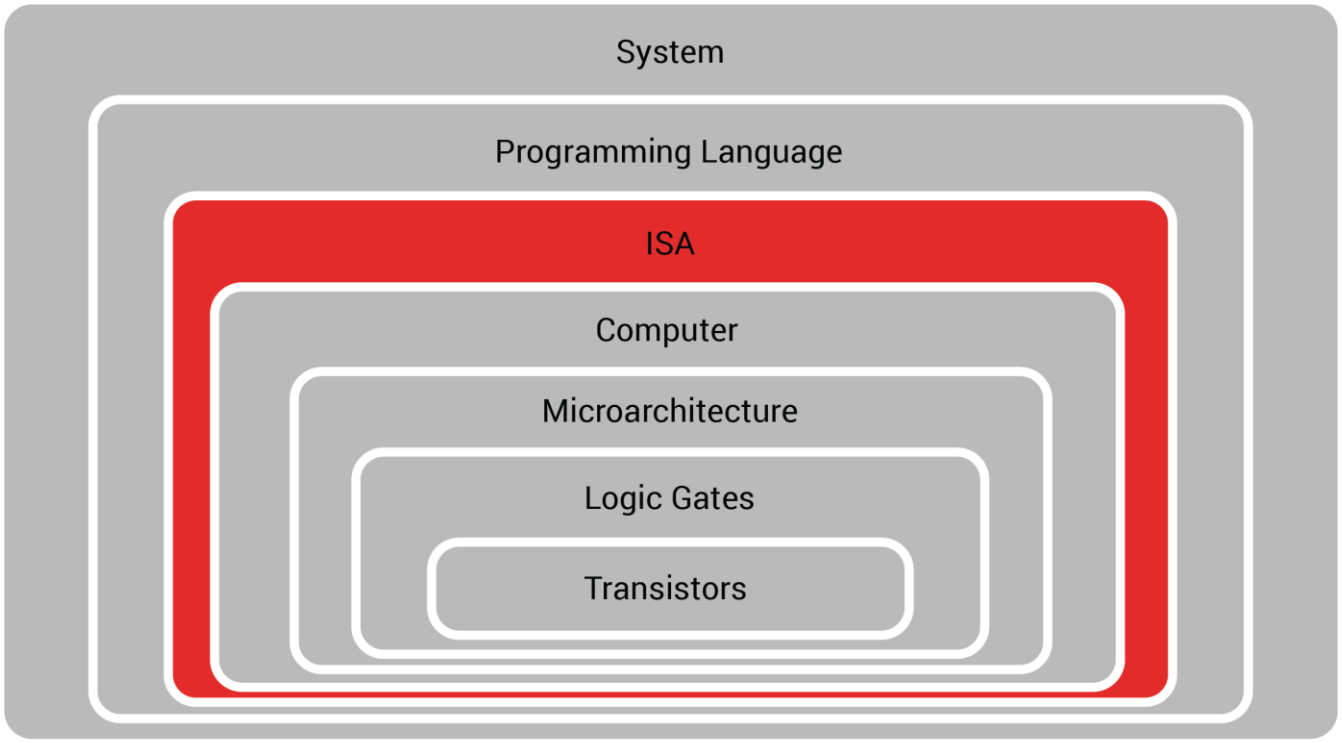
What we (hope) to cover today

- Assembler Directives
  - Filling RAM (Bytes and Strings)
  - Using Labels
- Useful Constructs (If-Else, While)
- The Stack
- Functions

Assembly Language

- Remember this picture about our layers:



Assembly Language

- Assembly
  - ISA corresponds to what the microarchitecture can do
  - Still needs to go through an assembler to get to binary
    - Similar to how Python needs to go through a compiler
  - ISA + other features to make our lives easier = Assembly

Assembly Language

- A few definitions for Assembly
  - A line is an *ISA operation*, a *label*, or an *assembler directive*
    - We can have whitespace and comments, but they are ignored by the assembler
  - An ISA operation is any operation we have described, plus offsets can use label names, and instead of numbers, you are allowed to use characters
  - Comments are anything after a semicolon character
  - Assembler Directives
  - Labels

Assembler Directives

Assembler Directives

- Allow us to fill RAM with data before executing our program
  - Useful!
  - Two types:
    - Byte Directives
    - String Directives

Assembler Directives

- Byte Directive
  - Fills a section of RAM from a specified address with given values
  - Syntax:

```
.byte(address) bytes,to,fill,separated,by,commas
```

An example:

.byte(1231) 12,189,200,0,0 →

Address	Value
1231	12
1232	189
1233	200
1234	0
1235	0

Assembler Directives

- Byte Directive
  - What's another thing that is represented by a byte? Characters!
  - ASCII Characters all have a single byte value (Chapter 6)

```
.byte (504) 'H','e','l','l','o'
```

Address	Value
504	H
505	e
506	l
507	l
508	o

Assembler Directives

- Storing a bunch of characters like that can be clumsy
- String directive
  - Stores a string of characters (special characters escaped using \)
  - Syntax:

```
.string(address) “string to store”
```

Example:

```
.string(504) “Hello”
```

Address	Value
504	H
505	e
506	l
507	l
508	o

Labels

Labels

- Labels allow us to specify locations in our program, and use the label names instead of offsets
- Label names are constructed using numbers, letters, or underscores. They cannot begin with a number
- The label will then point to the following code after the label
- Syntax

```
Label_name:
[other code]
```

Useful Constructs (Using Labels)

- If/Else

```
if(x == y):
        x = x + 1
else:
        y = y + 1
z = z + x + y
```

```
;Assembly
;x is in r30
;y is in r31
;z is in r29
cp r30, r31
breq if_block

else_block:
inc r31                 ;Increment y
rjmp after_block

if_block:
inc r30                 ;Increment x

after_block:
add r29, r30            ;Add z and x
add r29, r31            ;Add (z+x) and y
```

Useful Constructs (Using Labels)

- While

```
while(x == y):
       x = x-2
```

```
;Assembly
;x is in r30
;y is in r31

begin_while:
cp r30, r31
brne done_while
subi r30, 2
rjmp begin_while

done_while:
```

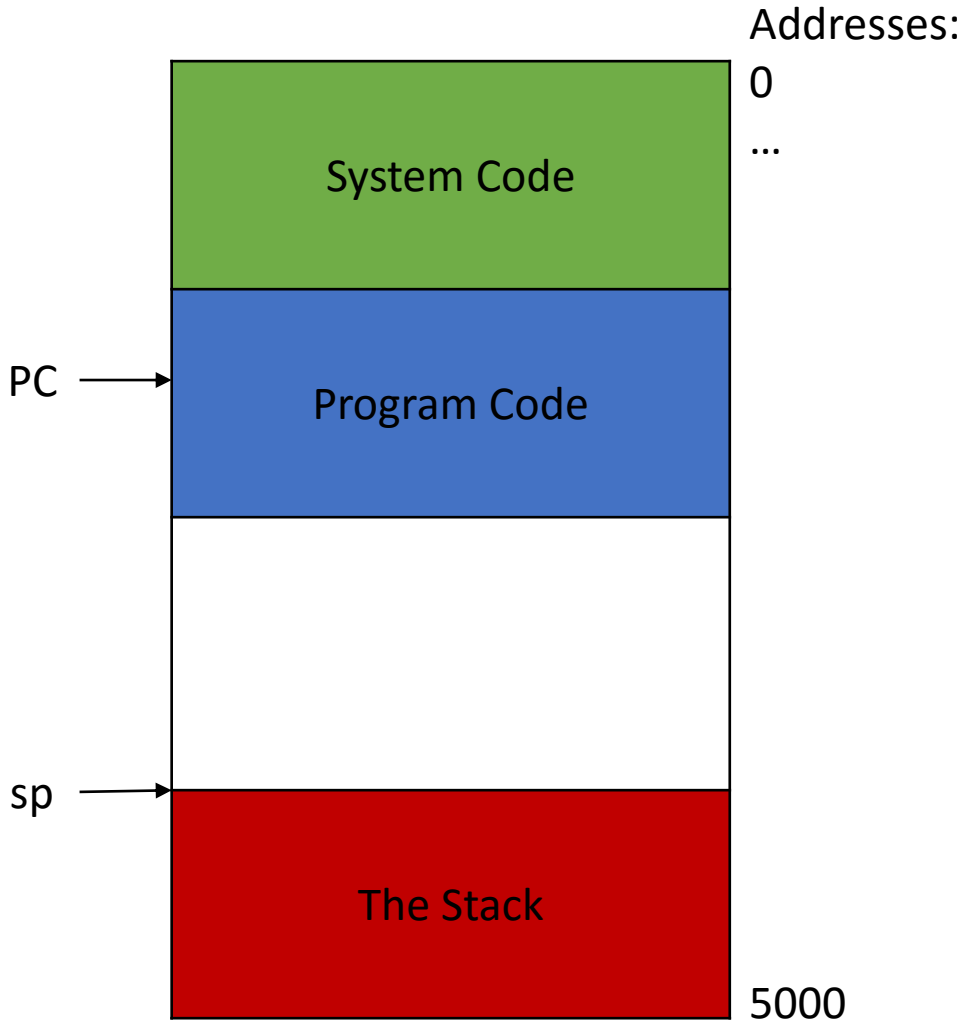
The Stack

The Stack

- A way to save and restore values in registers
- Uses two operations, “pushing” and “popping”
- Works like a stack of plates
  - “Pushing” is like adding a plate on top of the stack
  - “Popping” is like taking the plate off the top of the stack
- Essential for Functions

The Stack

- Values are stored in decreasing addresses in memory.
- The top of the stack is tracked using the stack pointer (sp), a 16 bit value stored in IO registers.



The Stack

- Two instructions to operate on the stack
  - Pushing a value
    - Store the value at the stack pointer
    - Decrement the stack pointer

    Syntax:

    ```
    push [register to push value from]
    ```
  - Popping a value
    - Increment the stack pointer
    - Take the value from the stack pointer

    Syntax:

    ```
    pop [register to store popped value]
    ```

The Stack

- One final thing: sp is NOT set automatically!
  - Stack pointer corresponds to I/O registers 61 and 62.
  - IO[62] contains the upper 8 bits, IO[61] contains the lower 8 bits.
  - We need to set these registers before we use the stack.

Example:

```
5000 = 136 + 19*256 ->
```

```
ldi r31, 136
out 61, r31
ldi r31, 19
out 62, r31
```

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	255
31	120

sp
5000

RAM

Address	Value
4996	
4997	
4998	
4999	
5000	

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	255
31	120

sp
4999

RAM

Address	Value
4996	
4997	
4998	
4999	
5000	3

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	255
31	120

sp
4998

RAM

Address	Value
4996	
4997	
4998	
4999	255
5000	3

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	255
31	120

sp
4997

RAM

Address	Value
4996	
4997	
4998	4
4999	255
5000	3

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	4
31	120

sp
4998

RAM

Address	Value
4996	
4997	
4998	
4999	255
5000	3

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	4
31	120

sp
4997

RAM

Address	Value
4996	
4997	
4998	4
4999	255
5000	3

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	4
31	120

sp
4996

RAM

Address	Value
4996	
4997	2
4998	4
4999	255
5000	3

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	2
29	3
30	4
31	2

sp
4997

RAM

Address	Value
4996	
4997	
4998	4
4999	255
5000	3

The Stack

Example:

```
push r29
push r30
push r27
pop r30
push r30
push r28
pop r31
pop r28
```

Register File

Register	Value
27	4
28	4
29	3
30	4
31	2

sp
4998

RAM

Address	Value
4996	
4997	
4998	
4999	255
5000	3

Functions

Functions

- We want functions to operate similar to Python, where we call them, and the function comes back when it is done.
- First, a few design decisions need to be considered

Functions

- Consideration: We only want functions to execute when we call them.
- Consideration: Programs execute by incrementing the PC counter (or modifying it in some way).
- Where should we put our functions in RAM?
  - We want functions to be before our program in memory (in a lower address of RAM).
  - We will jump around the functions we write to our program

Functions

Example, in assembly:

```
rjmp program
our_function:
... [function code]
program:
... [program code]
```

Functions

- Consideration: Functions will (probably) use registers for computation.
- Consideration: We don’t want to lose values we have stored in registers.
- What should we do?
  - We have something we can use to save registers, the stack!
  - Someone will need to save the registers on the stack

Caller Saved vs Callee Saved

- Caller Saved registers
  - The section of code that calls the function saves the registers it wants to save.
  - Requires either knowledge of which registers the function will modify, or having to save every register we might want to prevent being modified.
  - Functions are smaller and faster, since they don’t have to consider saving registers.

Caller Saved vs Callee Saved

Caller saved, in assembly:

```
rjmp program
;The function modifies r29, let’s show caller-saved registers
our_function:
... [function code]
program:
...
push r29
[call the function]
pop r29
```

Caller Saved vs Callee Saved

- Callee Saved registers
  - The function saves all values in registers it is going to modify, then restores them.
  - The code that calls the function doesn’t have to worry about saving these registers.
  - No unneeded saving happens
  - The function size is larger, meaning slower code.

Caller Saved vs Callee Saved

Callee saved, in assembly:

```
rjmp program
;The function modifies r29, let’s show callee-saved registers
our_function:
push r29
... [function code]
pop r29
program:
...
[call the function]
```

Functions

- One last thing to consider: instructions for calling functions and returning.
  - `rcall [offset]` and `ret`
  - These functions automatically push the PC + 1 to the stack and pops the value back whenever `ret` is called.

Functions

```
rjmp program
;The function modifies r29, callee-saved
our_function:
push r29
... [function code]
pop r29
ret
program:
...
rcall our_function
```

Full Example

- AVR includes a mult instruction, but in many cheaper AVR chips, the mult instruction is not implemented.
- Let's implement a function doing multiplication!
  - We want to use the stack and the function design considerations.
  - How should we do it?
    - Think about multiply like adding over and over

Full Example

- Python code

```
def mult(x,y):
        iteration = 0
        result = 0
        while(iteration != y):
                result = result + x
                iteration = iteration + 1
        return result

mult(4,5)
```

Full Example

```
;Initialize sp
ldi r31, 136
out 61, r31
ldi r31, 19
out 62, r31
rjmp program
;multiply assumes the values desired are in r20, r21.
;The result is put in r22. r19 is modified, and callee-saved
multiply:
push r19
ldi r19, 0
ldi r22, 0
begin_mult:
cp r19, r20
breq done_mult
add r22, r21
inc r19
rjmp begin_mult
done_mult:
pop r19
ret
program:
ldi r20, 4 ;Initialize r20
ldi r21, 5 ;initialize r21
push r22   ;Caller-Save r22, where the result will be saved
rcall multiply
...
```

Summary

- Assembly Language
  - Assembled with an assembler, like a programming language is compiled with a compiler
  - Has neat tricks, like Assembler Directives and Labels
- Stack
  - Uses the stack pointer, which is in IO[61] and IO[62]
  - Operates using push and pop
  - Starts at initial sp and stores in decreasing addresses in RAM

Summary

- Functions
  - Functions should be put before program code and jumped around, so they are not executed accidentally.
  - Modified registers need to be saved
    - Caller vs Callee Saved
  - Uses `ret` and `rcall`

CS 252
Lecture 15; 2015 Oct 14th; Transcribed Lecture notes

Outline

- Assembly Directives (filling RAM, labels)
- Useful constructs (if-else, while)
- Stack
- Functions

Assembly Language

- In the ISA of the layers stack
- ISA corresponds to what the microarchitecture can do
- Still need to go through an assembler to get to binary
- ISA + other features
- A line of assembly language contains ISA operation, a label, or an assembler directive
  - ISA operation: add, load, compare
  - labels: a location specification
  - directives: instead of numbers, we can use characters to fill RAM
  - comments: anything after semicolon to annotate code

Assembler directives

- Allows us to fill RAM with data before executing program
- Byte direction
  - fills a section of RAM from a specified address with given values
  - .byte(address) bytes,to,fill,separated,by,commas
  - Can also be used to represent ASCII characters
    - .byte(504) ‘H’,’e’,’l’,’l’,’o’
- String directive
  - stores a string of characters in RAM
  - .string(address) “string to store”
    - .string(504) “Hello”

Labels

- allows use to specify locations in our program, and use the label names instead of offsets
- Syntax:
  - label_name:
  - [other code]

- If-else
  - # python

```
if(x==y):
        x = x + 1
else:
        y = y + 1
z = z + x + y

; assembly
; x is in r30
; y is in r31
; z is in r29
cp r30, r31
breq if_block

else_block:
inc r31                 ; increment y
rjmp after_block

if_block:
inc r30                 ; increment x

after_block:
add r29, r30            ; add x to z; z = z + x
add r29, r31            ; add y to z; z = z + x + y
```

While

```
while(x == y):
        x = x - 2

; assembly
; x is in r30
; y is in r31

begin_while:
cp r30, r31
brne done_while
subi r30, 2
rjmp begin_while

done_while:
```

Stack

A way to save and restore values in registers

push to add element on top of stack

pop to take element off top of stack
values are stored in decreasing address in memory
the stack pointer (sp) points to the top of stack
stack is at the bottom to avoid overwriting our program code or heap
In assembly
- pushing a value
  - store the value at the stack pointer
  - decrement the stack pointer
  - syntax:
    - push [register to push value from]
- popping a value
  - increment the stack pointer
  - take the value from the stack pointer
  - syntax:
    - pop [register to store popped value]
- The stack pointer is NOT set automatically!
  - stack pointer corresponds to IO registers 61 and 62

- pointer setup example

```
5000 = 136 + 19*256

; assembly
ldi r31, 136
out 61, r31
ldi r31, 19
out 62, r31
```

- stack example [see slides for full example]

```
; stack pointer is initially 5000
push r29      ; push value of r29 to 5000
push r30      ; push value of r30 to 4999
push r27      ; push value of r27 to 4998
pop r30       ; pop data in 4998 into r30
push r30      ; push value of r30 to 4998
push r28      ; push value of r28 to 4997
pop r31       ;
pop r28       ;
```

Functions

Want functions to operate similar to Python, where call them and get a return value
We want functions to execute only when we call them. Therefore, we want functions at the beginning of our program so that the PC does not accidentally fall into it.

Assembly Example

```
rjmp program
our_function:
[code here to implement our function]
program:
[code here to implement program]
```

We need to pass values into functions.

- Caller saved registers
  - the function caller saves the registers it wants to save
  - push values before calling the function
  - pop values after returning from the function
- Callee saved registers
  - The function saves and restore all registers it is going to modify
  - push values at the beginning of the function
  - pop values at the end of the function

Instructions for calling functions

- rcall [offset]
  - pushes PC register + 1 on stack
- ret
  - pops stack and store to PC

Full Example of Multiplication function in AVR

```
# python code
def mult(x,y):
    iteration = 0
    result = 0
    while(iteration != y):
        result = result + x
        iteration = iteration + 1
    return result

mult(4,5)

; assembly
; we want to use the stack for function call
; prepare stack
ldi r31, 136
out 61, r31
ldi r31, 19
out 62, r31
; [see slide for full multiplication example]
```