CSCI 262
Data Structures

3 – Pointers and Memory

Prelude

NUMBERS

Positional Notation

Also called *place-value* notation

- Each place represents a power of the *base*
- Each numeral is multiplied by positional value

E.g., base 10 (decimal):

$(4273)_{10} = 3 \times 10^0 + 7 \times 10^1 + 2 \times 10^2 + 4 \times 10^3$

Other Bases

Computer scientists tend to think in powers of 2:

- Hexadecimal (base-16) – use digits 0-9, a-f (or A-F)

  $(4273)_{10} = (10b1)_{16} = 1 \times 16^0 + 11 \times 16^1 + 1 \times 16^3$

- Octal (base-8) – mostly out of use now

  $(4273)_{10} = (10261)_8 = 1 \times 8^0 + 6 \times 8^1 + 2 \times 8^2 + 1 \times 8^4$

- Binary! (0s and 1s)

  $(4273)_{10} = (0001\ 0000\ 1011\ 0001)_2$

Bits and Bytes

Computers work with *bits* – 0's and 1's

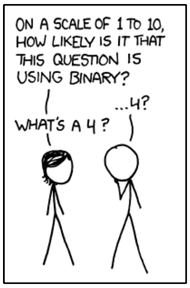
- (Positive) integers are represented in base 2:

  $0_{10} = 0_2$,
  $1_{10} = 1_2$,
  $2_{10} = 10_2$,
  $3_{10} = 11_2$,
  $4_{10} = 100_2$,
  $5_{10} = 101_2$, etc.

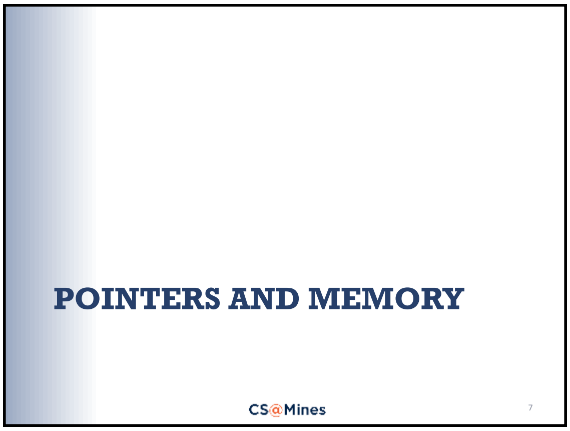
The maximum (unsigned) integer we can store in n bits is 2^n-1.

- Computers organize bits into *bytes* – 8-bit chunks
- C++ data types are organized into bytes
  - `char` uses 1 byte
  - `int` uses 4 bytes
  - `double` uses 8 bytes
- Get size of a variable/object type with sizeof:

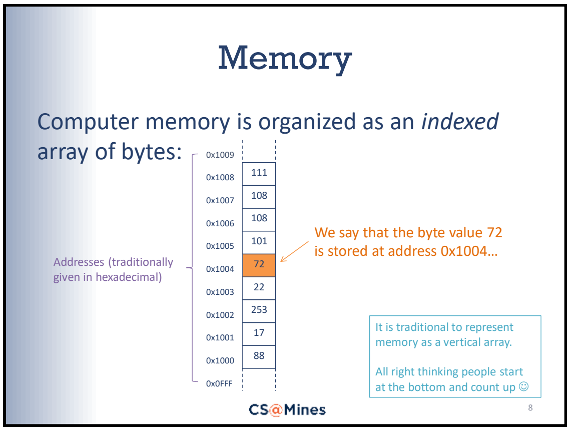
```
     int sz_of_dbl = sizeof(double);
```


ON A SCALE OF 1 TO 10, HOW LIKELY IS IT THAT THIS QUESTION IS USING BINARY?
...4?
WHAT'S A 4?

http://xkcd.com/953/



POINTERS AND MEMORY



Memory

Computer memory is organized as an *indexed* array of bytes:

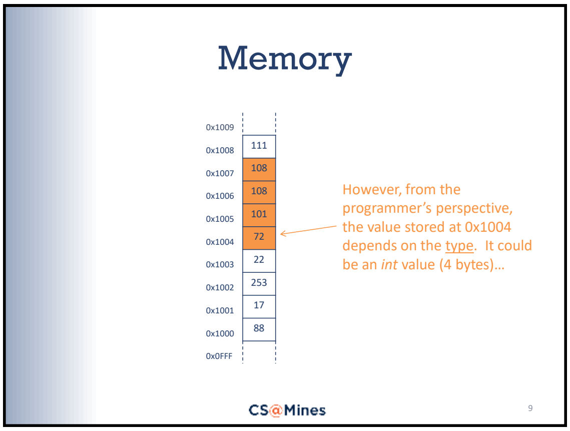
0x1009	
0x1008	111
0x1007	108
0x1006	108
0x1005	101
0x1004	72
0x1003	22
0x1002	253
0x1001	17
0x1000	88
0x0FFF	

Addresses (traditionally given in hexadecimal)

We say that the byte value 72 is stored at address 0x1004…

It is traditional to represent memory as a vertical array.

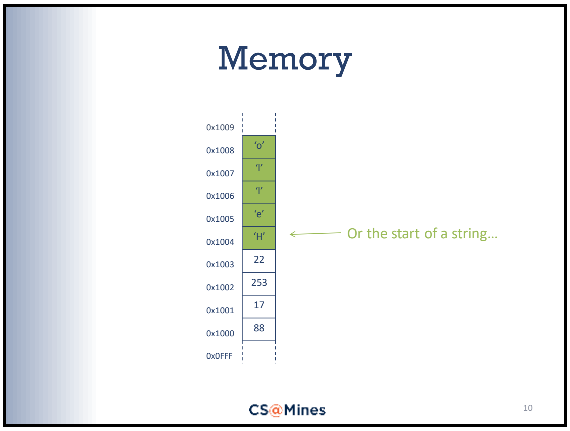
All right thinking people start at the bottom and count up ☺



Memory

0x1009	
0x1008	111
0x1007	108
0x1006	108
0x1005	101
0x1004	72
0x1003	22
0x1002	253
0x1001	17
0x1000	88
0x0FFF	

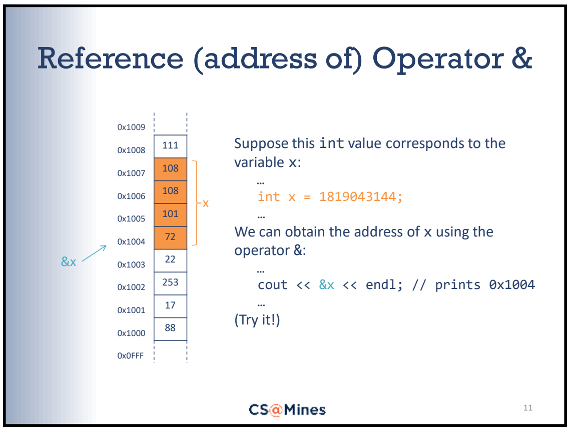
However, from the programmer's perspective, the value stored at 0x1004 depends on the type. It could be an *int* value (4 bytes)…



Memory

0x1009	
0x1008	'o'
0x1007	'l'
0x1006	'l'
0x1005	'e'
0x1004	'H'
0x1003	22
0x1002	253
0x1001	17
0x1000	88
0x0FFF	

Or the start of a string…



Reference (address of) Operator &

0x1009		
0x1008	111	
0x1007	108	x
0x1006	108	
0x1005	101	
0x1004	72	
0x1003	22	
0x1002	253	
0x1001	17	
0x1000	88	
0x0FFF		

&x

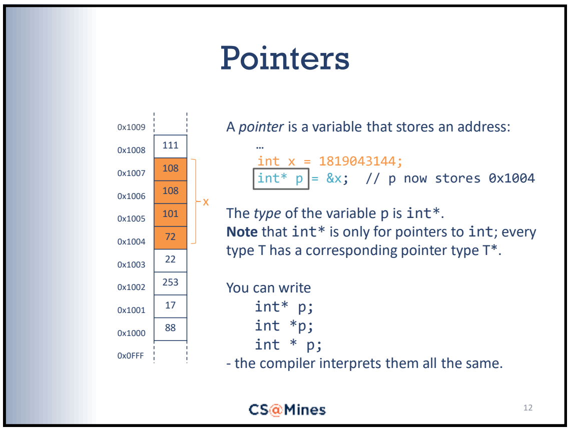
Suppose this `int` value corresponds to the variable x:

```
…
int x = 1819043144;
…
```

We can obtain the address of x using the operator &:

```
…
cout << &x << endl; // prints 0x1004
…
```

(Try it!)



Pointers

0x1009		
0x1008	111	
0x1007	108	x
0x1006	108	
0x1005	101	
0x1004	72	
0x1003	22	
0x1002	253	
0x1001	17	
0x1000	88	
0x0FFF		

A *pointer* is a variable that stores an address:

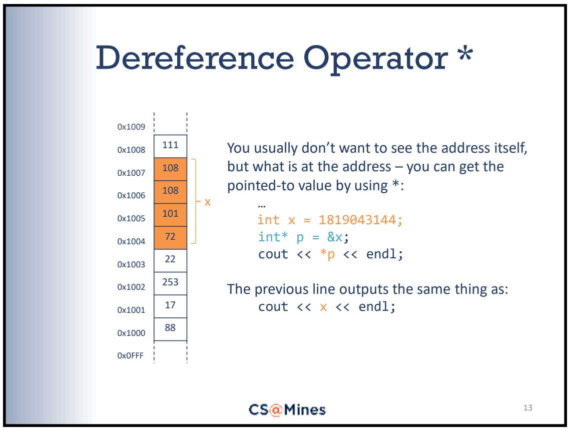
```
…
int x = 1819043144;
int* p = &x;  // p now stores 0x1004
```

The *type* of the variable p is `int*`. **Note** that `int*` is only for pointers to `int`; every type T has a corresponding pointer type T*.

You can write

```
int* p;
int *p;
int * p;
```

- the compiler interprets them all the same.



Dereference Operator *

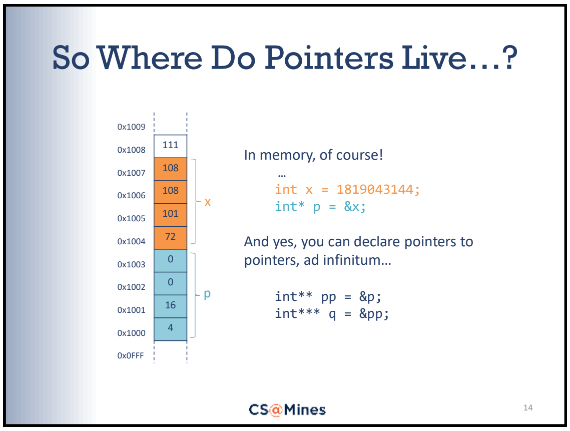
0x1009		
0x1008	111	
0x1007	108	
0x1006	108	x
0x1005	101	
0x1004	72	
0x1003	22	
0x1002	253	
0x1001	17	
0x1000	88	
0x0FFF		

You usually don't want to see the address itself, but what is at the address – you can get the pointed-to value by using *:

```
…
int x = 1819043144;
int* p = &x;
cout << *p << endl;
```

The previous line outputs the same thing as:

```
cout << x << endl;
```



So Where Do Pointers Live…?

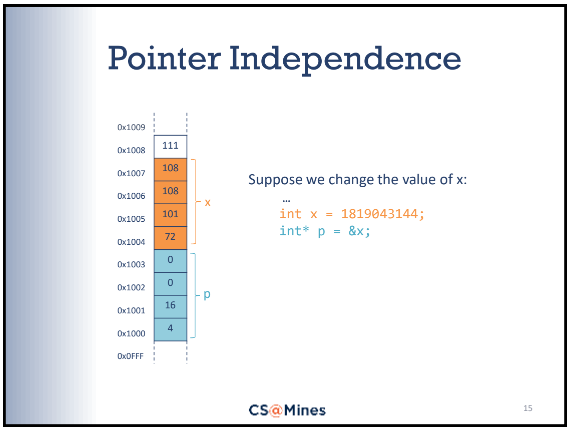
0x1009		
0x1008	111	
0x1007	108	
0x1006	108	x
0x1005	101	
0x1004	72	
0x1003	0	
0x1002	0	p
0x1001	16	
0x1000	4	
0x0FFF		

In memory, of course!

```
…
int x = 1819043144;
int* p = &x;
```

And yes, you can declare pointers to pointers, ad infinitum…

```
int** pp = &p;
int*** q = &pp;
```

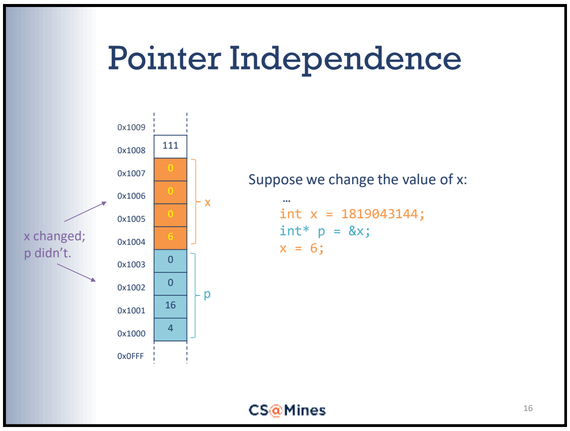


Pointer Independence

0x1009		
0x1008	111	
0x1007	108	
0x1006	108	x
0x1005	101	
0x1004	72	
0x1003	0	
0x1002	0	p
0x1001	16	
0x1000	4	
0x0FFF		

Suppose we change the value of x:

```
…
int x = 1819043144;
int* p = &x;
```



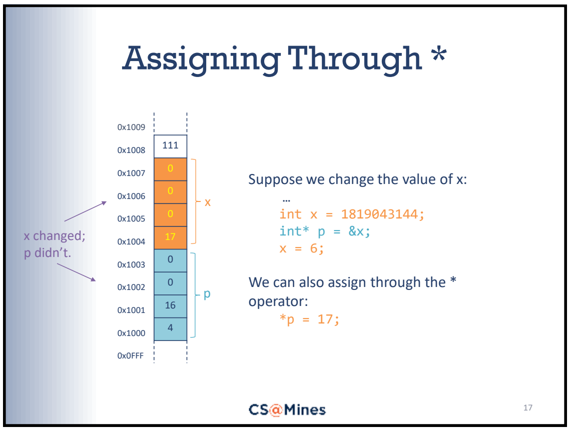
Pointer Independence

0x1009		
0x1008	111	
0x1007	0	
0x1006	0	x
0x1005	0	
0x1004	6	
0x1003	0	
0x1002	0	p
0x1001	16	
0x1000	4	
0x0FFF		

x changed;
p didn't.

Suppose we change the value of x:

```
…
int x = 1819043144;
int* p = &x;
x = 6;
```



Assigning Through *

0x1009		
0x1008	111	
0x1007	0	
0x1006	0	x
0x1005	0	
0x1004	17	
0x1003	0	
0x1002	0	p
0x1001	16	
0x1000	4	
0x0FFF		

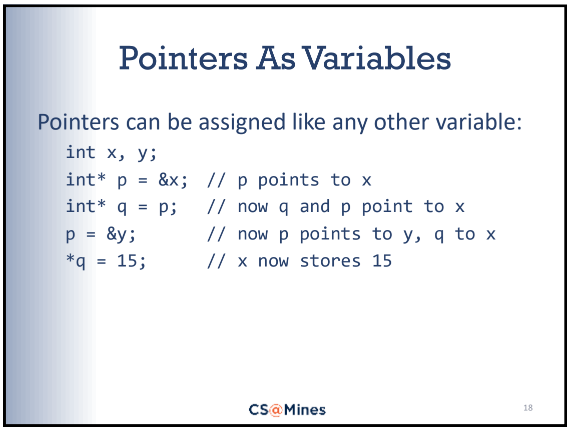
x changed;
p didn't.

Suppose we change the value of x:

```
…
int x = 1819043144;
int* p = &x;
x = 6;
```

We can also assign through the * operator:

```
*p = 17;
```



Pointers As Variables

Pointers can be assigned like any other variable:

```
int x, y;
int* p = &x;  // p points to x
int* q = p;   // now q and p point to x
p = &y;       // now p points to y, q to x
*q = 15;      // x now stores 15
```

The `nullptr` Pointer

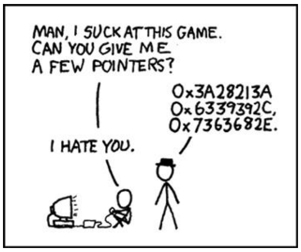
- C++ defines a special keyword for pointers which do not currently point to anything: `nullptr`

```
int* p = nullptr;
```

- A null pointer is *never* a valid memory address:

```
int* p = nullptr;
cout << *p << endl;   // crash
*p = 42;              // also crash
```

- Prior to C++ 11, the value NULL was used instead of nullptr. You will see a lot of code using NULL.



http://xkcd.com/138/

POINTER NOTES

Dereferencing Pointers

- Given a pointer p to some value:
  *p dereferences p, is equivalent to the value.

- Suppose p points to an object or structure:
  `(*p).foo` dereferences p and accesses the member `foo`
  `p->foo` does the same thing

- In the next lecture we'll see that array indexing is another kind of dereferencing:
  `p[i] == *(p + i)`
  (But we'll have to explain pointer arithmetic first.)

Multiple Pointer Declaration

An oddity of C/C++: we must do

```
int *p, *q;   // we have to use * for both
```

even though `int*` is the type.

Otherwise:

```
int *p, q;   // p is an int*, but q is an int
```

Up Next

- Today
  - Lab 1 due
  - Reading: Chapter 14.1-14.2
- Wednesday, January 16
  - Linked Lists
  - Reading: Chapter 14.4-14.6
- Friday, January 18
  - Lab 2 – I/O
  - APT 1 due
  - Project 1 assigned