COMP 122/L Lecture 6

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Assembly

What’s in a Processor?

Simple Language

- We have variables, integers, addition, and assignment
- Restrictions:
  - Can only assign integers directly to variables
  - Can only add variables, always two at a time

Want to say:

```
z = 5 + 7;
```

$\xrightarrow{\text{Translation}}$

```
x = 5;
y = 7;
z = x + y;
```

Implementation

- What do we need to implement this?

```
x = 5;
y = 7;
z = x + y;
```

Core Components

- Some place to hold the statements as we operate on them
- Some place to hold which statement is next
- Some place to hold variables
- Some way to add numbers

Back to Processors

- Amazingly, these are all the core components of a processor
    - Why is this significant?

Back to Processors

- Amazingly, these are all the core components of a processor
    - Why is this significant?
- Processors just reads a series of statements (instructions) forever. No magic.

Core Components

- Some place to hold the statements as we operate on them
- Some place to hold which statement is next
- Some place to hold variables
- Some way to add numbers

Core Components

- Some place to hold the statements as we operate on them - **memory**
- Some place to hold which statement is next - **program counter**
- Some place to hold variables - **registers**
    - Behave just like variables with fixed names
- Some way to add numbers - **arithmetic logic unit (ALU)**
- Some place to hold which statement is currently being executed - **instruction register (IR)**

Basic Interaction

- Copy instruction from memory at wherever the program counter says into the instruction register
- Execute it, possibly involving registers and the arithmetic logic unit
- Update the program counter to point to the next instruction
- Repeat

Basic Interaction

```
initialize();
while (true) {
  instruction_register =
    memory[program_counter];
  execute(instruction_register);
  program_counter++;
}
```

Instruction Register

?

Registers

```
x:  ?
y:  ?
z:  ?
```

Program Counter

?

Memory

?

Arithmetic Logic Unit

?

Instruction Register

?

Registers

```
x:  ?
y:  ?
z:  ?
```

Program Counter

```
0
```

Memory

```
0:  x  =  5;
1:  y  =  7;
2:  z  =  x  +  y;
```

Arithmetic Logic Unit

?

Instruction Register

```
x = 5;
```

Registers

```
x: ?
y: ?
z: ?
```

Program Counter

```
0
```

Memory

```
0: x = 5;
1: y = 7;
2: z = x + y;
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
x = 5;
```

Registers

```
x: 5
y: ?
z: ?
```

Program Counter

```
0
```

Memory

```
0: x = 5;
1: y = 7;
2: z = x + y;
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
x = 5;
```

Registers

```
x:  5
y:  ?
z:  ?
```

Program Counter

```
1
```

Memory

```
0: x = 5;
1: y = 7;
2: z = x + y;
```

Arithmetic Logic Unit

```
0 + 1 = 1
```

Instruction Register

```
y = 7;
```

Registers

```
x:  5
y:  ?
z:  ?
```

Program Counter

```
1
```

Memory

```
0:  x = 5;
1:  y = 7;
2:  z = x + y;
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
y = 7;
```

Registers

```
x:  5
y:  7
z:  ?
```

Program Counter

```
1
```

Memory

```
0: x = 5;
1: y = 7;
2: z = x + y;
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
y = 7;
```

Registers

```
x:  5
y:  7
z:  ?
```

Program Counter

```
2
```

Memory

```
0: x = 5;
1: y = 7;
2: z = x + y;
```

Arithmetic Logic Unit

```
1 + 1 = 2
```

Instruction Register

```
z = x + y;
```

Registers

```
x:  5
y:  7
z:  ?
```

Program Counter

```
2
```

Memory

```
0:  x = 5;
1:  y = 7;
2:  z = x + y;
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
z = x + y;
```

Registers

```
x: 5
y: 7
z: ?
```

Program Counter

```
2
```

Memory

```
0: x = 5;
1: y = 7;
2: z = x + y;
```

Arithmetic Logic Unit

```
5 + 7 = 12
```

Instruction Register

$\boxed{\texttt{z = x + y;}}$

Registers

```
x: 5
y: 7
```
z: $\boxed{12}$

Program Counter

```
2
```

Memory

```
0: x = 5;
1: y = 7;
2: z = x + y;
```

Arithmetic Logic Unit

$5 + 7 = \boxed{12}$

ARM

Why ARM?

- Incredibly popular in embedded devices
- Much simpler than Intel processors

Code on ARM

Original

```
x = 5;
y = 7;
z = x + y;
```

ARM

```
mov r0, #5
mov r1, #7
add r2, r0, r1
```

Code on ARM

Original

```
x = 5;
y = 7;
z = x + y;
```

ARM

```
mov r0, #5
mov r1, #7
add r2, r0, r1
```

move: put the given value into a register

r0: **r**egister **0**

Code on ARM

Original

```
x = 5;
y = 7;
z = x + y;
```

ARM

```
mov r0, #5
mov r1, #7
add r2, r0, r1
```

move: put the given value into a register

r1: **r**egister **1**

Code on ARM

Original

```
x = 5;
y = 7;
z = x + y;
```

ARM

```
mov r0, #5
mov r1, #7
add r2, r0, r1
```

add: add the rightmost registers, putting the result in the first register

r2: **r**egister **2**

Available Registers

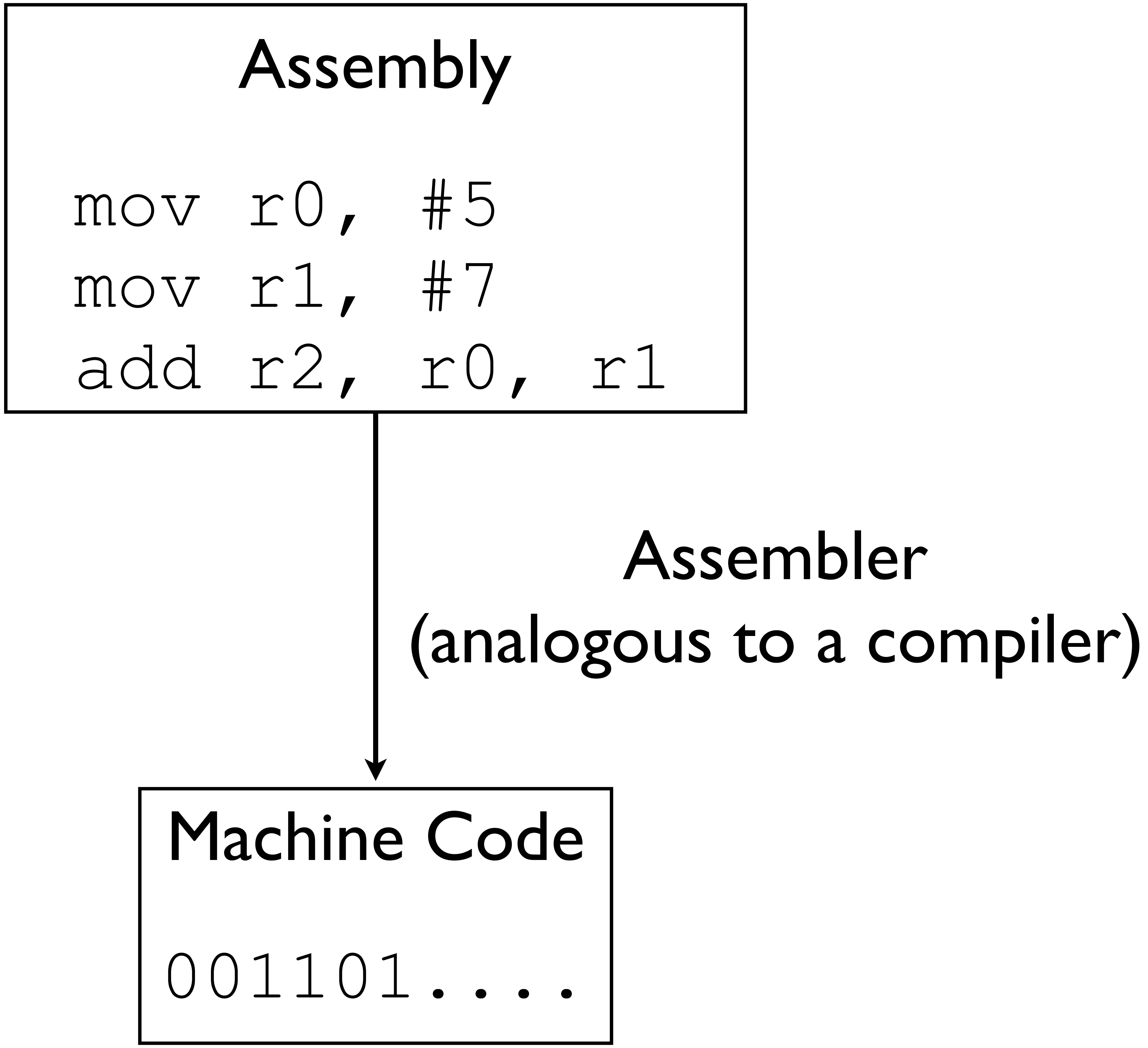
- 17 registers in all
    - 16 “general-purpose”
    - 1 “special-purpose”
- For the moment, we will only consider registers `r0` - `r12`

Assembly

- The code that you see below is *ARM assembly*
- Assembly is *almost* what the machine sees. For the most part, it is a direct translation to binary from here (known as *machine code)*

```
mov r0, #5
mov r1, #7
add r2, r0, r1
```

Workflow



```
mov r0, #5
mov r1, #7
add r2, r0, r1
```

```
001101....
```

Machine Code

- This is what the process actually executes and accepts as input
- Each instruction is represented with 32 bits

```
add r2, r0, r1
```

Instruction Register

?

Registers

```
r0: ?
r1: ?
r2: ?
```

Program Counter

?

Memory

?

Arithmetic Logic Unit

?

Instruction Register

```
mov r0, #5
```

Registers

```
r0: ?
r1: ?
r2: ?
```

Program Counter

```
0
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
mov r0, #5
```

Registers

```
r0: 5
r1: ?
r2: ?
```

Program Counter

```
0
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
mov r0, #5
```

Registers

```
r0: 5
r1: ?
r2: ?
```

Program Counter

```
4
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
0 + 4 = 4
```

Instruction Register

```
mov r1, #7
```

Registers

```
r0: 5
r1: ?
r2: ?
```

Program Counter

```
4
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
mov r1, #7
```

Registers

```
r0: 5
r1: 7
r2: ?
```

Program Counter

```
4
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
mov r1, #7
```

Registers

```
r0: 5
r1: 7
r2: ?
```

Program Counter

```
8
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
4 + 4 = 8
```

Instruction Register

```
add r2, r0, r1
```

Registers

```
r0: 5
r1: 7
r2: ?
```

Program Counter

```
8
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
?
```

Instruction Register

```
add r2, r0, r1
```

Registers

```
r0: 5
r1: 7
r2: ?
```

Program Counter

```
8
```

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

```
5 + 7 = 12
```

Instruction Register

```
add r2, r0, r1
```

Registers

r0: 5

r1: 7

r2: $\boxed{12}$

Program Counter

8

Memory

```
0: mov r0, #5
4: mov r1, #7
8: add r2, r0, r1
```

Arithmetic Logic Unit

$5 + 7 = \boxed{12}$

Adding More Functionality

- We need a way to display the result
- What does this entail?

Adding More Functionality

- We need a way to display the result
- What does this entail?
    - Input / output. This entails talking to devices, which the operating system handles
    - We need a way to tell the operating system to kick in

Talking to the OS

- We are going to be running on an ARM simulator, ARMSim#
- We cannot directly access system libraries (they aren't even in the same machine language)
- How might we print something?

ARMSim# Routines

- ARM features a `swi` instruction, which triggers a *software interrupt*
- Outside of a simulator, these pause the program and tell the OS to check something
- Inside the simulator, it tells the **simulator** to check something

`swi`

- So we have the OS/simulator’s attention. But how does it know what we want?

`swi`

- So we have the OS/simulator's attention. But how does it know what we want?
  - `swi` operand: integer saying what to do
  - The OS/simulator can also read the registers to get extra information as needed

(Finally) Printing an Integer

- For ARMSim#, the integer that says "print an integer" is `0x6B`
- Register `r1` holds the integer to print
- Register `r0` holds where to print it; `1` means "print to standard output (screen)"

Augmenting with Printing

```
mov r0, #5
mov r1, #7
add r2, r0, r1

mov r1, r2 ; r1: integer to print
mov r0, #1 ; r0: where to print it
swi 0x6B   ; 0x6B: print integer
```

Exiting

- If you are using ARMSim#, then you need to say when you are done as well
- How might this be done?

Exiting

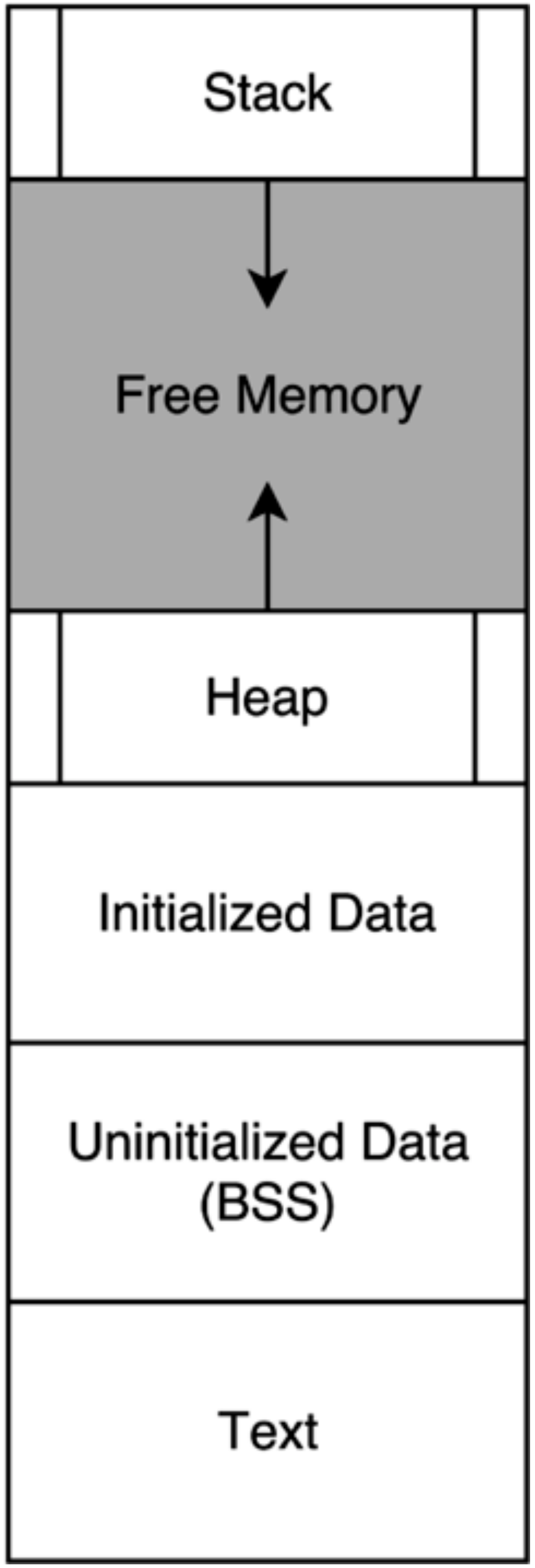
- If you are using ARMSim#, then you need to say when you are done as well
- How might this be done?
    - `swi` with a particular operand (specifically `0x11`)

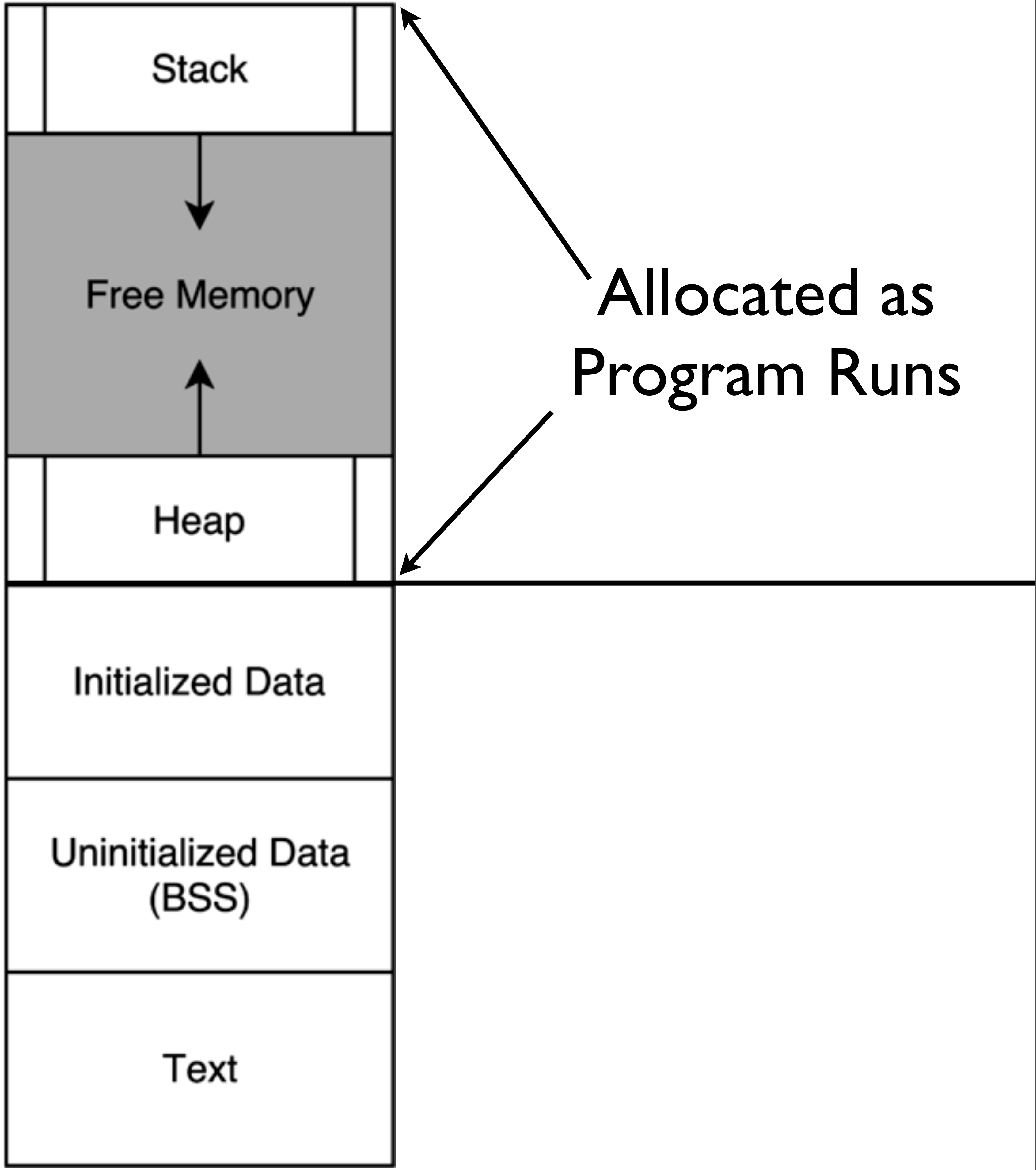
Augmenting with Exiting

```
mov r0, #5
mov r1, #7
add r2, r0, r1

mov r1, r2 ; r1: integer to print
mov r0, #1 ; r0: where to print it
swi 0x6B   ; 0x6B: print integer

swi 0x11   ; 0x11: exit program
```

Making it a Full Program

- Everything is just a bunch of bits
- We need to tell the assembler which bits should be placed where in memory


Stack
Free Memory
Heap
Initialized Data
Uninitialized Data (BSS)
Text

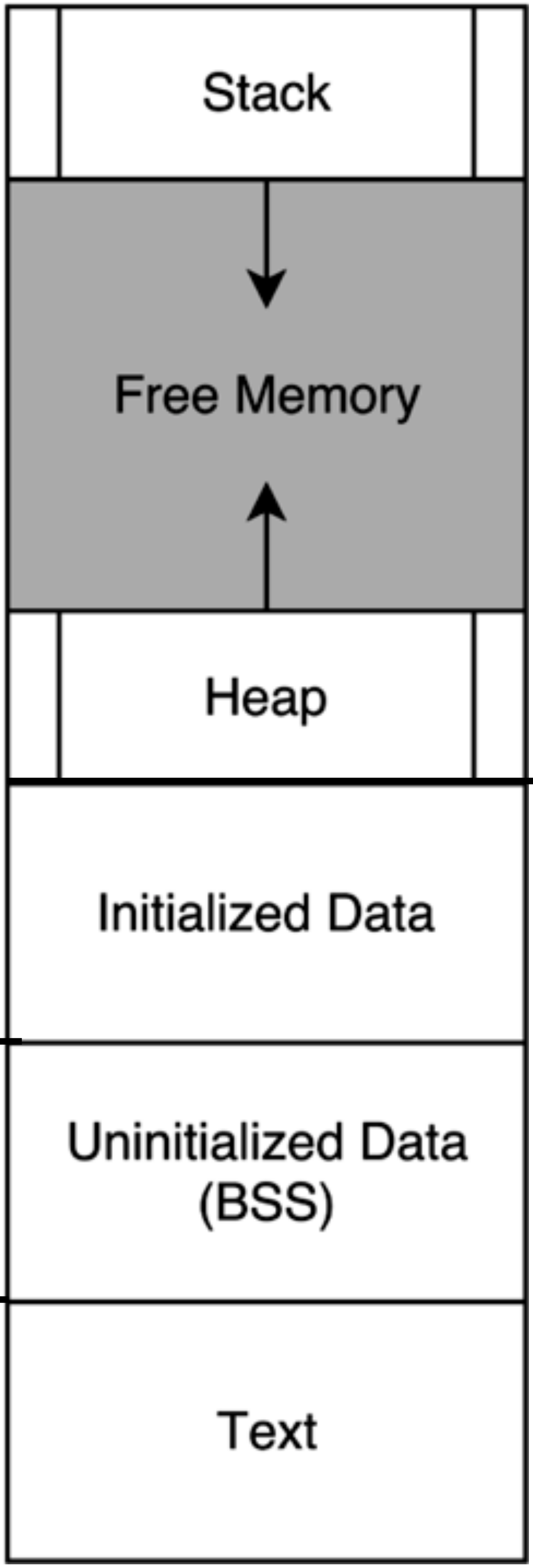

Stack
Free Memory
Heap
Initialized Data
Uninitialized Data (BSS)
Text
Allocated as Program Runs

Everything Below is Allocated at Program Load
↓
Constants (e.g., strings)

Mutable Global Variables

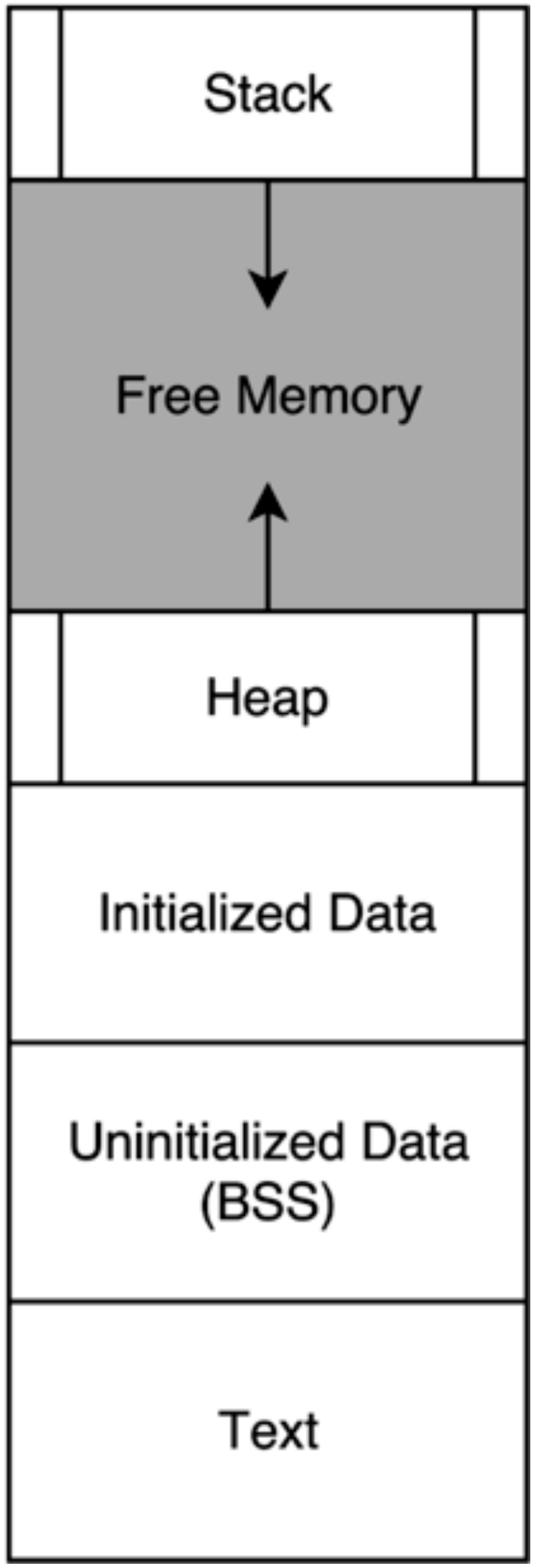
Code

Allocated as Program Runs



Marking Code

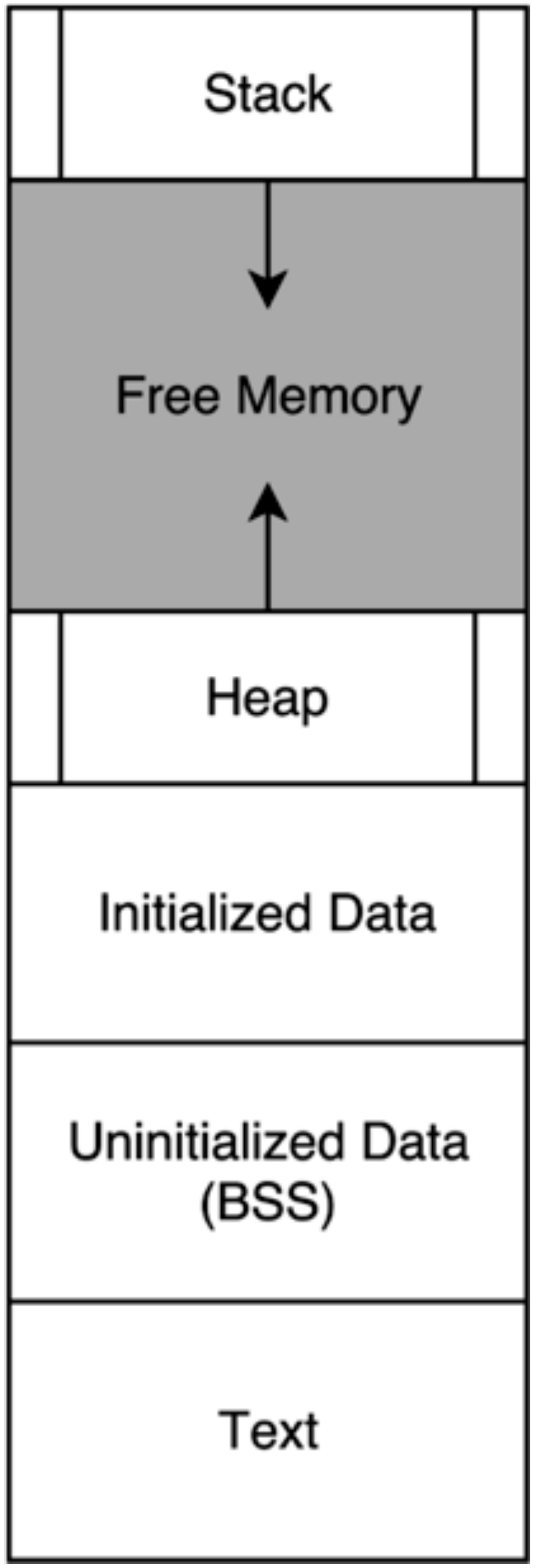
Use a `.text` *directive* to specify code section



```
.text
mov r0, #5
mov r1, #7
add r2, r0, r1

mov r1, r2
mov r0, #1
swi 0x6B

swi 0x11
```

Marking Code

Use a `.data` *directive* to specify data section



```
        .data
string1:
        .asciz "hello"
string2:
        .asciz "bye"
```

ARMSim# Demo: `hello.s`

ARMSim# Demo:
`arithmetic_ops.s`

ARMSim# Demo:
`read_and_print_int.s`