Review

- Machine codes vs. High level languages
- C compiler
- C programming
  - Making first C program
  - C vs. Python
  - Basic C code analysis

Variables in C

Lecture 26-1

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Variables

- **Variables** hold the values upon which a program acts
  - The most basic type of **memory object**

- A variable has a **symbolic name** instead of the storage location where its value resides
  - Programmers can focus on the program logic without concern about where to store various values

- **Compiler** generates the full set of data movement operations (to/from memory)
  - To this end, it needs to know a variable's **name** (identifier)**, data type,** and **scope** (where it will be accessible)
  - The information is given by the programmer, in a variable's **declaration**

Variables – Identifiers (Names)

- Alphabet, digit, and underscore
  - Case sensitive
- Variables are almost never declared in all uppercase letters
  - All uppercase letters are usually used for #define
- Typical ways to combine multiple words in a variable name
  - By using capitals: wordsPerSecond
  - By using underscore: words_per_second
- Giving meaningful names is important!

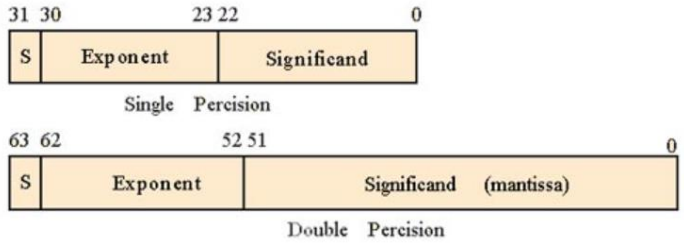
Variables – Data Type

- One bit pattern can have different meanings depending on its data type
  - 0110 0110
    - **102**, if its data type is **2's complement integer**
    - **f**, if its data type is **ASCII**
  - The compiler uses a variable's type information to allocate a proper amount of storage for the variable

- One operator can be performed differently at the machine level depending on the data type of its operands
  - IntegerA + IntegerB ➡ ADD instruction
  - FloatA + FloatB ➡ a set of instructions (there is no single instruction to add two floats)

Variables – Data Type

- **int** integerVariable; / int integerVariable = 10;
  - A 2's complement integer whose size depends on machines
- **char** characterVariable; / char characterVariable = 'Q';
  - A single ASCII code (8 bits)
- **float** floatVariable = 2.1; / float floatVariable = 2.1E2;
  - A single precision floating point number (32 bits)
- **double** doubleVariable = 2.1; / double doubleVariable = 2.1E2;
  - A double precision floating point number (64 bits)
- **_Bool** flag = 1; / **bool** flag = true;
  - _Bool takes 1 or 0, neither true nor false
  - To use bool, #include <stdbool.h> is needed - true or false (no capital T nor F!)
- Variable type is **immutable**!



Variables – Data Type

- C allows the programmer to specify larger or smaller versions of the basic types int, char, float, and double
  - long
  - short
- **unsigned int** is also provided

Variables – Scope

- The scope of a variable is the regions of the program in which the variable is "**alive**" and accessible
  - All C variables must be declared before they are used
  - The C compiler infers a variable's scope from where it is declared within the code

- **Local** variables
  - A **block** is any subsection of a program beginning with '{' and ending with '}'
  - If a variable is declared within a block, it is visible until the end of the block
    - The variable is **local** to the block
- **Global** variables
  - If a variable is declared outside of all blocks, it is a **global** variable that can be accessed anywhere in the program
  - WARNING: Using global variables is very **error prone**!

Variables – Initializer

- **Initializer**: Variable declaration with an initial value
  - int a = 0;
- It not initialized,
  - A global variable's value will become 0
  - A local variable's value will become a garbage value

- It is a standard coding practice to explicitly initialize **all local variables** in their declarations
  - To make everything predictable

- We can make a constant by using the initializer (without #define)
  - **const** double pi = 3.14159;

Variables – C vs. Python

- What programmers should consider additionally in C
  - Determine data type explicitly
  - A variable's data type is immutable
  - To use Boolean variables, <stdbool.h> should be included and no capitals for the values! (true/false, instead of True/False)
  - Again, don't forget semicolon(;)!

Operators in C

Lecture 26-2

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Operators

- Assignment (A = B)
  - Evaluate the right expression (B) and assigns it to A

- Arithmetic operators
  - *: multiplication
  - /: division
  - %: remainder
  - +: addition
  - -: subtraction
  - Same order of evaluation as in Python

Operators

- Bitwise operators
  - ~: bitwise NOT (~x)
  - &: bitwise AND (x & y)
  - |: bitwise OR (x | y)
  - ^: bitwise XOR (x ^ y)
  - <<: left shift (x << y)
  - >>: right shift (x >> y)

- Logical operators
  - !: logical NOT (!x)
  - &&: logical AND (x && y)
  - ||: logical OR (x || y)

Operators

- Assignment with arithmetic or bitwise operators
  - x += y ⟹ x = x+y
  - x -= y ⟹ x = x-y
  - x *= y ⟹ x = x*y
  - x /= y ⟹ x = x/y
  - x %= y ⟹ x = x%y
  - x &= y ⟹ x = x&y
  - x |= y ⟹ x = x|y
  - x ^= y ⟹ x = x^y

Operators

- Increment (++) / Decrement (--) operators
  - Similar to x = x+1; or x = x-1;

- Subtle difference
  - x++: evaluate and increment
  - ++x: increment and evaluate
  - Ex.1) x = 4; y = x++;
    - x will be 5 and y will be 4
  - Ex.2) x = 4; y = ++x;
    - Both x and y will be 5

Memory in C

Lecture 26-3

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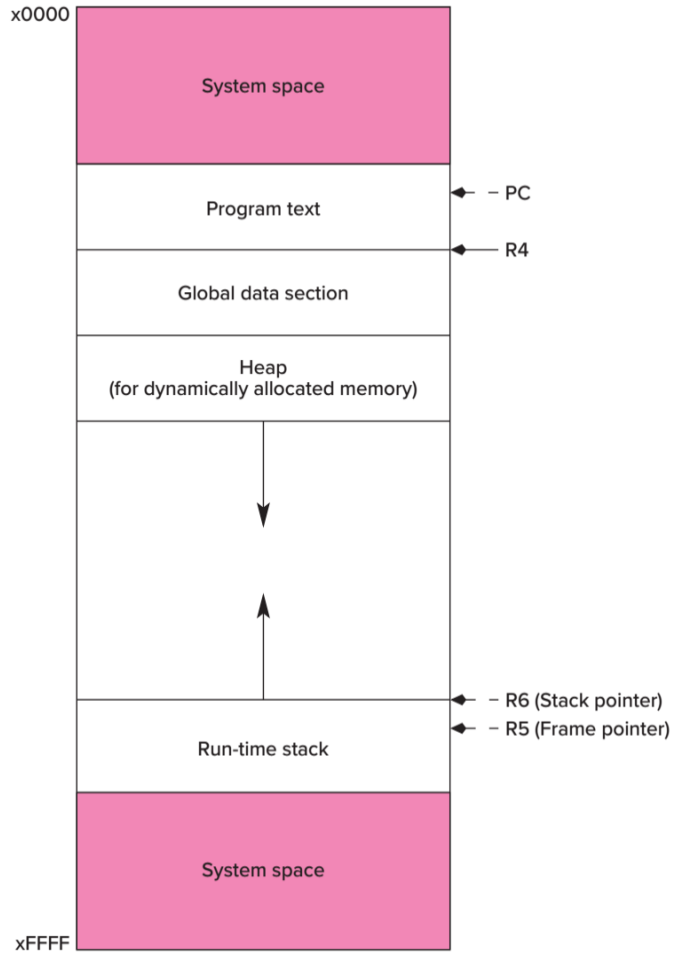
Memory in C

- Global variables are stored in **global data section**
  - A register (R4) contains the memory address of the beginning of the global data section (i.e., base)
  - As more global variables are stored, the offset from the base **increases**
- Local variables are stored in **run-time stack**
  - When a function is executing, the highest numbered memory address of its stack is stored in **frame pointer**
  - As more local variables in the function is stored, the offset from the frame pointer **decreases**
- Another region reserved for dynamically allocated data called **heap** (out of scope)



Memory in C – Example

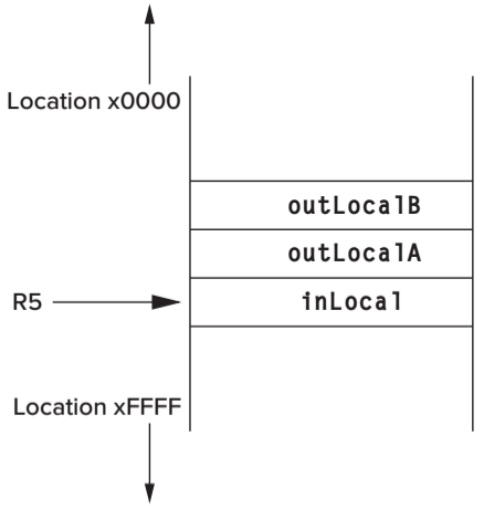
```
#include <stdio.h>
int inGlobal

int main
{
    int inLocal = 5;
    int outLocalA;
    int outLocalB;
    inGlobal = 3;

    outLocalA = inLocal * inGlobal;
    outLocalB = inLocal & inGlobal;
    printf("outLocalA = %d, outLocalB = %d\n", outLocalA, outLocalB);
    return 0;
}
```

Symbol table

Identifier	Type	Location (as an offset)	Scope	Other info...
inGlobal	int	0	global	...
inLocal	int	0	main	...
outLocalA	int	–1	main	...
outLocalB	int	–2	main	...



Summary

- Variables and Operators
  - Variables: Identifiers, Data type, Scope, Initializer.
  - Operators: Assignment, Arithmetic / Bitwise / Logical operators, etc.
  - Memory in C

Thanks!