VARIABLES AND STORAGE

Today

- Variables
- Data types
- Data storage
- Binary numbers
- ASCII

Some of this recaps what we did last lecture, most of it is new.

Data types

- Programs = objects + methods
- Objects = data
  - There is more to be said here, but we won't say it until CIS 15.
- Data must be *stored*.
- All storage is numeric (0's and 1's)

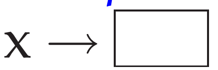
Data storage

- Think of the computer's memory as a bunch of boxes
- Inside each box, there is a number
- You give each box a name
  ⇒ defining a *variable*
- Example:

Program code:

```
int x;
```

Computer's memory:



Variables

- Variables have:
  - name
  - type
  - value
- Naming rules:
  - names may contain letters and/or numbers
  - but cannot begin with a number
  - names may also contain underscore (_)
  - can be of any length
  - cannot use C++ keywords (also called *identifiers*)
  - C++ is *case-sensitive!!*

Intrinsic data types

Type	Size	Minimim value	Maximum value
bool	1 bit	0	1
byte	8 bits	$-128 = -2^7$	$127 = 2^7 - 1$
char	8 bits	$-128 = -2^7$	$127 = 2^7 - 1$
short	16 bits	$-32,768 = -2^{15}$	$32,767 = -2^{15} - 1$
int	32 (or 16) bits	$-2^{31}(2^{15})$	$2^{31} - 1(2^{15} - 1)$
long	32 bits	-2^{31}	$2^{31} - 1$
float	32 bits	$\approx -3.4E + 38$, 7 sig. dig.	$\approx 3.4E + 38$, 7 sig. dig.
double	64 bits	$\approx -1.7E + 308$, 15 sig. dig.	$\approx 1.7E + 308$, 15 sig. dig.

"sig. dig." = significant digits

Assignment

- = is the assignment operator
- Example:

Program code:

```
int x;
// declaration
x = 19;
// assignment
```

or

```
int x = 19;
```

Computer's memory:

x → 19

Storage is binary

x → 19

is really stored like this:

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1

this is base 2!

$19_{10} = 10011_2$

Remember bases?

Base 10:

$$
\begin{aligned}
362 &= (2 * 1) + (6 * 10) + (3 * 100) \\
&= (2 * 10^0) + (6 * 10^1) + (3 * 10^2)
\end{aligned}
$$

Base 2:

$$
\begin{aligned}
1 &= 2^0 = 1 \\
10 &= 2^1 = 2 \\
100 &= 2^2 = 4 \\
1000 &= 2^3 = 8 \\
10000 &= 2^4 = 16 \\
&\ldots
\end{aligned}
$$

so

$$
\begin{aligned}
10011_2 &= (1 * 2^0) + (1 * 2^1) + (0 * 2^2) + (0 * 2^3) + (1 * 2^4) \\
&= (1 * 1) + (1 * 2) + (0 * 4) + (0 * 8) + (1 * 16) \\
&= 19_{10}
\end{aligned}
$$

Base conversion: 2 to 10.

$1010100_2 =$

$$
\begin{array}{r|r|r}
 & = & = \\
(0 * 2^0) & (0 * 1) & 0 \\
+ (0 * 2^1) & + (0 * 2) & + 0 \\
+ (1 * 2^2) & + (1 * 4) & + 4 \\
+ (0 * 2^3) & + (0 * 8) & + 0 \\
+ (1 * 2^4) & + (1 * 16) & + 16 \\
+ (0 * 2^5) & + (0 * 32) & + 0 \\
+ (1 * 2^6) & + (1 * 64) & + 64
\end{array}
$$

$= 84_{10}$

Base conversion: 10 to 2.

84_{10} =

84 / 2	=	42	rem 0
42 / 2	=	21	rem 0
21 / 2	=	10	rem 1
10 / 2	=	5	rem 0
5 / 2	=	2	rem 1
2 / 2	=	1	rem 0
1 / 2	=	0	rem 1

Read the remainders from the bottom up, and we get the binary number we want:

$84_{10} = 1010100_2$

Two tricks.

Base 8 (octal):

000	0
001	1
010	2
011	3
100	4
101	5
110	6
111	7

Base 16 (hexadecimal, “hex”):

0000	0	1000	8
0001	1	1001	9
0010	2	1010	A (10)
0011	3	1011	B (11)
0100	4	1100	C (12)
0101	5	1101	D (13)
0110	6	1110	E (14)
0111	7	1111	F (15)

- Replace each octal digit with 3 binary digits
- Replace every 3 binary digits with one octal digit

- Thus 37_8 is 011111 in binary.
- And 101011 is 53_8
- Replace each hex digit with 4 binary digits.
- Replace every 4 binary digits with one hex digit
- Thus 37_{16} is 00110111 in binary.
- And 11110110 is $\mathrm{F}6_{16}$

Back to storage

x $\longrightarrow$ 19

is really stored like this:

31	30	...	7	6	5	4	3	2	1	0
0	0	...	0	0	0	1	0	0	1	1

- Bits are numbered, from right to left, starting with 0
- Highest (rightmost, "most significant") bit is *sign* bit

ASCII.

- ASCII = American Standard Code for Information Interchange
- Characters are stored as numbers
- Standard table defines 128 characters
- Example:

```
char c = 'A';
```

'A' = $65_{10} = 01000001_2$

c $\longrightarrow$

7	6	5	4	3	2	1	0
0	1	0	0	0	0	0	1

Casting

- Sometimes it is useful to be able to convert from one kind of variable to another.
- For example, if we have:

```
int i;
char c = 'A';
```

- We know that the `A` is really stored as the number `65`, what if we want to use that `65`?
- We can't just do:

```
i = c;
```

- But we can *cast* from `char` to `int`:

```
i = (int) c;
```

- The `(int)` is an operation that coverts the value in the variable `c`, which is a `char` to be and `int` so that it can be stored in `i`.

- We can cast between the types of variable that we have already met.

```
int i = 10;
char c = 'A';
double d = 3.5;

d = (double) c;
d = (double) i;
i = (int) c;
```

- We can also do the following:

```
c = (char) d;
c = (char) i;
i = (int) d;
```

  but there is a problem with this second batch of casts.
- The problem is that the variables we are casting into do not have enough bits to store all the data that is being assigned.
- Some information will be lost

  Like pouring a whole jug of water into a glass — you will end up with some on the floor.

Mathematical operators.

+	unary plus
−	unary minus
+	addition
−	subtraction
*	multiplication
/	division
%	modulo

Example:

```
int x, y;
x = -5;
y = x * 7;
y = y + 3;
x = x * -2;
y = x / 19;
```

What are `x` and `y` equal to?

Modulo means “remainder after integer division”

Increment and decrement operators

- We are always increasing and decreasing values by one, so there are shortcuts.
- Increment: ++

  ```
  i++;
  ```

  is the same as:

  ```
  i = i + 1;
  ```

- Decrement: −−

  ```
  i--;
  ```

  is the same as:

  ```
  i = i - 1;
  ```

Assignment operators.

- There are shorthand ways of doing other combinations of arithmetic and assignment.

  `+=`

  `i += 3;` is the same as: `i = i + 3;`

  `-=`

  `i -= 3;` is the same as: `i = i - 3;`

  `*=`

  `i *= 3;` is the same as: `i = i * 3;`

- Also:

  /=

  `i /= 3;` is the same as: `i = i / 3;`

  %=

  `i %= 3;` is the same as: `i = i % 3;`

Summary

- This lecture expanded on the idea of a variable.
- We considered how variables are represented in computer memory.
- We mentioned binary, octal and hexidecimal.
- We talked about how to cast from one kind of variable to another.
- With the idea of a variable under our belts, we recapped arithmetic and assignment.