University of BRISTOL

Integer Overflows

Sanjay Rawat

Integer Operation Errors

- Integers are native datatypes in C/C++.
- There are multiple ways to represent numbers
  - `signed int`
  - `unsigned int`
  - `short/long`
  - `etc….`

Integer Operation Errors

- Integers are native datatypes in C/C++.
- There are multiple ways to represent numbers
  - `signed int`
  - `unsigned int`
  - `short/long`
  - `etc….`
- We can type-cast one to other!

Integer Operation Errors

- Integers are native datatypes in C/C++.
- There are multiple ways to represent numbers
  - `signed int`
  - `unsigned int`
  - `short/long`
  - `etc….`
- We can type-cast one to other!
- Each can hold values of certain size!

Unsigned Integers

- Unsigned integer values range from zero to a maximum that depends on the size of the type.
- This maximum value can be calculated as 2^{n-1}, where n is the number of bits used to represent the unsigned type.
- For each signed integer type, there is a corresponding unsigned integer type.

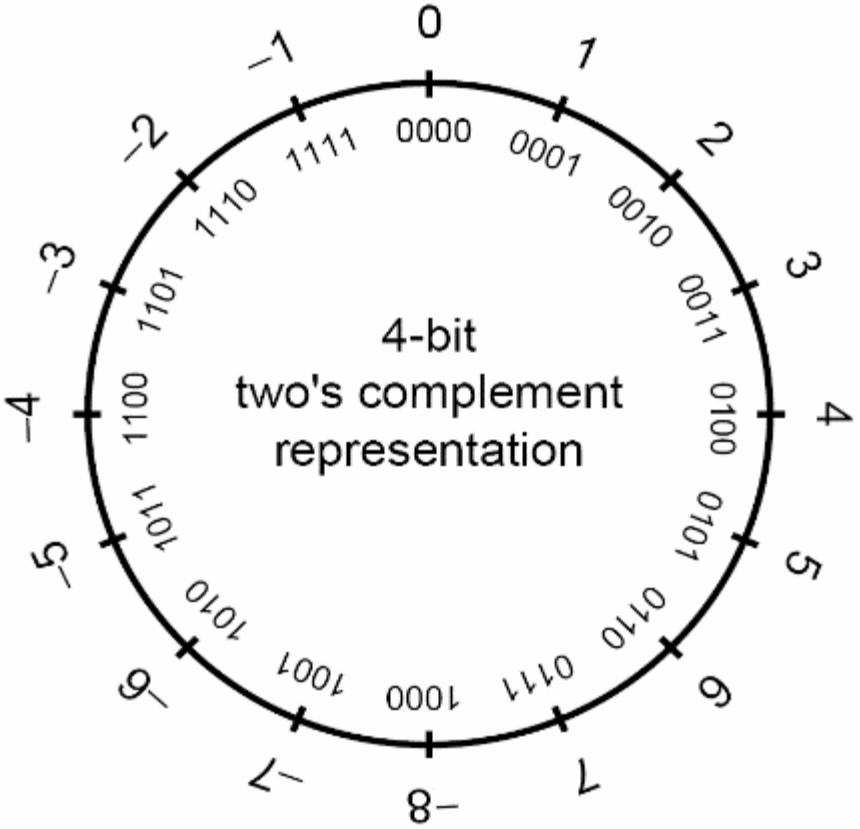
Signed and Unsigned Types

- Integers in C and C++ are either signed or unsigned.
- For each signed type there is an equivalent (though interpreted differently) unsigned type.

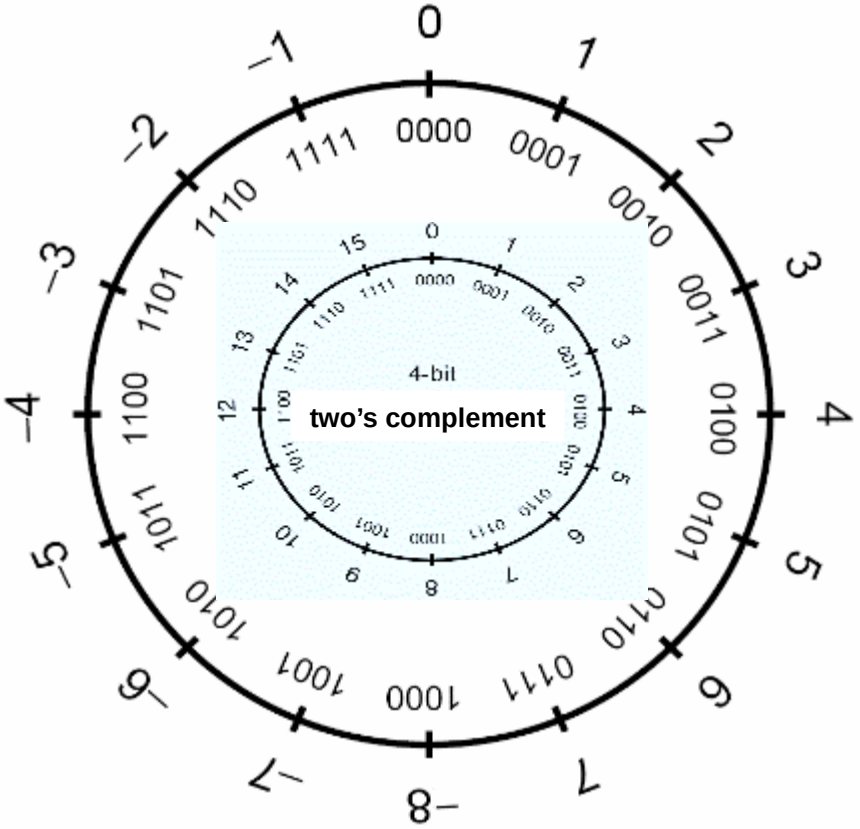
Signed Integers

- Signed integers are used to represent positive and negative values.
- On a computer using two's complement arithmetic, a signed integer ranges from -2^{n-1} through $2^{n-1}-1$.

(un)signed Integer Representation



(un)signed Integer Representation



Example Integer Ranges

Type	Storage size	Value range
char	1 byte	-128 to 127 or 0 to 255
unsigned char	1 byte	0 to 255
signed char	1 byte	-128 to 127
int	2 or 4 bytes	-32,768 to 32,767 or -2,147,483,648 to 2,147,483,647
unsigned int	2 or 4 bytes	0 to 65,535 or 0 to 4,294,967,295
short	2 bytes	-32,768 to 32,767
unsigned short	2 bytes	0 to 65,535
long	8 bytes	-9223372036854775808 to 9223372036854775807
unsigned long	8 bytes	0 to 18446744073709551615

Unsigned Integer Conversions

- Conversions of smaller unsigned integer types to larger unsigned integer types is
  - always safe
  - typically accomplished by zero-extending the value
- When a larger unsigned integer is converted to a smaller unsigned integer type the
  - larger value is truncated
  - low-order bits are preserved

Integer Error Conditions 1

- Integer operations can resolve to unexpected values as a result of an
  - overflow
  - sign error
  - truncation

Overflow

- An integer overflow occurs when an integer is increased beyond its maximum value or decreased beyond its minimum value.
- Overflows can be signed or unsigned

A signed overflow occurs when a value is carried over to the sign bit

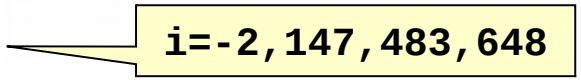
An unsigned overflow occurs when the underlying representation can no longer represent a value

Overflow Examples 1

```
1. int i;
2. unsigned int j;

3. i = INT_MAX;  // 2,147,483,647
4. i++;
5. printf("i = %d\n", i);

6. j = UINT_MAX; // 4,294,967,295;
7. j++;
8. printf("j = %u\n", j);
```

Overflow Examples 1

```
1. int i;
2. unsigned int j;

3. i = INT_MAX;  // 2,147,483,647
4. i++;
5. printf("i = %d\n", i);

6. j = UINT_MAX; // 4,294,967,295;
7. j++;
8. printf("j = %u\n", j);
```



Overflow Examples 1

```
1. int i;
2. unsigned int j;

3. i = INT_MAX;  // 2,147,483,647
4. i++;
5. printf("i = %d\n", i);

6. j = UINT_MAX; // 4,294,967,295;
7. j++;
8. printf("j = %u\n", j);
```

i=-2,147,483,648

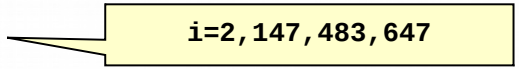
j = 0

Overflow Examples 2

```
 9. i = INT_MIN; // -2,147,483,648;
10. i--;
11. printf("i = %d\n", i);

12. j = 0;
13. j--;
14. printf("j = %u\n", j);
```

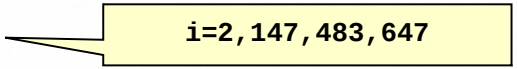
Overflow Examples 2

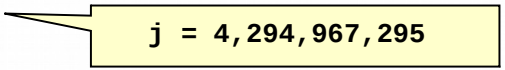
```
 9. i = INT_MIN; // -2,147,483,648;
10. i--;
11. printf("i = %d\n", i);

12. j = 0;
13. j--;
14. printf("j = %u\n", j);
```



Overflow Examples 2

```
 9. i = INT_MIN; // -2,147,483,648;
10. i--;
11. printf("i = %d\n", i);

12. j = 0;
13. j--;
14. printf("j = %u\n", j);
```





Truncation Errors

- Truncation errors occur when
  - an integer is converted to a smaller integer type and
  - the value of the original integer is outside the range of the smaller type
- Low-order bits of the original value are preserved and the high-order bits are lost.

Truncation Error Example

- `1. char cresult, c1, c2, c3;`
- `2. c1 = 100;`
- `3. c2 = 90;`
- `4. cresult = c1 + c2;`

Truncation Error Example

- `1. char cresult, c1, c2, c3;`
- `2. c1 = 100;`
- `3. c2 = 90;`
- `4. cresult = c1 + c2;`

Adding **`c1`** and **`c2`** exceeds the max size of **`signed char (+127)`**

Truncation Error Example

- `1. char cresult, c1, c2, c3;`
- `2. c1 = 100;`
- `3. c2 = 90;`
- `4. cresult = c1 + c2;`

Adding **`c1`** and **`c2`** exceeds the max size of **`signed char (+127)`**

Integers smaller than **`int`** are promoted to **`int`** or **`unsigned int`** before being operated on

Truncation Error Example

- `1. char cresult, c1, c2, c3;`
- `2. c1 = 100;`
- `3. c2 = 90;`
- `4. cresult = c1 + c2;`

Adding **`c1`** and **`c2`** exceeds the max size of **`signed char (+127)`**

Truncation occurs when the value is assigned to a type that is too small to represent the resulting value

Integers smaller than **`int`** are promoted to **`int`** or **`unsigned int`** before being operated on

Precondition unsigned

Overflow occurs when **`A`** and **`B`** are **`unsigned int`** and

```
A + B > UINT_MAX
```

Precondition unsigned

Overflow occurs when **A** and **B** are **unsigned int** and

A + B > UINT_MAX

To prevent the test from overflowing, code this test as

A > UINT_MAX – B

Overflow also occurs when **A** and **B are long long int** and

A + B > ULLONG_MAX