Types, Values & Variables

EECS 211

Winter 2019

Initial code setup

```
$ cd eecs211
$ wget $URL211/lec/02types_values.tgz
…
$ tar zxf 02types_values.tgz
$ cd 02types_values
```

Introduction to `int` and `double`

Defining a variable

Every variable in C must be defined with a *type*:

```
int x = 5;
double f = 5.1;
```

What does this do?

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What does this do?

A variable names an *object* of the given type, which is a chunk of memory that can hold a value of that type:

x:	+0x00000005
f:	+5.0999999999999964...e+00

(The notation *AeB* means $A \times 10^B$)

Let’s observe this in C!

```
#include <stdio.h>

int main()
{
    int x = 5;
    double f = 5.1;

    printf("x:␣%d\n", x);
    printf("f:␣%.60e\n", f);

    printf("sizeof␣x:␣%zu␣bytes\n", sizeof x);
    printf("sizeof␣f:␣%zu␣bytes\n", sizeof f);
}
```

Output from the previous slide

```
$
```

Output from the previous slide

```
$ make build/types
```

Output from the previous slide

```
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cc -o build/types src/types.c -std=c11 -pedantic -
W…
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```

Output from the previous slide

```
$ make build/types
cc -o build/types src/types.c -std=c11 -pedantic -
W…
$ build/types
x: 5
f: 5.09999999999999964472863211994990706443786621093…
sizeof x: 4 bytes
sizeof f: 8 bytes
```

Including headers

This is a directive that causes the functions defined in `stdio.h` to be known to the compiler:

```
#include <stdio.h>
```

(Without it, we wouldn't have access to `printf`.)

The `main` function

C programs can have multiple functions, but they always start by calling `main`:

```
int main()
{
    // ...
}
```

(The `int` is `main`'s return type. C programs return an *error code* to the OS, where 0 means success and non-zero means failure. The `main` function magically returns 0 for you if you don't tell it otherwise.)

Producing output

The usual way to print in C is the `printf` function, which takes a *format string* followed by arguments to *interpolate* in place of the format string's *directives*:

```
printf("x:␣%d\n", x);
```

(Prints format string "`x: %d\n`", replacing directive `%d` with the value of `x`.)

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```
printf("x:␣%d\n", x);
```

(Prints format string "`x: %d\n`", replacing directive `%d` with the value of `x`.)

Each directive specifies the type of the argument to print, possibly with some options:

`%d`	expects an `int`
`%.60e`	expects a `double`; includes 60 digits of precision
`%zu`	expects a `size_t` (the result of `sizeof`)

Reading input

To input numbers in C, use the `scanf` function.

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int x = 0;
scanf("%d", &x);
```

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`scanf` reads keyboard input, converts it to the required type, and stores it in an existing variable:

```
int x = 0;
scanf("%d", &x);
```

- Like `printf`, `scanf` uses a format string to determine what type to convert the input to.
- But `scanf`'s directives are not all the same as `printf`'s! (Use `%lf` to read a `double`.)
- An argument `x` would pass the *value* of variable `x` to `scanf`, but `&x` means to pass `x`'s *location*.

Example of reading input

```c
#include <stdio.h>

int main()
{
    int x = 0;
    int y = 0;

    printf("Enter␣two␣integers:␣");
    scanf("%d%d", &x, &y);
    printf("%d␣*␣%d␣==␣%d\n", x, y, x * y);
}
```

Output from the previous slide

```
$
```

Output from the previous slide

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cc -o build/input src/input.c -std=c11 -pedantic -
W…
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W…
$ build/input
Enter two integers:
```

Output from the previous slide

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cc -o build/input src/input.c -std=c11 -pedantic -
W…
$ build/input
Enter two integers: 5 7
```

Output from the previous slide

```
$ make build/input
cc -o build/input src/input.c -std=c11 -pedantic -
W…
$ build/input
Enter two integers: 5 7
5 * 7 == 35
$
```

Output from the previous slide

```
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$ build/input
Enter two integers: 5 7
5 * 7 == 35
$ build/input
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$ make build/input
cc -o build/input src/input.c -std=c11 -pedantic -
W…
$ build/input
Enter two integers: 5 7
5 * 7 == 35
$ build/input
Enter two integers: 5 seven
```

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$ make build/input
cc -o build/input src/input.c -std=c11 -pedantic -
W…
$ build/input
Enter two integers: 5 7
5 * 7 == 35
$ build/input
Enter two integers: 5 seven
5 * 0 == 0
$
```

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cc -o build/input src/input.c -std=c11 -pedantic -
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Enter two integers: 5 7
5 * 7 == 35
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Enter two integers: 5 seven
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Enter two integers:
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Enter two integers: 5 7
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Enter two integers: 5 7
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5 * 0 == 0
$ build/input
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Enter two integers: 5 7
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$ build/input
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5 * 0 == 0
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Enter two integers: five 7
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Enter two integers:
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W…
$ build/input
Enter two integers: 5 7
5 * 7 == 35
$ build/input
Enter two integers: 5 seven
5 * 0 == 0
$ build/input
Enter two integers: five 7
0 * 0 == 0
$ build/input
Enter two integers: ^D
```

Output from the previous slide

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cc -o build/input src/input.c -std=c11 -pedantic -
W…
$ build/input
Enter two integers: 5 7
5 * 7 == 35
$ build/input
Enter two integers: 5 seven
5 * 0 == 0
$ build/input
Enter two integers: five 7
0 * 0 == 0
$ build/input
Enter two integers: ^D0 * 0 == 0
$
```

How `scanf` reports errors

`scanf` returns the number of successful conversions.

Example of reading input and checking for errors

```
#include <stdio.h>

int main()
{
    int x, y;

    printf("Enter␣two␣integers:␣");

    if (scanf("%d%d", &x, &y) != 2) {
        printf("Input␣error\n");
        return 1;
    }

    printf("%d␣*␣%d␣==␣%d\n", x, y, x * y);
}
```

Syntax for functions and arithmetic

```c
#include <stdio.h>

unsigned long factorial(unsigned long n)
{
    if (n == 0)
        return 1;
    else
        return n * factorial(n - 1);
}

int main()
{
    unsigned long n = 0;
    scanf("%lu", &n);
    printf("%lu! == %lu\n", n, factorial(n));
}
```

Facts from the previous slide

- `long` is an integral type that might have more bits than `int` (like maybe 64 instead of 32)
- `unsigned` means it does not include negative numbers (which means it includes twice as many positive numbers instead)
- `*` multiplies, `-` subtracts, and `==` compares for equality
- The result of a function must be given in a `return` statement
- The `printf` and `scanf` directive for `unsigned long` is `%lu`

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- For example, 32-bit `int`s (usually) range from -2^{31} to $2^{31} - 1$ (inclusive)
- The actual values are defined in `limits.h` as `INT_MIN` and `INT_MAX`
- An `int` operation whose mathematical result is out of range produces **UNDEFINED BEHAVIOR**

WTF IS UNDEFINED BEHAVIOR?!?!

It’s like a kind of error…

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Technically, a program with **UB** has no meaning. It's allowed to do anything:

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- Reformat your hard disk
- Launch the missiles

Examples of UB

- Uninitialized memory access
- Integer division by 0
- Integer “overflow”

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```
int x, y;
scanf("%d%d", &x, &y);
printf("%d\n", x / y);
```

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Example of all three:

```
int x, y;
scanf("%d%d", &x, &y);
printf("%d\n", x / y);
```

Fix for all three:

```
int x, y;
if (scanf("%d%d", &x, &y) == 2 &&
        y != 0 &&
        !(x == INT_MIN && y == -1))
    printf("%d\n", x / y);
```

UB is really weird

```c
#include <limits.h>
#include <stdio.h>

void check_int(int z)
{
    if (z < z + 1)
        printf("math\n");
    else
        printf("C.S.\n");
}

int main()
{
    check_int(0);
    check_int(INT_MAX);
}
```

The results depend on the optimization level

```
$
```

The results depend on the optimization level

```
$ make build/int_max
```

The results depend on the optimization level

```
$ make build/int_max
cc -o build/int_max src/int_max.c -std=c11 -pedanti…
$
```

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```

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$ make build/int_max
cc -o build/int_max src/int_max.c -std=c11 -pedanti…
$ build/int_max
math
C.S.
$
```

The results depend on the optimization level

```
$ make build/int_max
cc -o build/int_max src/int_max.c -std=c11 -pedanti…
$ build/int_max
math
C.S.
$ make build/int_max.opt
```

The results depend on the optimization level

```
$ make build/int_max
cc -o build/int_max src/int_max.c -std=c11 -pedanti…
$ build/int_max
math
C.S.
$ make build/int_max.opt
cc -O2 -o build/int_max.opt src/int_max.c -std=c11 …
$
```

The results depend on the optimization level

```
$ make build/int_max
cc -o build/int_max src/int_max.c -std=c11 -pedanti…
$ build/int_max
math
C.S.
$ make build/int_max.opt
cc -O2 -o build/int_max.opt src/int_max.c -std=c11 …
$ build/int_max.opt
```

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$ make build/int_max
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$ build/int_max.opt
math
math
$
```

(This is very, very bad.)

Structure types

Structure types in C

C (like BSL/ISL) uses structures to define new data types by composition of existing data types

A structure type has a name and some number of fields, each of which must be declared with a type

Syntax to define a `struct` type

```
struct posn
{
    double x;
    double y;
};

struct circle
{
    struct posn center;
    double radius;
};
```

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Note that the type defined by the `struct posn` definition, and used for field `center` of `struct circle` is `struct posn`, not merely `posn`. (In C++ you could refer to it either way, but not in C.)

Syntax to use a structure

Suppose we have a variable p whose type is `struct posn`.
How do we access p's fields?

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Let's write a function to compute the Manhattan distance between two points. Mathematically,

$$d_1((x_1, y_1), (x_2, y_2)) = |x_1 - x_2| + |y_1 - y_2|$$

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```c
// For the fabs(double) function:
#include <math.h>

// Finds the Manhattan distance between two points.
double manhattan_dist(struct posn p, struct posn q)
{
    return fabs(p.x - q.x) + fabs(p.y - q.y);
}
```

Creating a structure

C offers *literal* syntax for most types:

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`struct`	`(struct posn) {3.0, 4.0}`

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“string”	`"hello,␣world!"`
`struct`	`(struct posn) {3.0, 4.0}`

But this syntax for creating a `struct` is obscure! So the usual way of doing things is a bit more awkward…

Defining and initializing a structure

Usually to get a structure in C, first you define a structure variable and then initialize it by *assigning* each field:

```
struct posn p;
p.x = 3.0;
p.y = 4.0;

struct circle c;
c.center.x = 7.0;
c.center.y = -9.2;
c.radius = 6.4;
```

C won't force you to initialize all the fields, but guess what happens if you a access a field that hasn't been initialized?

Factory functions

If you get tired of initializing structures as on the previous slide, you can always define a *factory function* to do the work:

```
struct circle
make_circle(struct posn center, double radius)
{
    struct circle result;
    result.center = center;
    result.radius = radius;
    return result;
}
```

(Note that functions can both take and return structure values.)

Visualizing structure value layout

```
struct circle c;
c.center.x = 10.0;
c.radius = 50.0;
c.center.y = -7.0;
```

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```
struct circle c;
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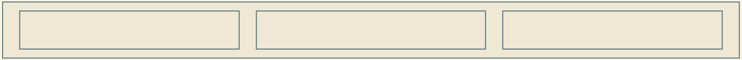
```

c:



Visualizing structure value layout

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struct circle c;
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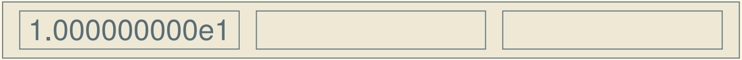
```

c:



Visualizing structure value layout

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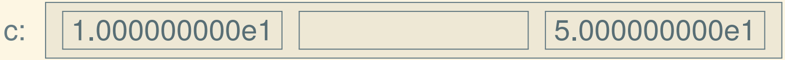

Visualizing structure value layout

```
struct circle c;
c.center.x = 10.0;
c.radius = 50.0;
c.center.y = -7.0;
```

c:	1.000000000e1	-7.000000000e0	5.000000000e1

Assignment

Values, objects, and variables

- Values are the actual information we want to work with: numbers, strings, widgets, etc. Example: 3 is an `int` value.

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- A variable is the name of an object, such as `x` from the previous bullet point.

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- A variable is the name of an object, such as `x` from the previous bullet point.

Assigning a variable changes the value stored in the object that is named by the variable.

Example of definition and assignment

```
int z = 5;
z = 7;
z = z + 4;
```

What happens?

Example of definition and assignment

```
int z = 5;
z = 7;
z = z + 4;
```

What happens?

z: 5

The first statement is a definition, `int z = 5`. It creates an `int` object, names it `z`, and initializes it to the value 5.

Example of definition and assignment

```
int z = 5;
z = 7;
z = z + 4;
```

What happens?

z: 7

The first statement is a definition, `int z = 5`. It creates an `int` object, names it `z`, and initializes it to the value 5.

The second statement is an assignment, `z = 7;`. It replaces the value 5 stored in the object named by `z` with the value 7.

Example of definition and assignment

```
int z = 5;
z = 7;
z = z + 4;
```

What happens?

z: 11

The first statement is a definition, `int z = 5`. It creates an `int` object, names it `z`, and initializes it to the value 5.

The second statement is an assignment, `z = 7;`. It replaces the value 5 stored in the object named by `z` with the value 7.

The third statement is also an assignment, `z = z + 4;`. It first retrieves the current value of `z` (7), then adds 4 to it, and then stores the result (11) back in the object named by `z`.

The key point: Indirection

A variable in C does not stand directly for a value.

A variable in C refers to a value *indirectly*, by naming an object that *contains* a value.

How to increment a variable

Simple:

```
x = x + 1;
```

Terse:

```
x += 1;
```

Auto-increment;

```
++x;
```

(Each of the above is actually an expression, and it has a value: the new value of x.)

– Next: Separate compilation –