Type Modifiers and References

What is a type modifier?

- C++ provides a set of modifiers that can be applied to some/all of the types in the system
  - Some are numeric specific
  - Some control variable access
  - Some change the meaning of a variable

Tracking

- Compiler tracks four things about variables (so it can turn stuff into assembly code)

1. Name (names, aliases), like variable names
2. Address (where it goes in memory)
3. Type (which determines how many bytes it might occupy)
4. Value

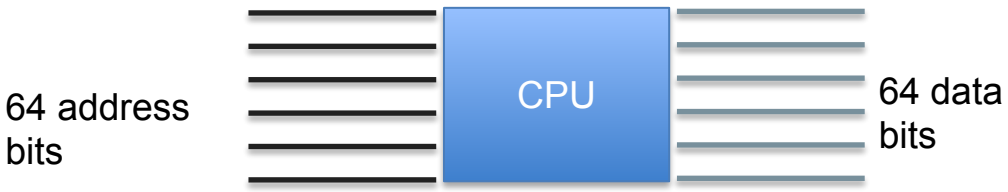
Architecture

- When someone says you are running a “64-bit” os/cpu/something
  - The number of bits that can be used in an address (to memory) is 64
  - The range of addresses (unsigned) is about 2^{64}, 0 to 1.85×10^{19} bytes
  - That is ~ 16 exabytes (10^18), (1000 petabytes, 1 million terabytes, 1 billion gigabytes)

64 Bits

1100 1011 0110 1111 0000 1010 0010 0111 1100 1011 0110 1111 0000 1010 0010 0111

- Each bit represents a signal on a line
- 64 such lines going to the CPU that it can use to select a byte
- Can select one of 18 exabytes, can move 8 bytes at once



64 Bits Addresses

```
1100 1011 0110 1111 0000 1010 0010 0111 1100 1011 0110 1111 0000 1010 0010 0111
 c    b    6    f    0    a    2    7    c    b    6    f    0    a    2    7
```

- A 64-bit address looks like 0xcb6f0a27cb6f0a27
- 0x prefix indicates hex in C++

Hey, wait a minute?

- You said an address on a 64-bit machine was 64 bits, 16 hex numbers
  - 0xcb6f0a276f0a27
- But the address on your future examples are only 12 hex numbers (48 bits)
  - 0x7fff519b7a8c

Expediency

- Hardware manufacturers know (or at least surmise) that no one will have that much memory anytime soon.
- Thus they cheat and provide fewer address lines since they know they won’t get used.
- Saves money!

A symbol table

Name	Type	Address	Value
my_long	long	0x7fff519b7a8c	123
p_long	long*	0x7fff519b7a80	0x7fff519b7a8c
r_long	long&	0x7fff519b7a8c	123

C++ Name rules

- Only alpha, digit, and underscore
- Cannot start with a digit
- Don’t use a keyword as a name
- Names are case-sensitive
  - Upper and lower-case are different
- No special characters

Which of the following are valid names?

- `42_or_fight`
- `sHiT`
- `_illegal_`
- `I don't know`

The &

- Is a type modifier in the context of declaration (it has other meanings)
  - In a declaration, the & means a reference to another type
  - Both parts matter, the reference and the type it references

References, a name alias

- A *reference* is a variable declaration that is a name alias for another variable
  - It is indicated by the & (ampersand)
    - But it has different meanings in other contexts!
  - It **requires** initialization
    - When you declare a reference you have to say what it refers to
    - Must be an lvalue
      - No Literals
      - No expression results

A reference is not an object

- A reference is a name alias in the symbol table
- It does not create a new variable
- No new memory allocation
- It simply refers to an existing variable

Things to note

- Stuff happens sequentially, so if you have a variable declared before a reference, the reference can refer to it
- In a multiple declaration, the & goes with the variable

Example 5.1

Which of the following are legal intializations of a reference?

- `int & x;`
- `int & x = 4;`
- `int & x = 3 + 4;`
- None of the above

Which of the following are legal intializations of a reference?

- `int & x = func_call();`
- `int & x = x;`
- `int & x = y;`
- None of the above

Pointers

A symbol table

- my_long = 123;

Name	Type	Address	Value
my_long	long	0x7fff519b7a8c	123
ref_long	long&	0x7fff519b7a8c	123

- ref_long = 456;

Name	Type	Address	Value
my_long	long	0x7fff519b7a8c	456
ref_long	long&	0x7fff519b7a8c	456

Pointers, an address type

- A pointer is a variable whose value is an *address*
  - It has a value, but the value is to *another location in memory*
  - As a result, a pointer can “point to” another variable
  - Can refer to another variable in memory by that other variable’s memory address

A word on pointers

- Pointers are a topic much discussed in CS
  - Python and Java don’t have them (sort of) because they can be the source of so many problems
  - Tend to be confusing to beginner programmers
  - Is really a pretty easy to understand subject as long as you are careful

* for pointer

- In the context of a declaration, a star (*) following the type means that the variable being declared is a pointer.

```
long* my_pointer; // pointer to long
```

Like &, * follows the variable

- Like we saw in &, the * goes with the variable, not the type
- This is unfortunate. We'd like to say the type is long*, but the * only applies to the next var:

```
long* p_long, my_long; // Confusing
long *p_long, my_long; // Less confusing
```

The *

- * is a type modifier that means the type is a pointer to some other type
- Both matter: a pointer and to some type

Example 5.2

What is the size of a pointer?

- Another question, what kind OS/CPU is this?
  - If 32-bit then *every* pointer is 4 bytes
  - If 64-bit then *every* pointer is 8 bytes
- Why?

Could be 6 bytes, but...

- Since addresses are actually 48 bits, they could fit in 6 bytes, but the hardware is setup to fetch 8 bytes at a time (that is the data lines are in fact 64 bits wide) and so they do
- Might as well use 8 bytes. Perhaps someday memory will catch up.

Dereferencing

- In the context of an expression, as a unary operator, the * represents “dereference”
- The pointer has an address as its value. Dereferencing means to use the value that the pointer has as its value to either fetch or set a value

Dereferencing, lvalue vs rvalue

- This is kind of intuitive, but we need to be clear
- Dereferencing as an rvalue provides a value at the address pointed to

```
x = *y;
```

- Dereferencing as an lvalue provides a memory location where values can be stored

```
*x = y;
```

```
*x = *y;
```

Another meaning for &

- In an expression, the & means “address of”
  - These are the kinds of values stored in a pointer

Empty Pointer

- In the previous code, the pointer p_long points to address 0 (nothing)
  - It is an object
  - It has an address
  - Its value is indeterminate, maybe 0x0?
- Dereferencing a pointer to 0x0 is illegal. It compiles but fails at runtime

Before setting p_long

Name	Type	Address	Value
my_long	long	0x7fff519b7a8c	123
p_long	long*	0x7ff519b7a80	0

What is 0?
What does that point to?

After setting p_long = &my_long

Name	Type	Address	Value
my_long	long	0x7fff519b7a8c	123
p_long	long*	0x7ff519b7a80	0x7fff519b7a8c

Value of p_long is the address of my_long

***p_long = 456**

Name	Type	Address	Value
my_long	long	0x7fff519b7a8c	456
p_long	long*	0x7ff519b7a80	0x7fff519b7a8c

3 step process:

1. Get the value of p_long
2. p_long value is an address, go there
3. Set the value of that address to the new value

long &r_long = *p_long

Name	Type	Address	Value
my_long	long	0x7fff519b7a8c	456
p_long	long*	0x7ff519b7a80	0x7fff519b7a8c
r_long	long&	0x7fff519b7a8c	456

3 step process:

1. Get the value of p_long
2. p_long value is an address, go there
3. Set the value of that address to the new value

Hard topic

- Though it seems easy enough, pointers tend to be a hard topic.
  - Hard to do correctly
  - Introducing early to get the hang of it as we go