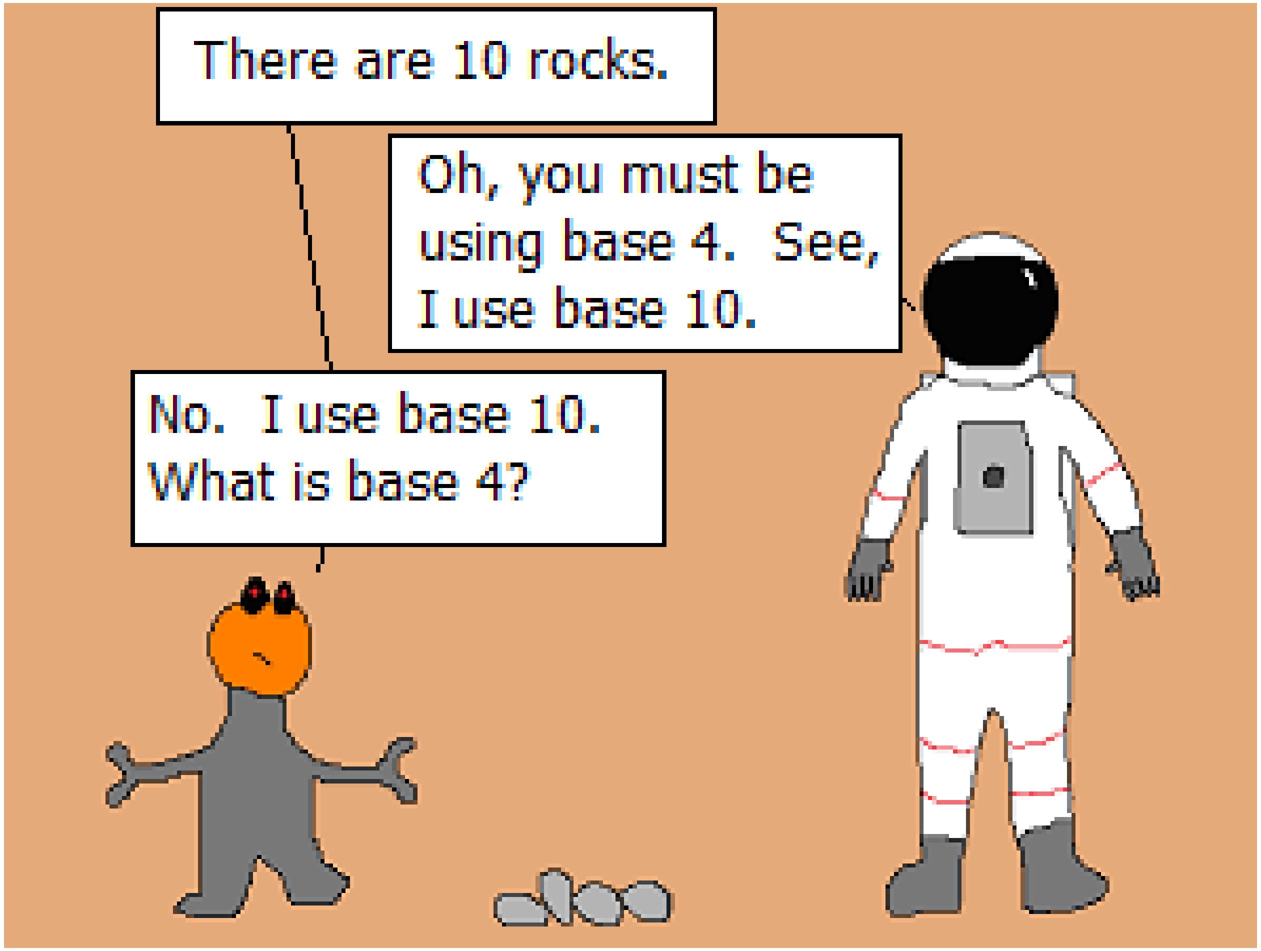
- Regardless of source or destination signed/unsigned type, truncation always just truncates
- This can cause the number to **change drastically in sign and value**

Type promotion in the char/short/int/long family

```
char          sc = 0xFF;     // 0xFF = -1
unsigned char uc = 0xFF;     // 0xFF = 255
int           s1 = sc;       // 0xFFFFFFFF = -1
int           s2 = uc;       // 0x000000FF = 255
unsigned int  u1 = sc;       // 0xFFFFFFFF = 4,294,967,295
unsigned int  u2 = uc;       // 0x000000FF = 255
```

- Promotion always happens according to the *source* variable's type
  - Signed: **"sign extension"** (copy MSB—0 or 1—to fill new space)
  - Unsigned: **"zero fill"** (copy 0's to fill new space)

- *Note:* When doing <, >, <=, >= comparison between different size types, it will promote to the larger type
  - "int < char" comparison will implicitly (1) assign char to int according to these promotion rules, *then* (2) do "int < int" comparison



Every base is base 10.

In closing

Bits As Individual Booleans

This is a very different way of thinking about what a particular set of 8 bits (one char) "means"

Bitwise operators and masking

- Let's say we want to represent font settings:
  - **Bold**
  - *Italic*
  - Red color
  - Superscript
  - Underline
  - ~~Strikethrough~~

- Observe that a particular piece of text can be any combination of these
  - Example 1: ***Bold Italic Red***
  - Example 2: *Italic Red Underline*
  - Example 3: ~~**Bold Superscript Underline Strikethrough**~~

Bitwise operators and masking

- Idea: Have a bool for each of these settings, **store them in struct**:

```
struct font_settings {
    bool is_bold;
    bool is_italic;
    bool is_red;
    bool is_super;
    bool is_under;
    bool is_strike;
};
```

This works and is easy to read, but each bool is one byte—7 of each 8 bits not being used. Wastes bigly. Sad!

- › Example 1: ***Bold Italic Red***

```
struct font_settings ex1;   /* how to set up */
ex1.is_bold = ex1.is_italic = ex1.is_red = true;
ex1.is_super = ex1.is_under = ex1.is_strike = false;
if (ex1.is_bold) { …        /* how to use */
```

Bitwise operators and masking

- New idea: Have one 0/1 bit for each of these settings:
  - **Bold** — 1 = bold, 0 = not bold
  - *Italic* — 1 = italic, 0 = not italic
  - Red color — 1 = red, 0 = not red
  - Superscript — …
  - <u>Underline</u>
  - ~~Strikethrough~~

- Store the collection of 6 bit settings together:
  - Example 1: ***Bold Italic Red*** — `111000`
  - Example 2: *<u>Italic Red Underline</u>* — `011010`
  - Example 3: ~~**Bold Superscript Underline Strikethrough**~~ — 100111

- **We can pack these into an** `unsigned char` **(uses lower 6 of the 8 bits)**
  - Example 1: ***Bold Italic Red*** — `00111000`

Bitwise operators and masking

- Use char and hexadecimal to store font settings:

  Example 1: ***Bold Italic Red***

  ```
  unsigned char ex1 = 0x38;        // 0x38 = 00111000
  ```

- …But how do we use this?

- **No way to "name" the bold bit by itself:**

  ```
  if (ex1) { …                // tests if whole char != 0
  if (ex1.is_bold) { …        // no nameable fields in char
  ```

- **Can't access individual bits (system is byte-addressable)**
- Not hopeless: we need *bitwise operators*

Bitwise operators and bits as individual booleans

MOVING BEYOND THE "INT" INTERPRETATION OF BITS

Stanford University

Bitwise operators

- You’ve seen these categories of operators in C/C++:
  - Arithmetic operators: `+, -, *, /`
  - Comparison operators: `==, !=, <, >, <=, >=`
  - Logical operators: `&&, ||, !`
  - (C++ only) Stream insertion operators: `<<, >>`
- Now meet a new category:
  - Bitwise operators: `&, |, ^, ~, >>, <<`

Bitwise operators

`unsigned char a =`		0	0	1	1	1	1	0	0
`unsigned char b =`		0	1	0	1	1	0	1	0
and, intersection	`a & b`	0	0	0	1	1	0	0	0
or, union	`a | b`	0	1	1	1	1	1	1	0
xor, different?	`a ^ b`	0	1	1	0	0	1	1	0
not	`~a`	1	1	0	0	0	0	1	1
shift left	`a << 2`	1	1	1	1	0	0	0	0
shift right	`a >> 3`	0	0	0	0	0	1	1	1

Bitwise operators and masking

- Use char and hexadecimal to store font settings:

  Example 1: ***Bold Italic Red***

  ```
  unsigned char ex1 = 0x38;        // 0x38 = 00111000
  ```

- **How can we write a test for bold?**

```
bool is_bold(unsigned char settings)
{
    unsigned char mask = 1 << 5;     // 00100000
    return mask & settings != 0;
}
```

- **“Mask” is what we call a number that we create solely for the purpose of extracting selected bits out of a bitwise representation**
  - Often crafted using 1 shifted by some amount
  - Writing as a hexadecimal value also acceptable (`0x20`)
  - More complex masks can be crafted in steps with | & etc to test for more than one condition at once

Bitwise operators and masking

- Reminder: here are our font settings, in bit order:
  - **Bold**
  - *Italic*
  - Red color
  - Superscript
  - Underline
  - ~~Strikethrough~~
- **How can we write code to turn off italics (*without* changing any other settings)?**

```
unsigned char italics_off(unsigned char settings)
{
    return ___________________;
}
```

A. `~settings`
B. `settings & 1 << 4`
C. `settings ^ 1 << 4`
D. `settings | ~(1 << 4)`
E. `settings & ~(1 << 4)`
F. Something else

(to be) || !(to be), that is the question

- ! and ~ are both “not” operators—are they the same?
- **In other words, is this guaranteed to always print?**

```
int i;
scanf("%d", &i);
if (!i == ~i) printf("same this time\n");
```

A. Yes, always prints
B. Sometimes prints, but not always
C. No, never prints
D. You lost me at the code version of Shakespeare

i = -1 is special case