Final Review

Logic Gates And Boolean Algebra

3/25 - Comparators

- A == B -> !(A xor B)
- A < B -> !A B
- A > B -> A !B

2 bit Comparator

A < B when:

$(A_1<B_1)$ OR $((A_1==B_1)$ AND $(A_0<B_0))$

How to translate this into a boolean expression?

$\bar{A}_1 B_1 + \left(\overline{A_1 \oplus B_1} \cdot \bar{A}_0 B_0\right)$

A > B when:

$(A_1>B_1)$ OR $((A_1==B_1)$ AND $(A_0>B_0))$

How to translate this into a boolean expression?

$A_1 \bar{B}_1 + \left(\overline{A_1 \oplus B_1} \cdot A_0 \bar{B}_0\right)$

3 bit comparator

A == B when:

$(A_2==B_2)$ AND $(A_1==B_1)$ AND $(A_0==B_0)$

How to translate this into a boolean expression?

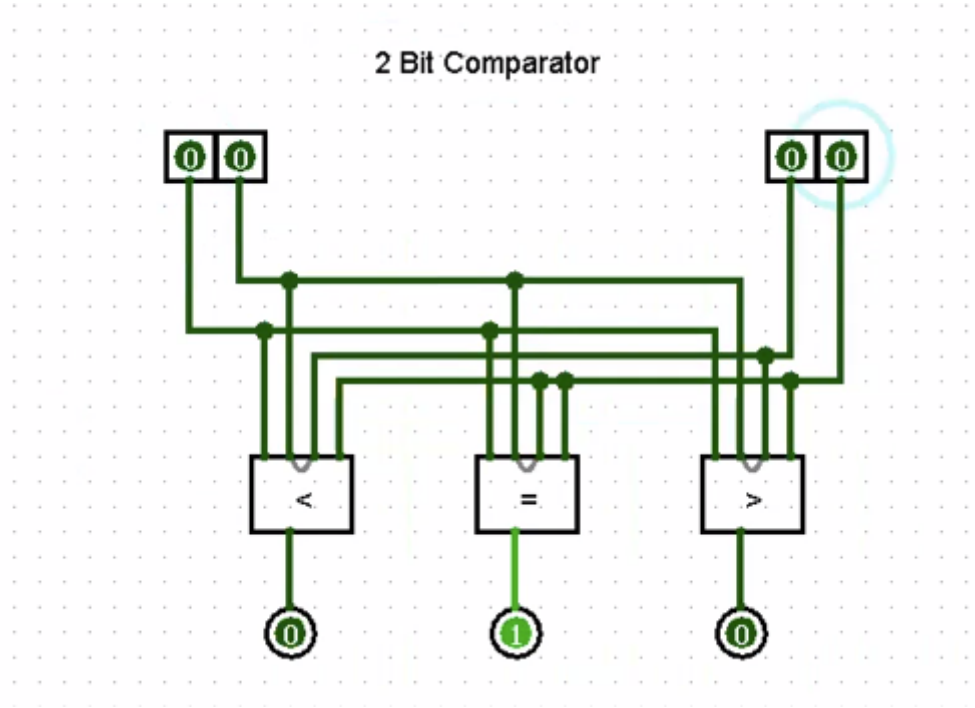
$\overline{A_2 \oplus B_2} \cdot \overline{A_1 \oplus B_1} \cdot \overline{A_0 \oplus B_0}$

A > B when:

$(A_2>B_2)$ OR $((A_2==B_2)$ AND $(A_1>B_1))$ OR $((A_2==B_2)$ AND $(A_1==B_1)$ AND $(A_0>B_0))$

How to translate this into a boolean expression?

$$(A_2\bar{B}_2) + (\overline{A_2 \oplus B_2} \cdot A_1\bar{B}_1) + (\overline{A_2 \oplus B_2} \cdot \overline{A_1 \oplus B_1} \cdot A_0\bar{B}_0)$$

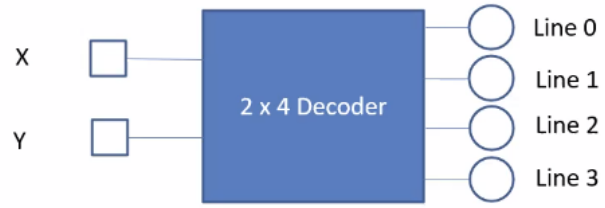


3/23 - Decoders

Definition

"Decodes" binary input into a line selection. Ex: 1 0 = 2, so line 2 would be on. 11 = 3, so line 3 would be on.

"Decodes" binary input into a line selection



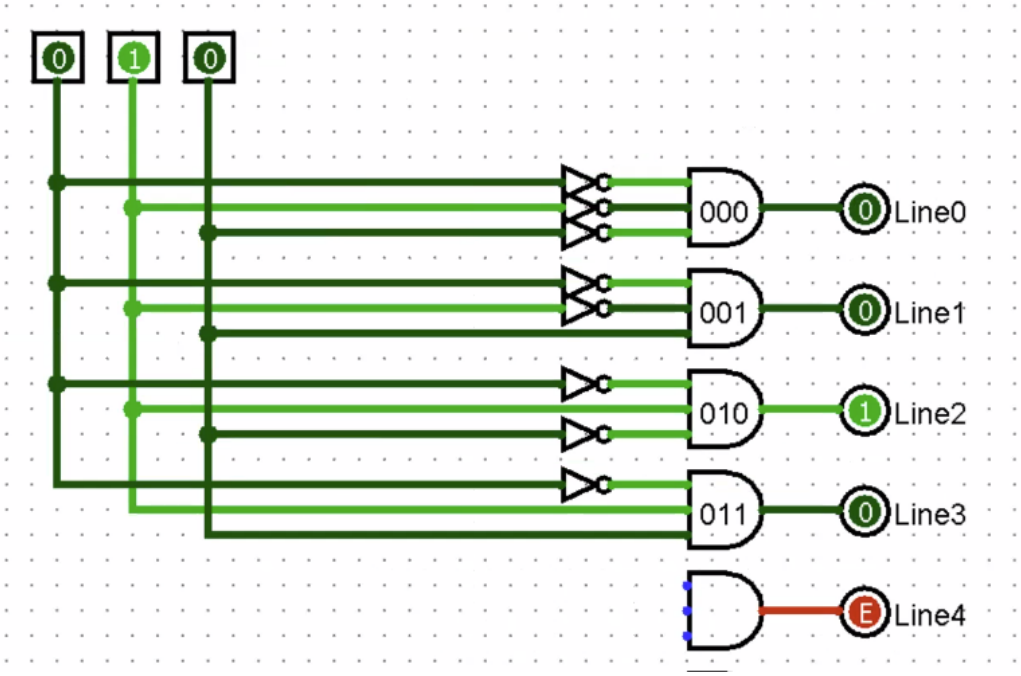
The general format of a decoder is N input lines to 2^N output lines.

i.e. 1 x 2
2 x 4
3 x 8

How to build a decoder

1. Find out how big you want the decoder to be, such as 2x4.
2. Come out with the outputs, line 0, line 1, line 2, line 3, etc
3. Add AND gates linking to each one, 00, 01, 10, 11 etc
4. Left bit is the upper input. If you input a 0, attach a NOT to it. 1 is a straight line.
5. Right most bit is the bottom. Same process 0, NOT. 1, straight wire.
6. Attach the two inputs **X, Y**. The most significant bit, **X** is inputted to the top connector of each AND gate. **Y** gets wired to the *bottom.*

Partial 3x8 Decoder

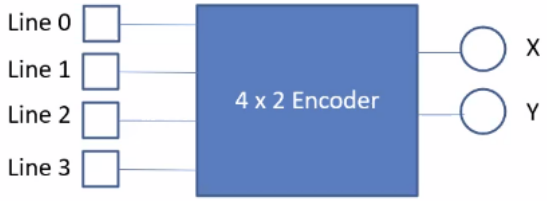


Encoder

Definition Does the opposite of a decoder: takes a line number and "encodes" into a binary number. The format of an ecoder is 2^N input lines N to output lines.

Encoders

Does the opposite of Decoder … takes a line number and "encodes" it to a binary number

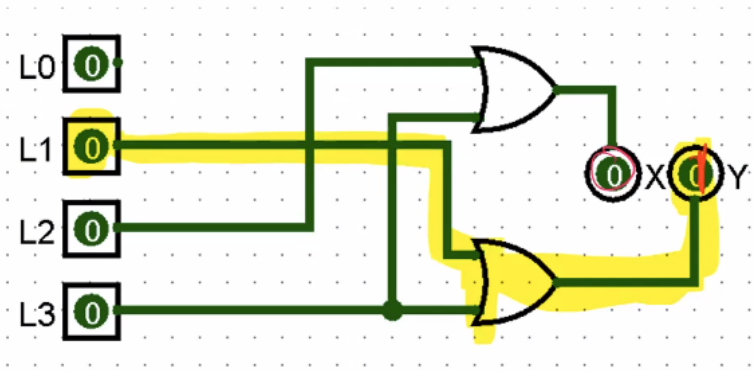


INPUTS				OUTPUT	
L0	L1	L2	L3	X	Y
1	0	0	0	0	0
0	1	0	0	0	1
0	0	1	0	1	0
0	0	0	1	1	1

The general format of an encoder is 2^N input lines N to output lines.

i.e. 2 x 1
4 x 2
8 x 3

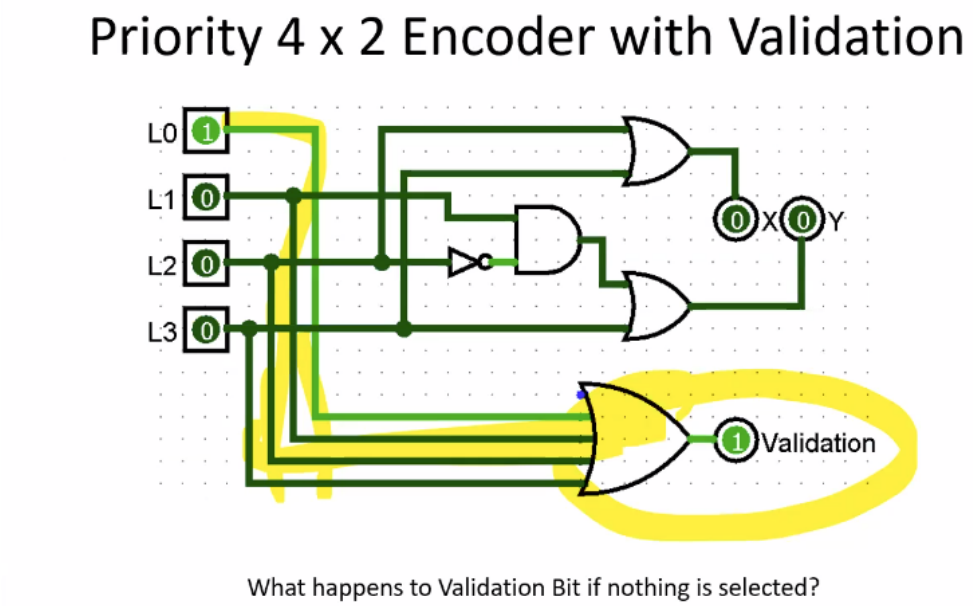
4 x 2 Encoder



If Line0 = 1, then Output = 00
If Line1 = 1, then Output = 01
If Line2 = 1, then Output = 10
If Line3 = 1, then Output = 11

2 Problems:

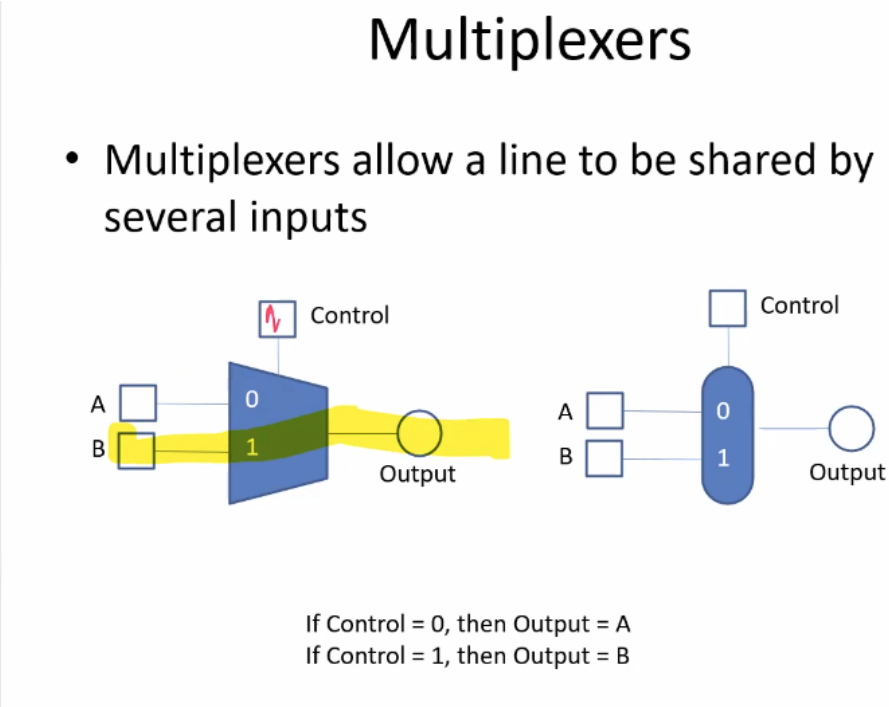
What happens if you select L1 and L2? How do i know if L0 was selected vs nothing was selected? Both are 11. Thus, priority encoder. Prioritizes the highest lineup.

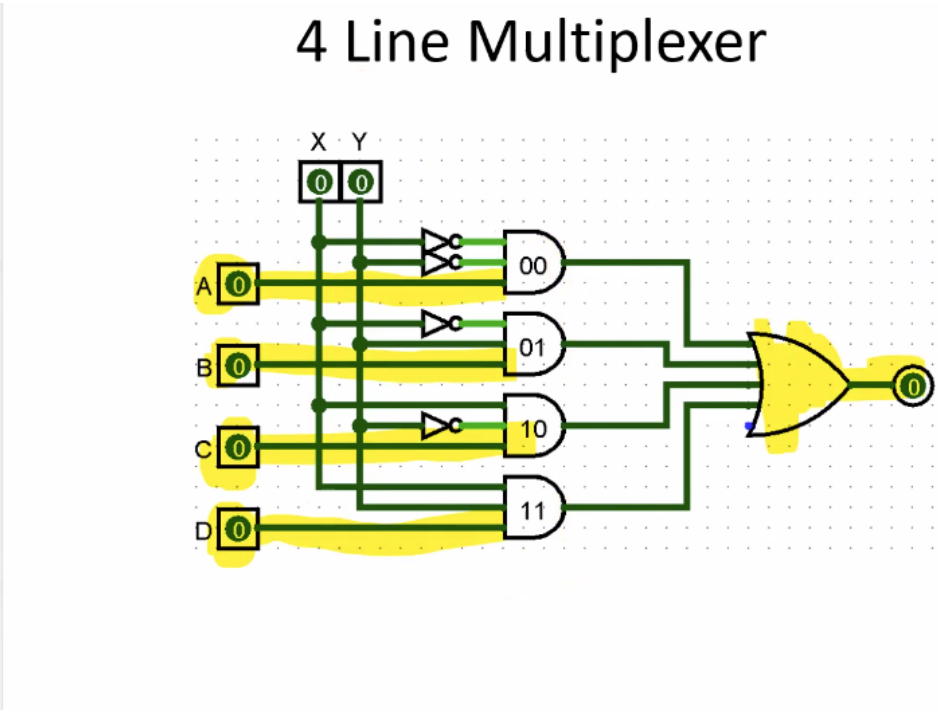


Multiplexer

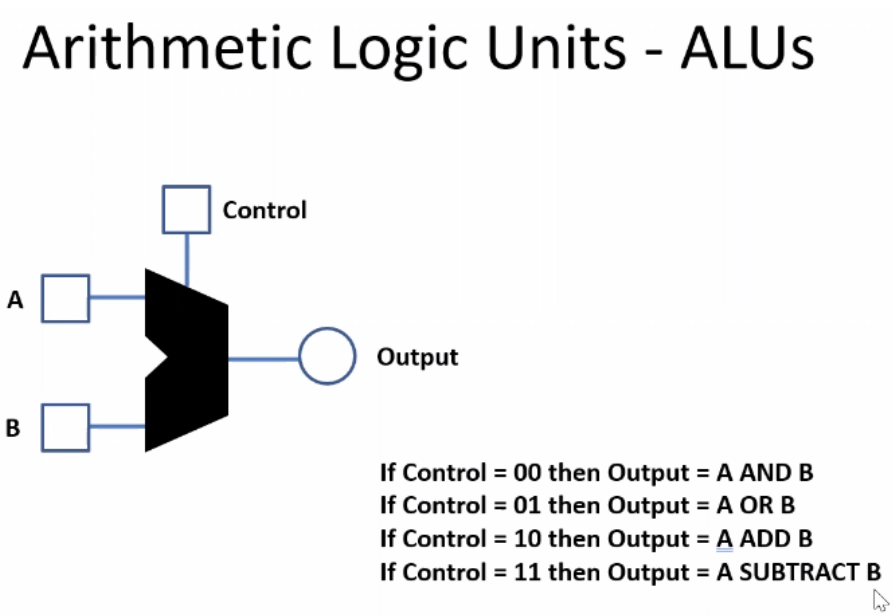
Allow a line to be shared by several inputs.

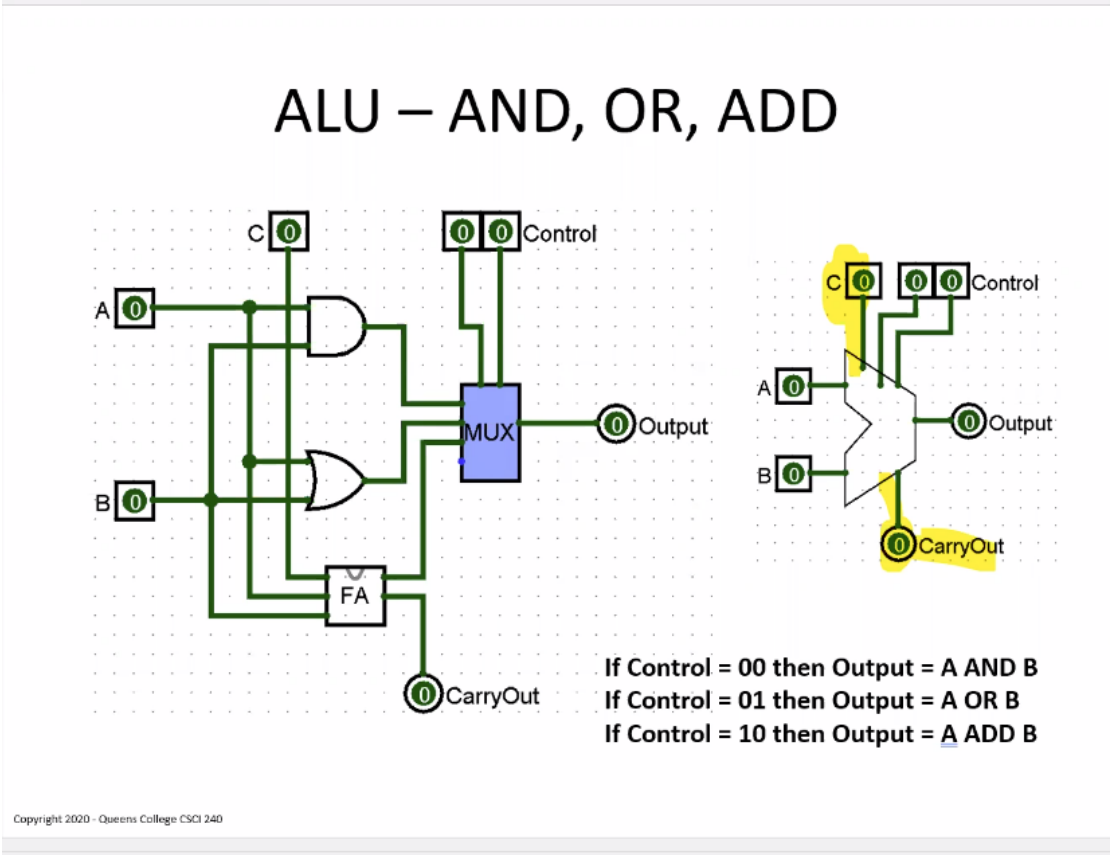
Note: A multiplexer is a decoder, but with extra inputs A-D and the outputs moving into an OR gate at the end.





03/28 - Arithmetic Logic Units, ALU





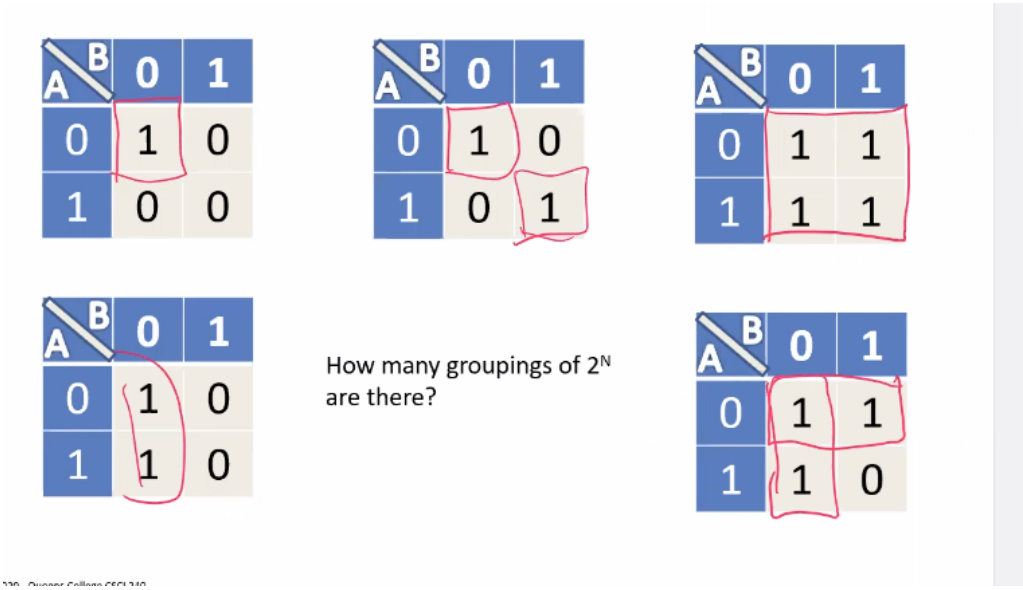
3/30 K-MAP

For each input, K-maps double in size.

A	B	Output
0	0	W
0	1	X
1	0	Y
1	1	Z

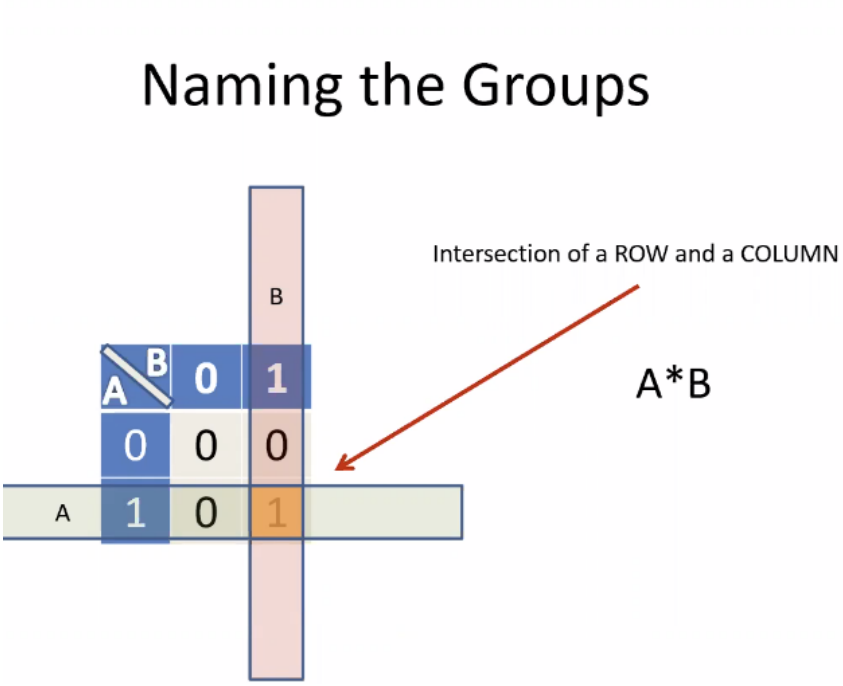
⟺

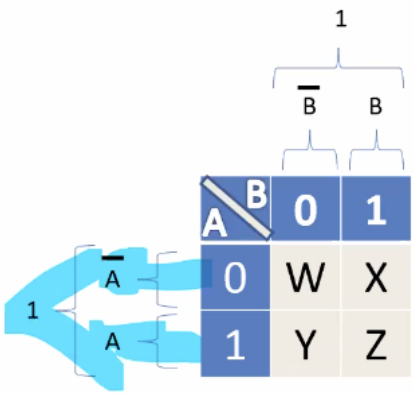
A \ B	0	1
0	W	X
1	Y	Z



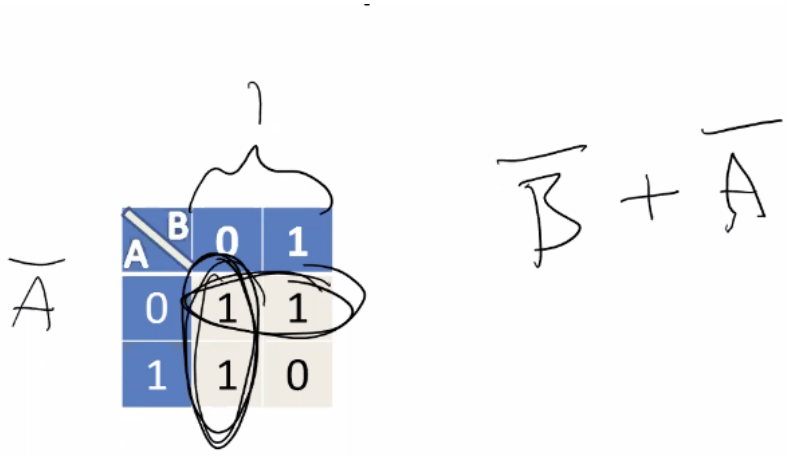
- **Look for groups of 2^n**
- Diagonals do not count - but you can have groups overlap

Examples of K-Maps

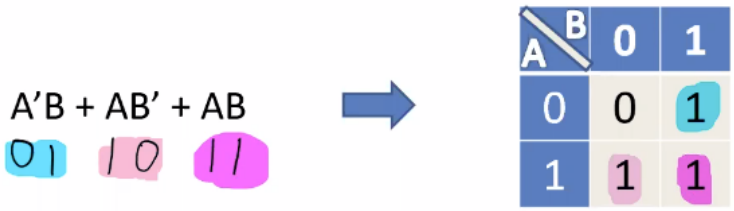




Note: if !A and A are both intersecting, that means that it doesn't matter if we have A, so we can simplify to 1. A + !A = 1



Boolean Expression to K-Map



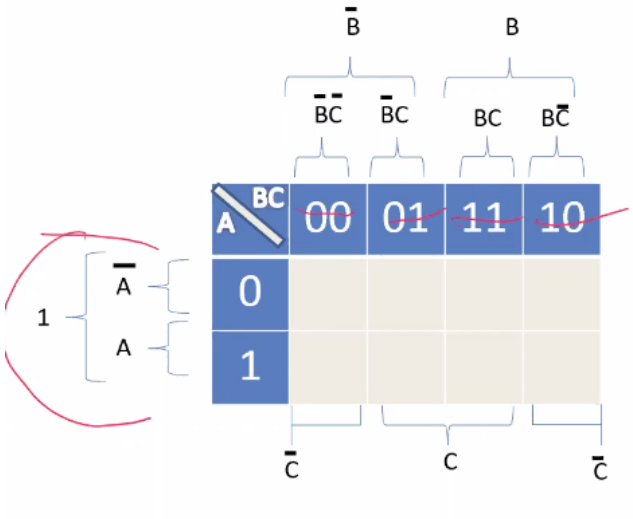
To figure out kmap:

Start with 1 bit. draw a line, and write the reflection. Everything above the line, pad with 0, below, pad with 1.

```
0 0
0 1
--
1 1
1 0
```

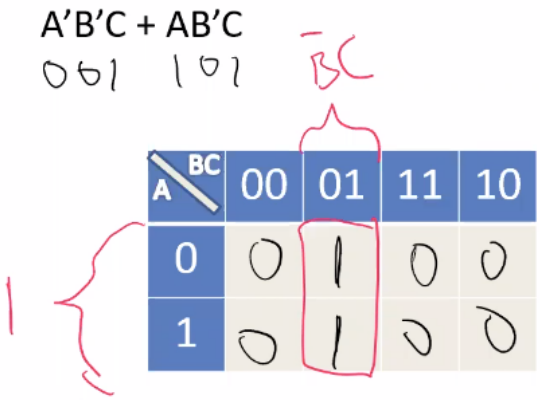
For 3 bits: Write the numbers out, draw a line, pad with 0s and 1s. Start with **TWO** bits./g

```
0 0 0
0 0 1
0 1 1
0 1 0
---
1 1 0
1 1 1
1 0 1
1 0 0
```

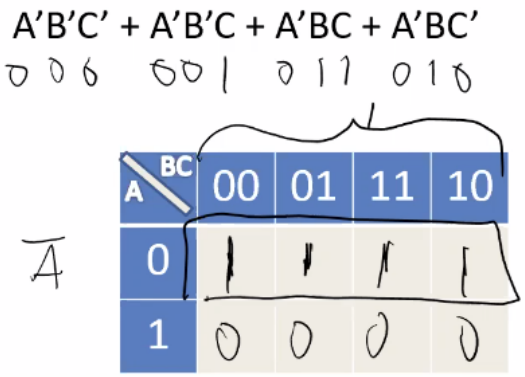


^ How a 3 input k-map would look like.

Simplifying boolean expressions to K-Map



Note - all of this reduces to !A, since it's the intersection of !A and 1



Note - this is simplified to C

AB'C + A'B'C + A'BC + ABC

A \ BC	00	01	11	10
0		1	1	
1		1	1	

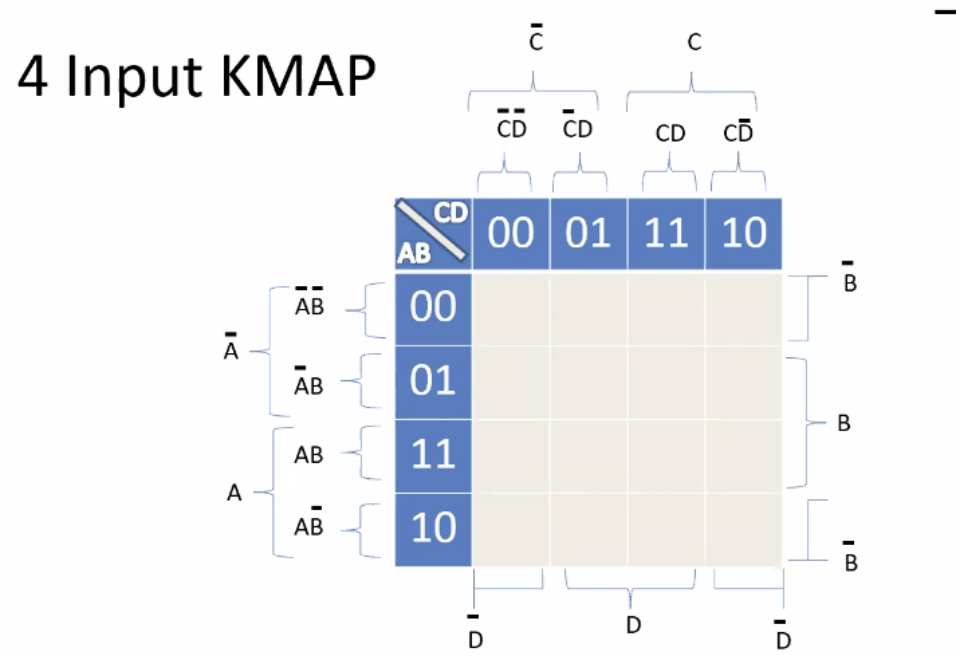
BIG NOTE: YOU CAN WRAP AROUND K-MAPS AND IT COUNTS AS A GROUP. See below.

A'B'C' + AB'C' + A'BC' + ABC'

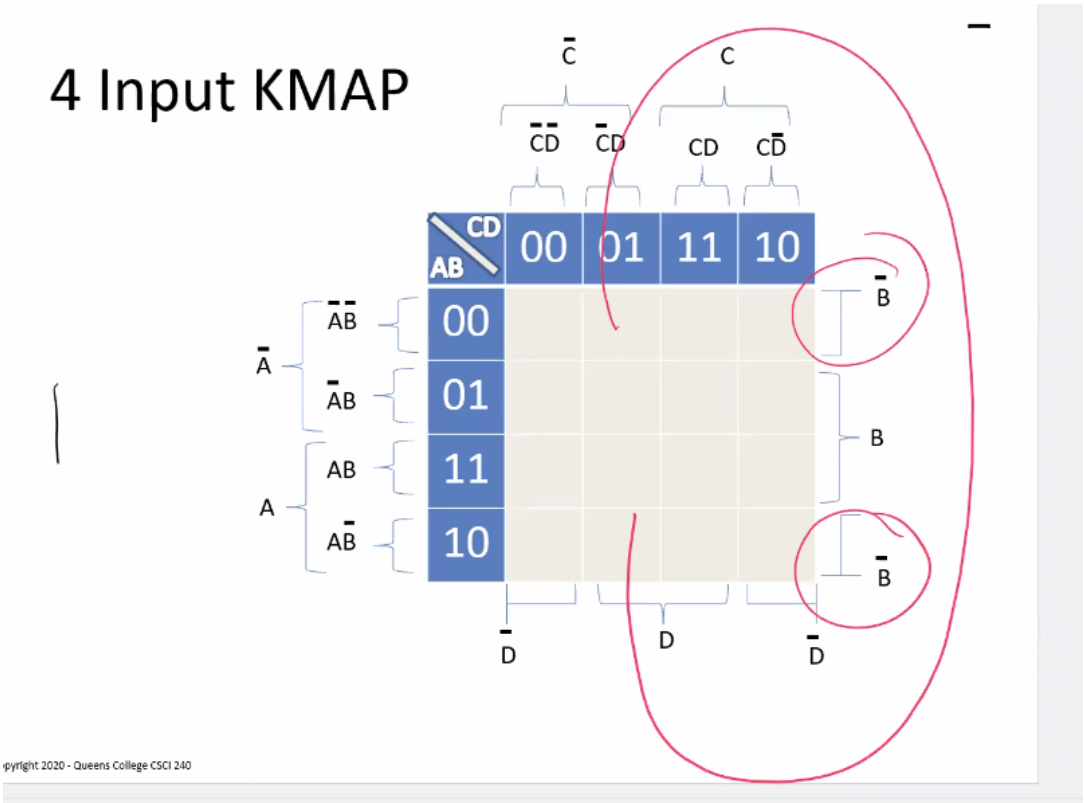
A \ BC	00	01	11	10
0	1			1
1	1			1

$1 \cdot \overline{C}$

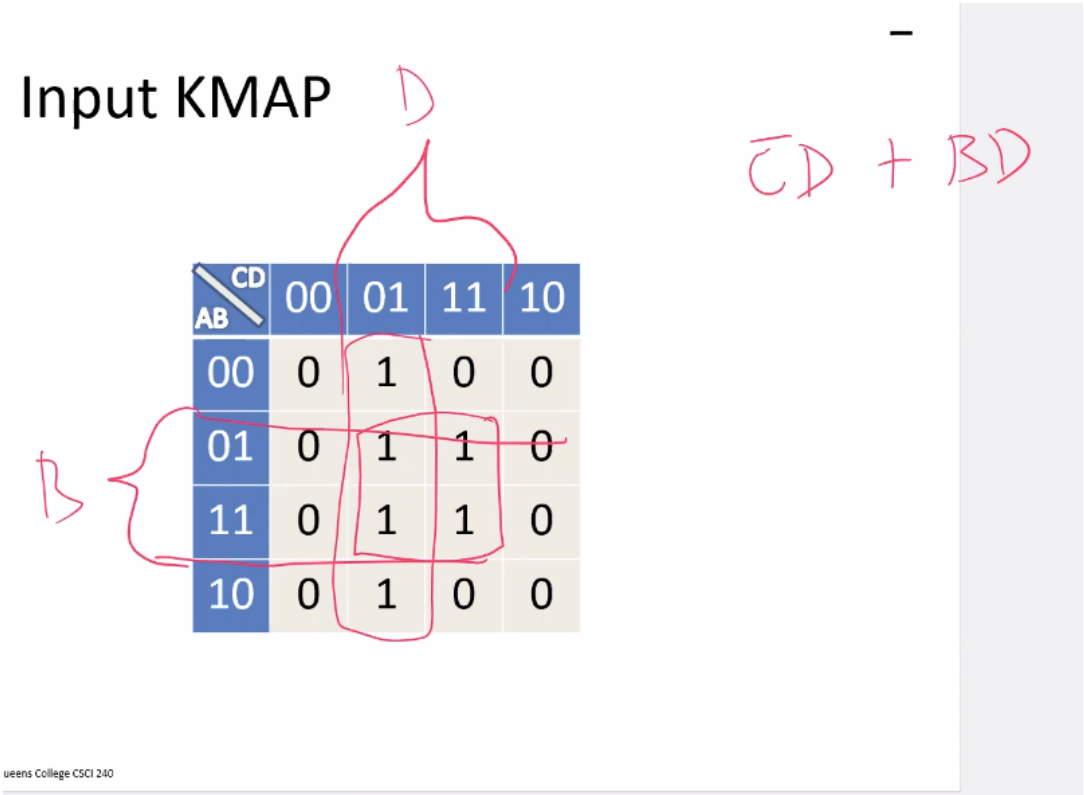
4 Input K-map

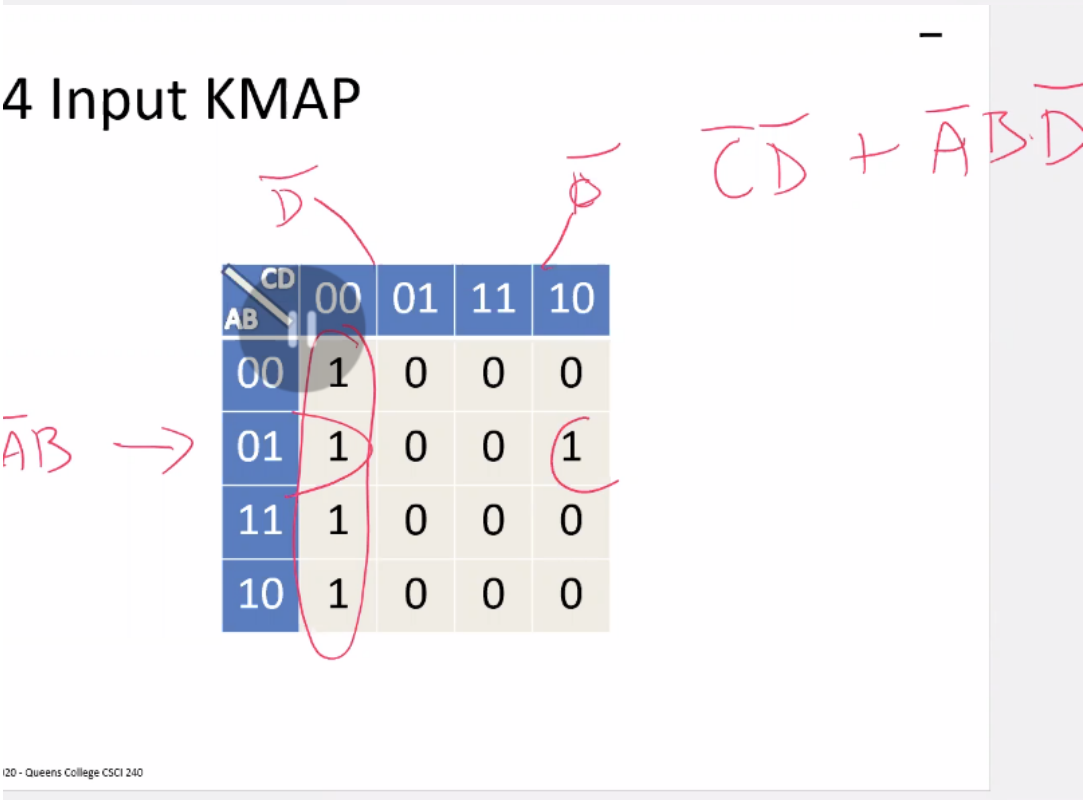


Notice the wrap arounds, !D for sides, !B for top/bottom



4 Input Examples





MIPS

4/18 - Intro to MIPS

Definition - Microprocessor without Interlocked Pipeline Stages

Primarily used in many embedded systems such as DVRs, routers, printers.

- 32 bit architecture, word size, instructions, mem addresses, registers all 32 bits.

- 32 bit processors take in 32 bits at a time.

```
add $7, $5, $3 #add is the operation, 7 is destination register, 5 and 3 are source register
#this is $7 = $5 + $3
```

Register is denoted by *$* and is the location in memory where things are stored. $7 is register 7, the location where the destination is. These are usually:

rs (source), rt(operand), rd (destination).

shamt = shift amount, or sh.

funct: function code (specific R-format instruction)

Decoding MIPS -> Binary

When you have binary, the instructions are 32 bits and are in the following order:

```
op rs rt rd sh func
#instructions are in the order
func $rd, $rs, $rt
```

This code is:

```
add $7, $5, $3
#function, rd, rs, rt
000000 00101 00011 00111 00000 100000
#opcode rs rt rd(destination) sh function
```

Ex 2:

```
and $9, $12, $5
000000 01100 00101 01001 000000 100100
```

Encoding Binary -> MIPS

Ex 1:

```
sub $8, $13, $10
000000 01101 01010 01000 00000 100010
```

R-type instructions:

op	rs	rt	rd	shamt	func
6 bit	5 bit	5 bit	5 bt	5 bit	6 bit

op - "opcode" - specifies instruction - for R-Type, opcode is 000000

func – further specification for instruction.

rs, rt, rd – registers used to store operands.

shamt – “shift amount” reserved for shift operations.

Instruction	func
add	100000
and	100100
div	011010
mult	011000
or	100101
sub	100010

R-Type vs I-Type

```
add $7, $5, $3 #R-Type, $7 = $5 + $3 - adds 2 registers together
addi $7, $5, 3 #I-Type: $7 = $5 + 3 adds register and immediate value, constant
```

I-Type Instructions

I-type instructions:

op	rs	rt	imm
6 bit	5 bit	5 bit	16 bit

op - "opcode" - specifies instruction

rs, rt – registers used to store operands.

imm – “immediate value”. Constant built into the Instruction to be used as an operand.

Instruction	opcode
addi	100000
andi	001100
lw	100011
sw	101011
ori	001101

NOTE: IN THIS CASE, RT IS DESTINATION

Examples:

```
andi $6, $3, 15 #op, $rt, $rs, imm
001100 00011 00110 000...01111
addi $10, $13, 5
100000 01101 01010 000...101
```

J-Type Instructions

J-type instructions:

op	target
6 bit	26 bit

op - "opcode" - specifies instruction

Instruction	opcode
J	000010
jr	000011

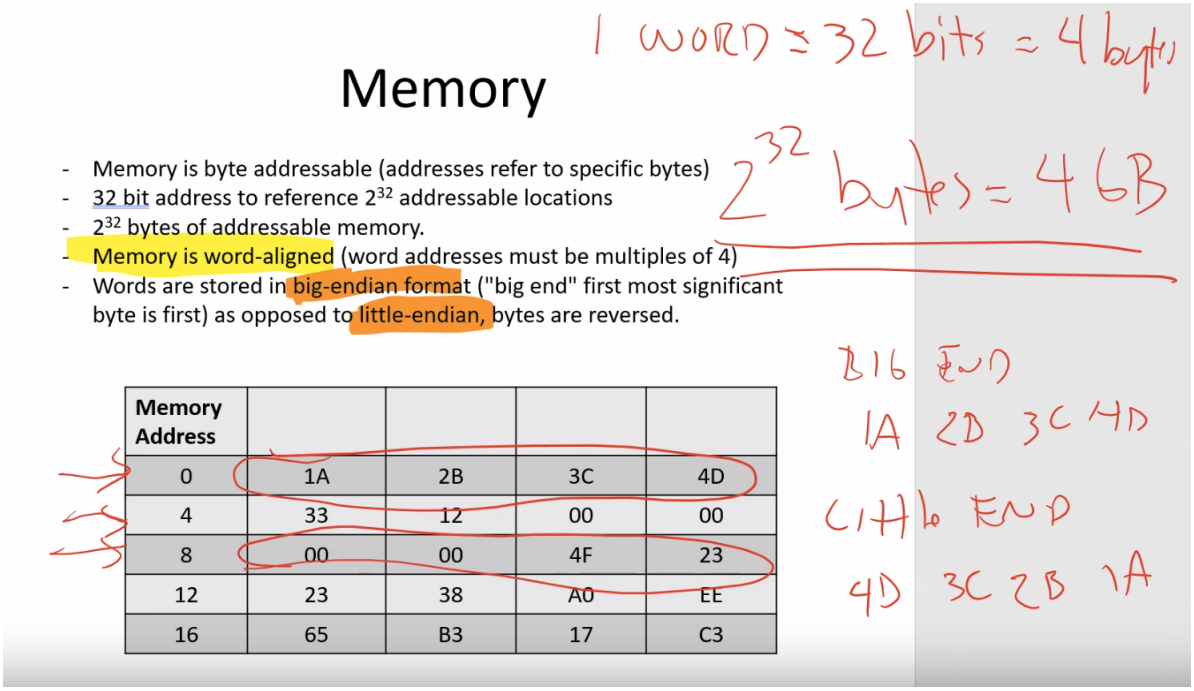
target: address to “jump to”

Pseudo instructions

Pseudoinstructions expand the MIPS instruction set but are not part of the MIPS set. They are translated into one or more MIPS instructions when translated to machine code.

```
move $6, $4 = #add $6, $4, $0 -> $0 always contains value 0. Adds $4 to $0, then put result into $6
clear $6 = #add $6, $0, $0 -> adding $0 to $0 and puts $0 into register 6
mul $6, $5, $4 = #mult $5, $4 -> product is placed into temporary registers due to overflow, send lower 32 bits to #mflo $6, higher 32 bits would go to mfhi, but we usually don't hit mfhi (>32 bit)
```

Memory

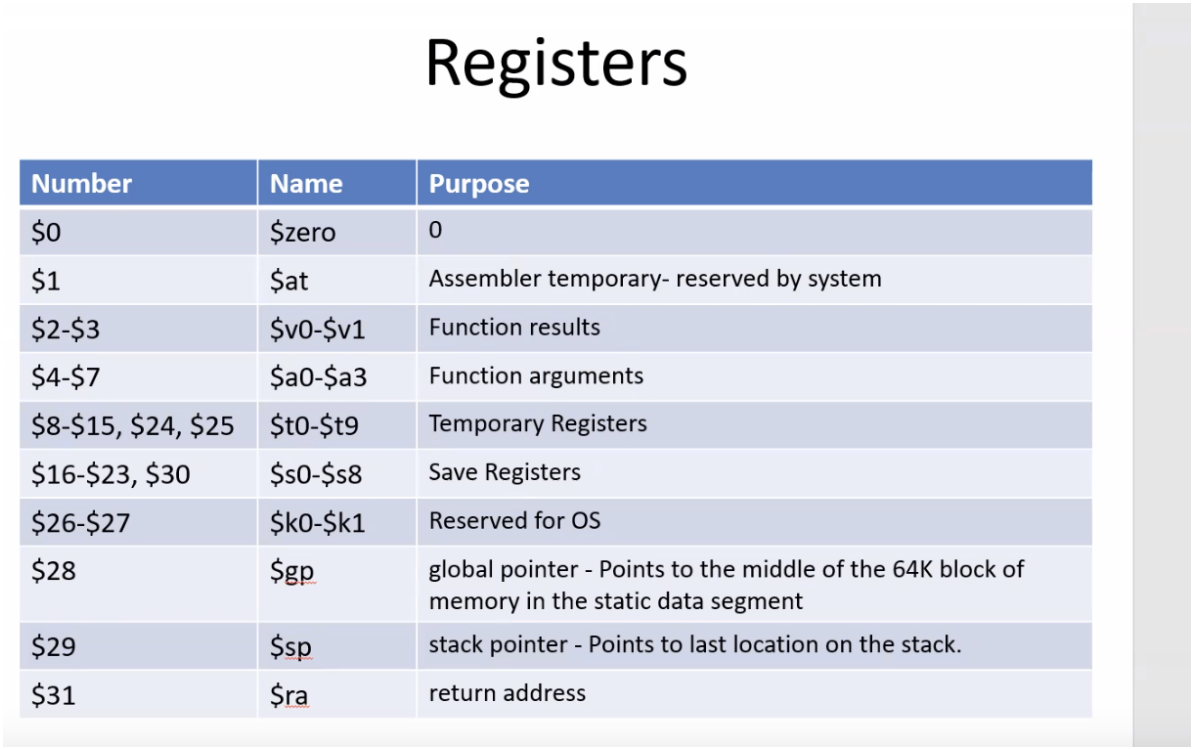


Big-endian format - left to right, Little-ending, right to left

Registers

32 registers in MIPS, preceded by **$**, with two formats for addressing:

1. Using register numbers $0 through $31
2. Using equivalent names, $t1, $sp, etc



4/20 - MIPS Assembly Programs

File Structure

- ASCII text file, can code in any text editor
- File type ***.ASM**
- Load directly into **PCSPIM**

Data Declarations

- Placed in section: .data
- Declares variable names used in program
- Allocate storage in Main Memory
- Assigns initial values into memory

Code

- Placed in section: .text
- Contains program code (instructions)
- Sections of code may contain labels for “jumping”

Comments

- # used for comments

Program Template

```
.data          # declare variables in this section
X:  .word 5
Y:  .word 7
Z:  .word 9

.text          # program code in this section
main:          # indicates start of program
        xxxx
        xxxx
Loop1:  xxxx
        xxxx
Loop2:  xxxx
        xxxx
Print:  xxxx
        xxxx

# End of program, leave a blank line afterwards
```

.data section

- X, Y, Z are pointers. Data section initializes values inside memory, **pointing into a block of memory containing 5, 7, 9.**

.text section

- Each line of code is stored in a block of memory, so labels such as main are also **pointers to a line of code.**
- Each program requires a **main** at the beginning of the program.
- **Loops** are used to label certain sections of code to use gotos, loops, if statements, everything that will take the executed line somewhere else in the code.
- **End of program requires a blank line.**

Data Declarations

Data Declarations

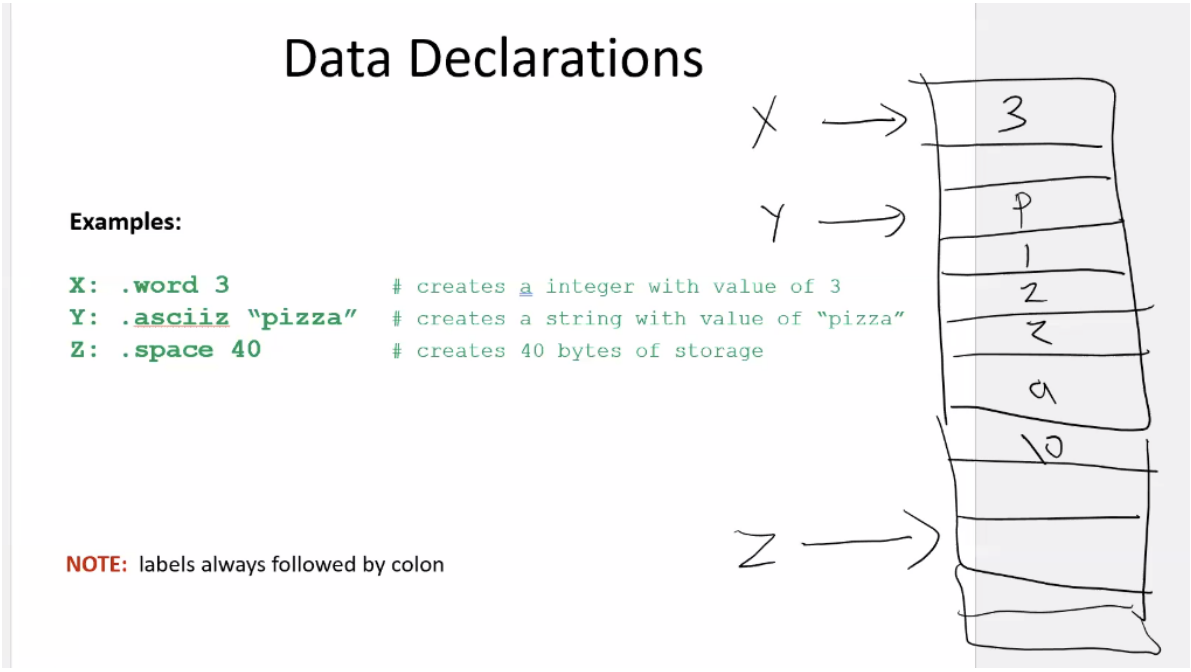
- Create storage in main memory for variable of specified type with given label name and initial value(s).
- Each label corresponds to a unique address in memory, which the assembler determines.

.word 32 bit

Format for declaration:

```
label: storage_type  value(s)
```

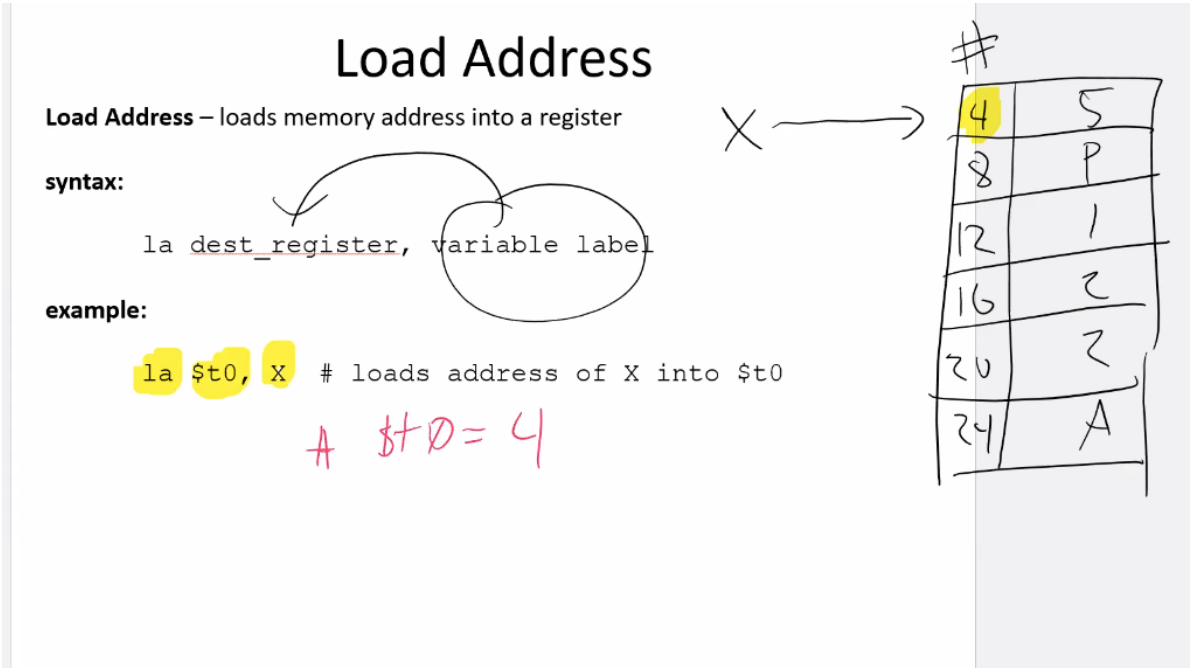
STORAGE TYPES	
.word	Stores a 32 bit word in memory
.ascii	Stores a string in memory without a null terminator
.asciiz	Stores a string in memory with a null terminator
.space	Reserves a block of space in memory



Loading in MIPS

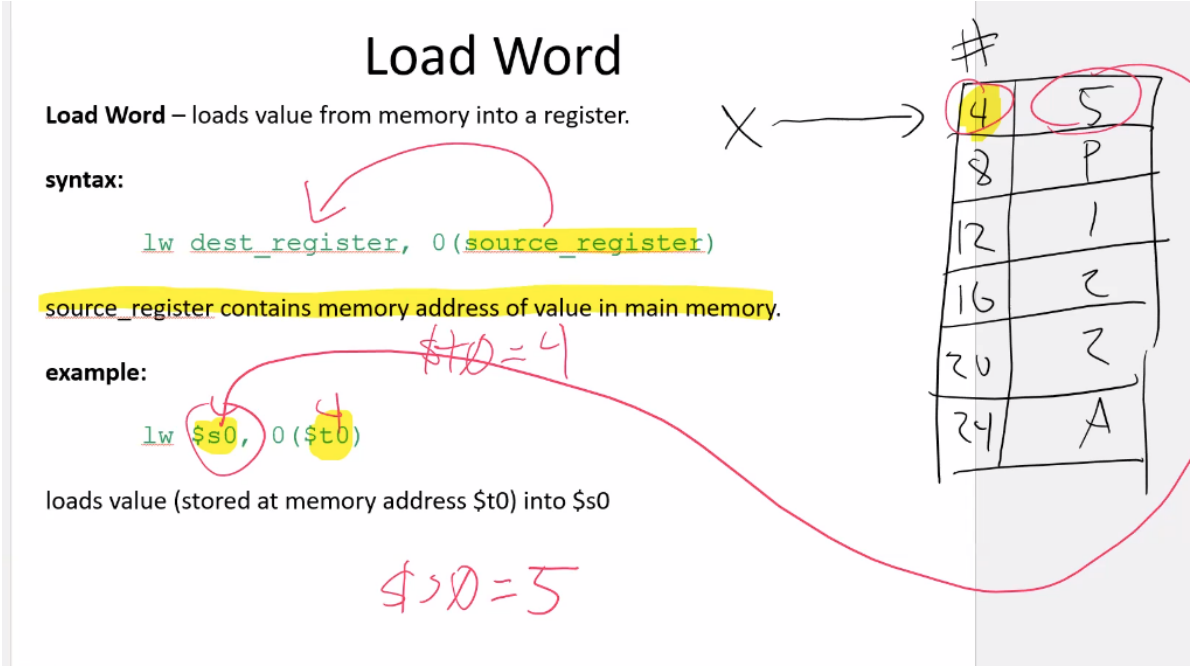
Load Address

Looks at a label and returns the address it is pointing to. **Taking pointer's memory address.**

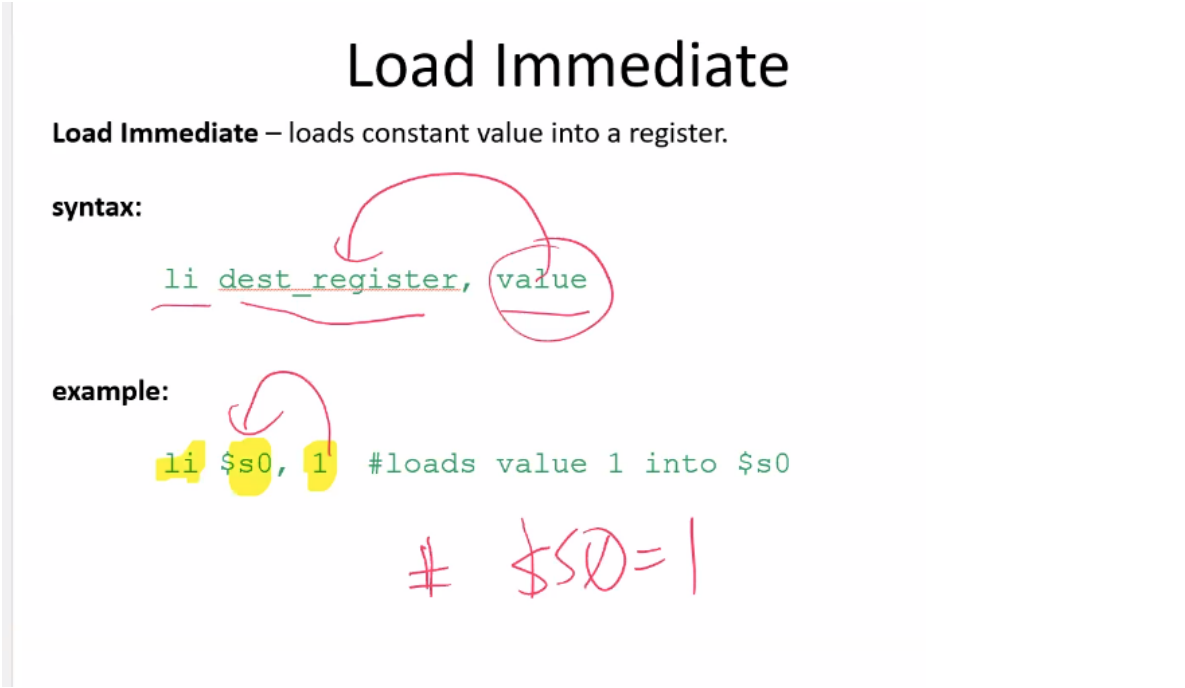


Load Word

Loads the address, then passes the address into the load word. Gives the word/value of the address.



Load Immediate

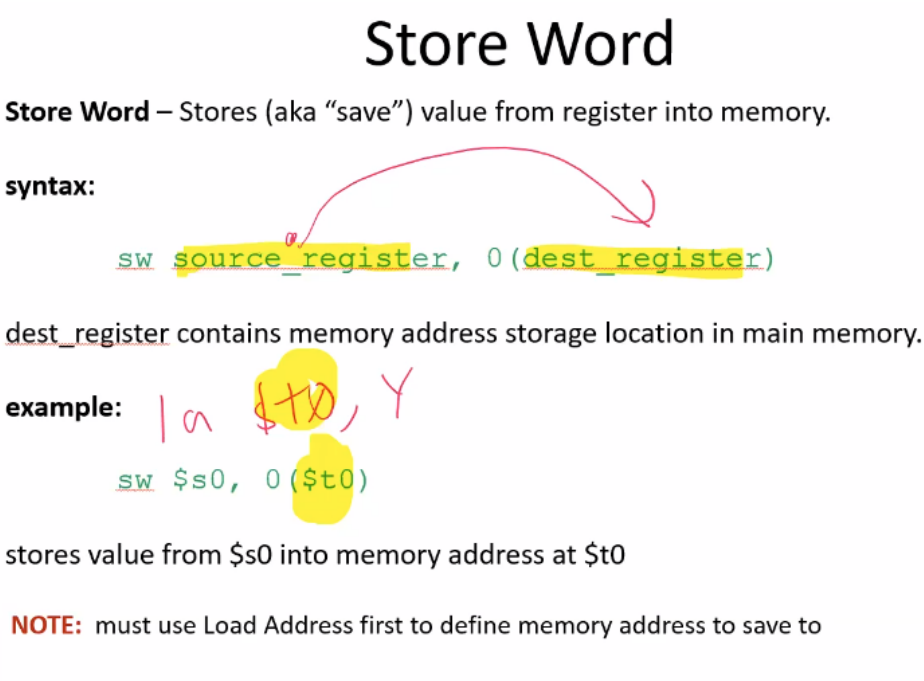


Sample Program using Loads

```
.data
X: .word 5
Y: .word 7

.text
main:

#load X into $s0
la $t0, X #loads memory address of X into $t0
lw $s0, 0($t0) #loads value stored at X into $s0

#load Y into $s1
la $t1, Y #loads memory address of Y into $t1
lw $s1, 0($t1) #loads value stored at Y into $s1
```

```
#note: You can re-use $t0, it is a temp register
```

Store Word



Exercise with Store Word

```
.data
A: .word 9
B: .word 7
C: .space 4

.text
main:

#load A into $s5
la $t0, A #loads memory add of A to $t0
lw $s5, 0($t0) #loads value stored at A to $s5
#load B into $s6
la $t1, B
lw $s6, 0($t1)
#add A and B and place sum into $s7
add $s7, $s5, $s6 #$s7 = $s5 + $s6
#save $s7 into memory at C
la $t2, C #loads memory address of C to $t2
sw $s7, 0($t2) #saves value from $s7 to memory address
```

04/25 - System Calls

System calls are used to communicate with the system for reading from keyboard or writing to the screen.

System calls require some parameter to be passed in an argument register (i.e. $a0) and service code to be passed via $v0

SYSCODES

System Call Codes

Service	Code	Argument(s)	Result
Print Integer	1	$a0 = integer value	(none)
Print Float	2	$f12 = float value	(none)
Print Double	3	$f12 = float value	(none)
Print String	4	$a0 = address of string	(none)
Read Integer	5	(none)	$v0 = value read
Read Float	6	(none)	$f0 = value read
Read Double	7	(none)	$f0 = value read
Read String	8	$a0 = address where string to be stored. $a1 = number of characters to read + 1.	(none)
Memory Allocation	9	$a0 = number of bytes of storage desired	$v0 = address of memory block
Exit (end of program)	10	(none)	(none)
Print Character	11	$a0 = integer value	
Read Character	12	(none)	$v0 = character read

The order to do a system call is:

```
#print integer 15, note li stands for load immediate
li $v0, 1 #loads code 1, which is print integer into $v0. $v0 contains call
code
li $a0, 15 #loads immediate 15 into $a0
syscall #prints 15

#print character 'x' (ASCII 120)
li $v0, 11 #load 11 (code for print char) into $v0, call code
li $a0, 120 #load immediate 120 into $a0, 120 is ASCII for x
syscall #prints 'x' - sees $v0 is 11, so we want to print char. sees $a0, 120,
prints ascii 120
```

Print String

```
.data
String1: .asciiz "Fried Chicken" #string1 is a pointer to a block of memory

.text
main:
    li $v0, 4 #load 4 (Code for print STRING) into $v0
    la $a0, String1 #load address of string1 into $a0
    syscall #prints "Fried Chicken"
```

Read Integer

```
li $v0, 5 #load 5 (read int) to $v0
syscall #starts capturing keyboard values into $v0 until <CR> encountered.
add $s0, $v0, $0 #copies value from $v0 into $s0
```

Exit Program

```
li $v0, 10 #load 10 (code for Exit) into $v0
syscall #exits program
```

Hello World!

```
.data
str = .asciiz "Hello World" #hello world string

.text
main:
    li $v0, 4 #load 4 (print string sys call)
    la $a0, str #loads address for str
    syscall #prints "Hello World"
    li $v0, 10 #load exit code 10
    syscall #exit program
```

Simple Addition Calculator

```
.data
Str1: .asciiz "Enter first number"
Str2: .asciiz "enter second number"
Str3: .asciiz "The sum is:"

.text
main:
    #print string "enter first number"
    li $v0, 4
    la $a0, Str1
    syscall

    #read integer into $s0
    li $v0, 5 #read int
    syscall
    add $s0, $v0, $0
```

```
    #print "enter second number"
    li $v0, 4 #print string
    la $a0, Str2
    syscall
    #read integer into $s1
    li $v0, 5 #read int
    syscall
    add $s1, $v0, $0

    #add $s0 and $s1 into $s2
    add $s2, $s0, $s1

    #print string "The sum is"
    li $v0, 4
    la $a0, Str3
    syscall

    #print integer stored in $s2raar
    li $v0, 1 #syscall 1 is print int
    move $a0, $s2 #copies contents of $s2 into $a0
    syscall
```

04/27 - Conditional Branching

- By default, instructions execute sequentially
- Conditional Branching alters the instruction sequence if certain conditions are met.

Branch on Equal, BEQ - branches to a specific instruction at a diff memory location when two register contains equal values

Branch Not Equal, BNE compares if != to each other.

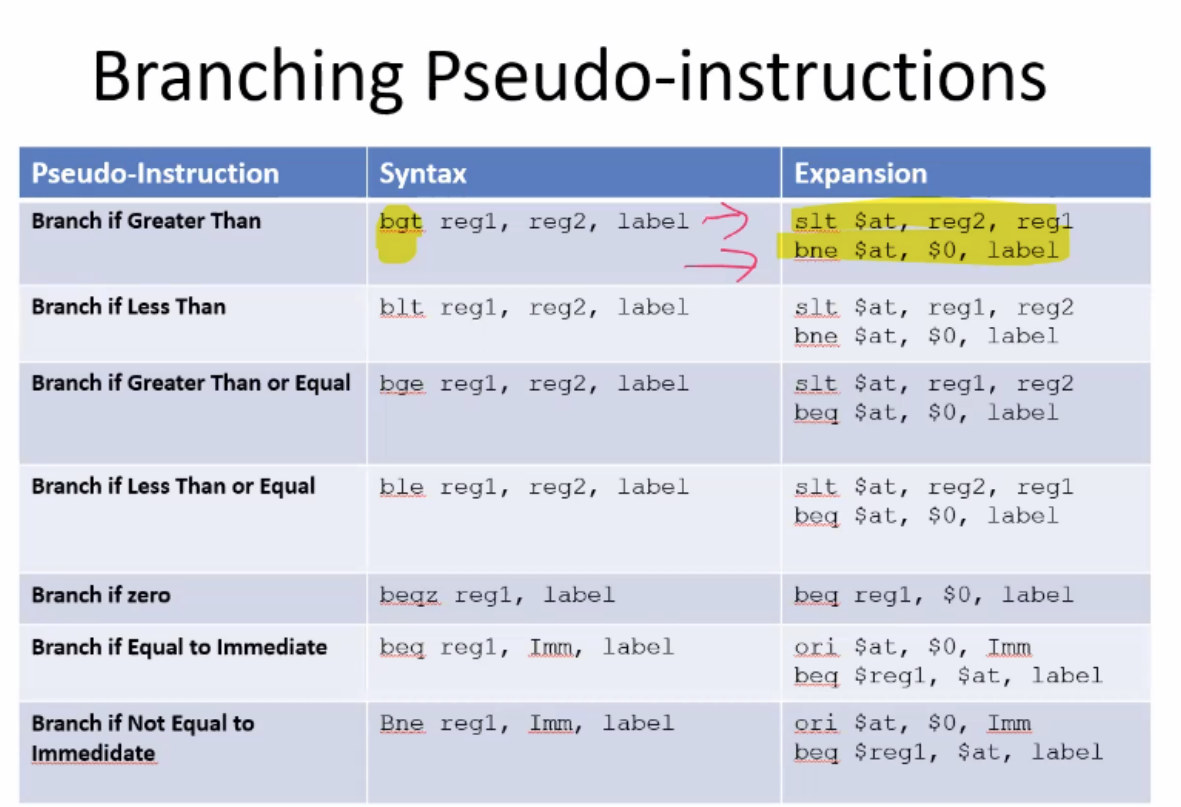
```
#syntax
beq reg1, reg2, label #branch equal
bne reg1, reg2, label #branch not equal
#if $t0==$s0 go to else
beq $t0, $s0, else
#if $t0 != $s0 go to else
bne $t0, $s0, else
```

Set on Less Than (SLT) - Compares two contents in registers and tests if less than. **IF TRUE - RETURN 1, 0 OTHERWISE**

Set on Less than Immediate same as SLT, but using an immediate rather than a var.

```
slt dest_reg, reg1, reg2
#dest_reg = 1 if reg1 < reg2
#dest_reg = 0 if reg1 >= reg2
# < -slt immediate ->
slti dest_Reg, reg1, imm
```

BRANCHING INSTRUCTIONS



Unconditional Branching

Similar to "goto" in C++

Jump -> goto

Jump and Link - copies the address of the next instruction into register $ra and then jumps to the address stored in LABEL

Jump Register - Jumps to the address stored in a register

```
j LABEL #syntax
j loop #jumps to loop

#<-Jump and Link ->
#ex: pretend address of print is 3
jal print
#then $ra = 4, then jumps to print
jr $ra #jumps to $ra, which would be register 4
```

Exercise 1

```
.data
A: .word 8
B: .word 3
C: .space 4

.text
main:
#load A into $s1
la $t0, A
lw $s1, 0($t0)
#load B into $s2
la $t0, B
lw $s2, 0($t0)
#if A<B goto WRITEB
blt $s1, $s2, WRITEB
#write A to memory at C
la $t0, C #$t0 = address of C
sw $s1, 0($t0) #write A to memory address at C
#goto END
j END
WRITEB:
#write B to memory at C
la $t0, C #$t0 address of C
sw $s2, 0($t0) #write B to memory at C
#goto END:

END:
```

Calculator

```
.data
Str1: .asciiz "First #"
Str2: .asciiz "2nd #"
Str3. asciiz "Enter operation + - * /"

.text
main:
#print String "Enter first #"
li $v0, 4 #load 4 (Code for print STRING) into $v0
la $a0, Str1 #load address of string1 into $a0
syscall #prints "first number"

#read int into $s0
li $v0, 5 #read int
syscall
add $s0, $v0, $0

#print String into Enter 2nd
li $v0, 4
la $a0 Str2
syscall
```

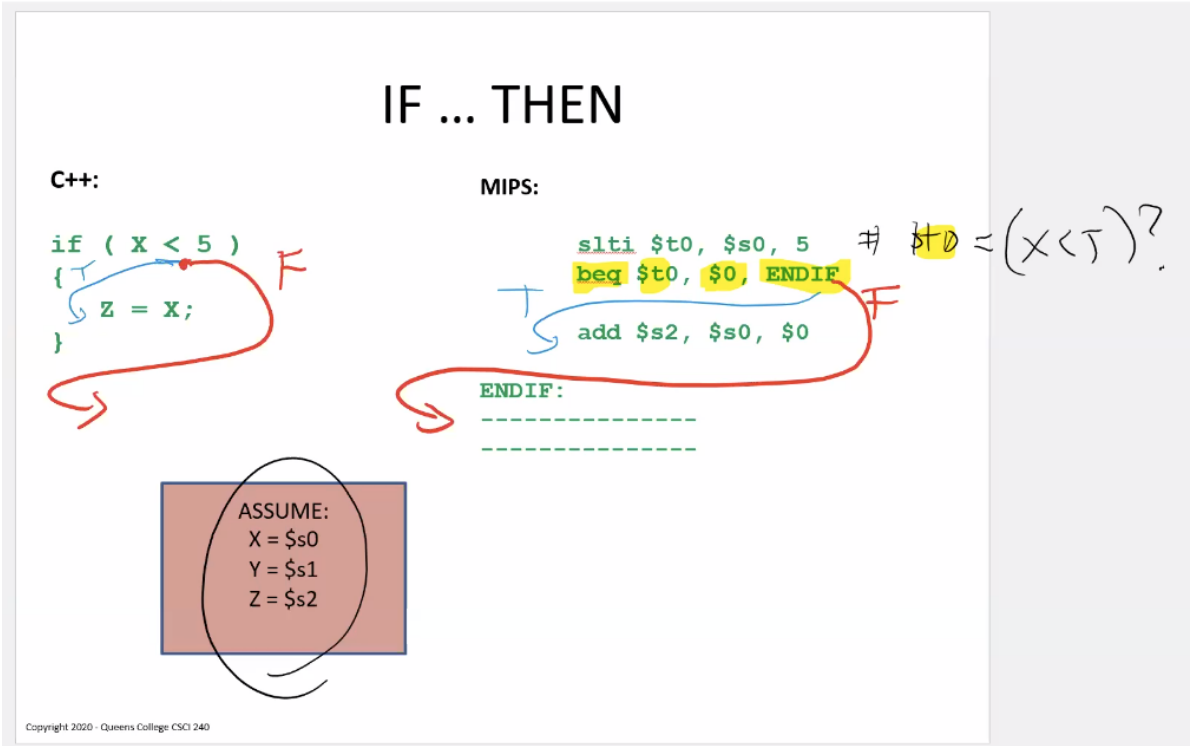
```
#read int into $s1
li $v0, 5
syscall
add $s1, $v0, $0

#print string enter operaiton
li $v0, 4
la $a0, Str3
syscall

#read char into $s2 +(43), -(45), *(42), /(47)
li $v0, 12 #read char
syscall
move $s2, $v0

#if + goto ADD
beq $s2, 43, ADD #branch eq to immediate, $s2 -> 43 ascii
#if - goto SUB
beq $s2, 45, SUB
#if * goto MULT
beq $s2, 42, MULT
#if / goto DIV
beq $s2, 47, DIV

ADD:
    #$s0 add $s1 into $s2
    add $s2, $s0, $s1
    #Print int stored in $s2
    li $v0, 1 #1 is syscode for print INT
    move $a0, $s2
    syscall
    j END
SUB:
    #$s0 sub $s1 into $s2
    sub $s2, $s0, $s1
    li $v0, 1 #1 is syscode for print INT
    move $a0, $s2
    syscall
    j END
MULT:
    mul $s2, $s0, $s1
    li $v0, 1 #1 is syscode for print INT
    move $a0, $s2
    syscall
    j END
DIV:
    div $s2, $s0, $s1
    li $v0, 1 #1 is syscode for print INT
    move $a0, $s2
    syscall
    j END
END:
li $v0, 10 #load exit code 10
syscall #exit program
```

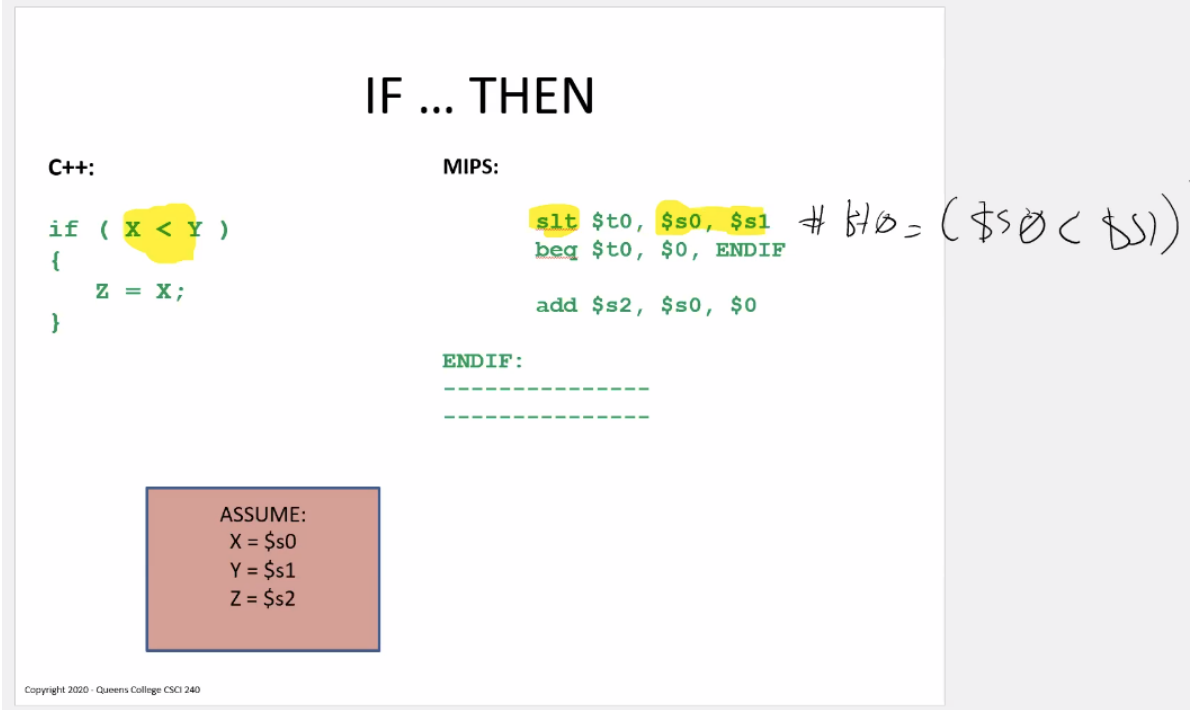
05/02 - Control Structures

A control structure determines the order in which statements are executed.

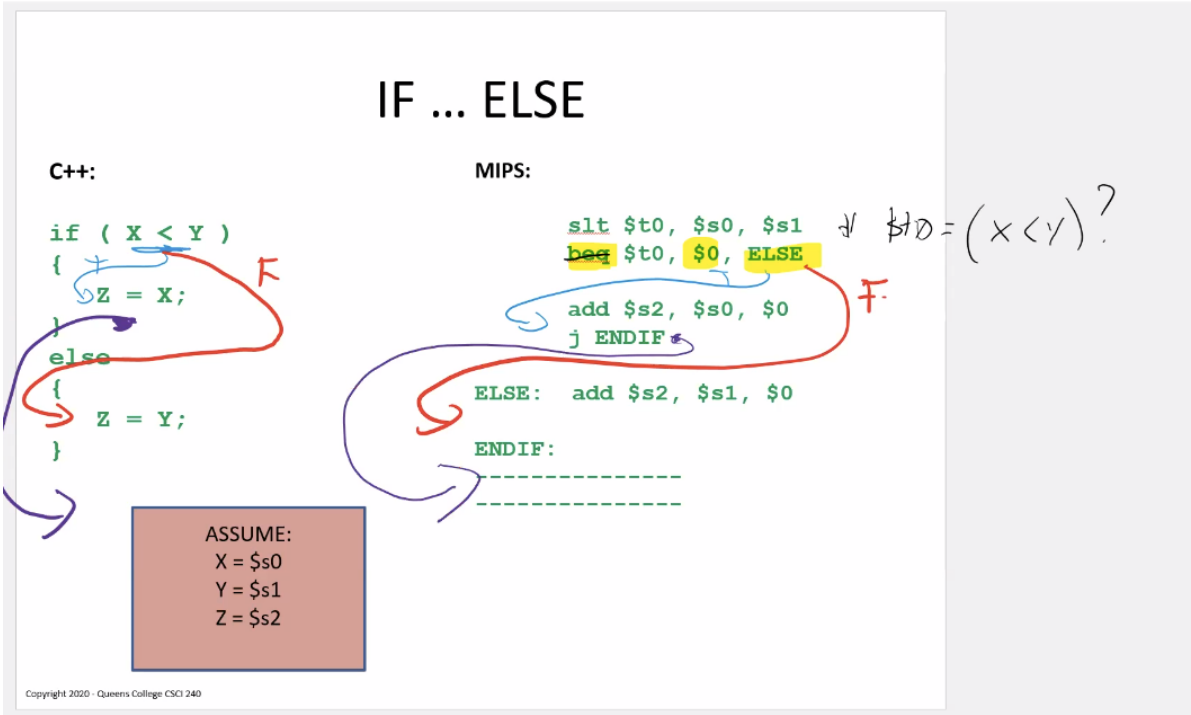
- Sequential: Default
- Repetition: Loops
- Selection: Choose between 2 or more paths.

If.. Then



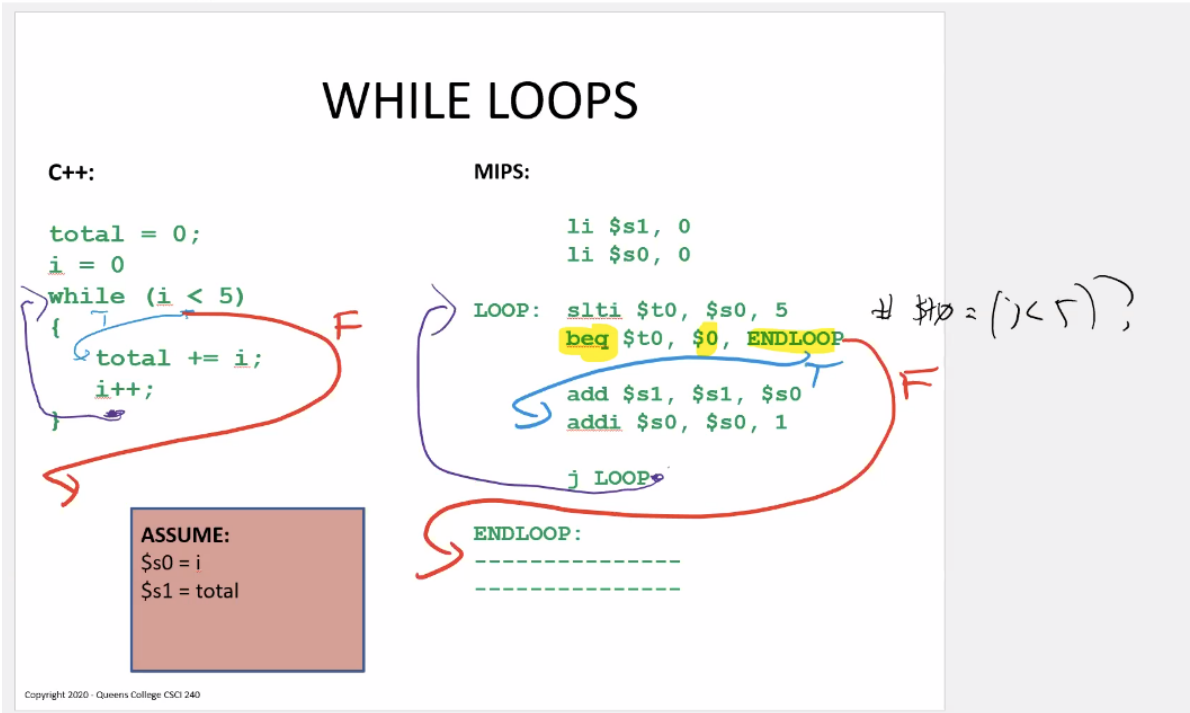


If.. Else



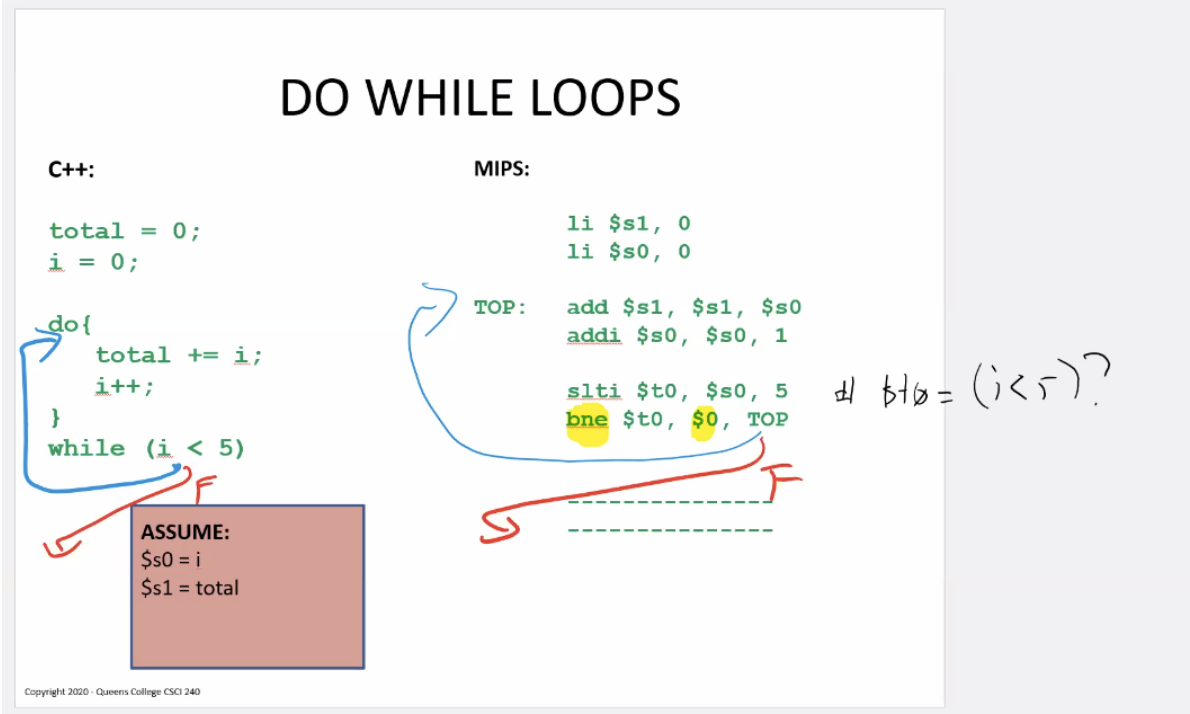
While Loops

1. Test condition at top
2. if condition fails
    1. Branch to the first instruction after the loop body.
3. If condition passes:
    1. continue to first instruction inside loop body
    2. jump to top of loop

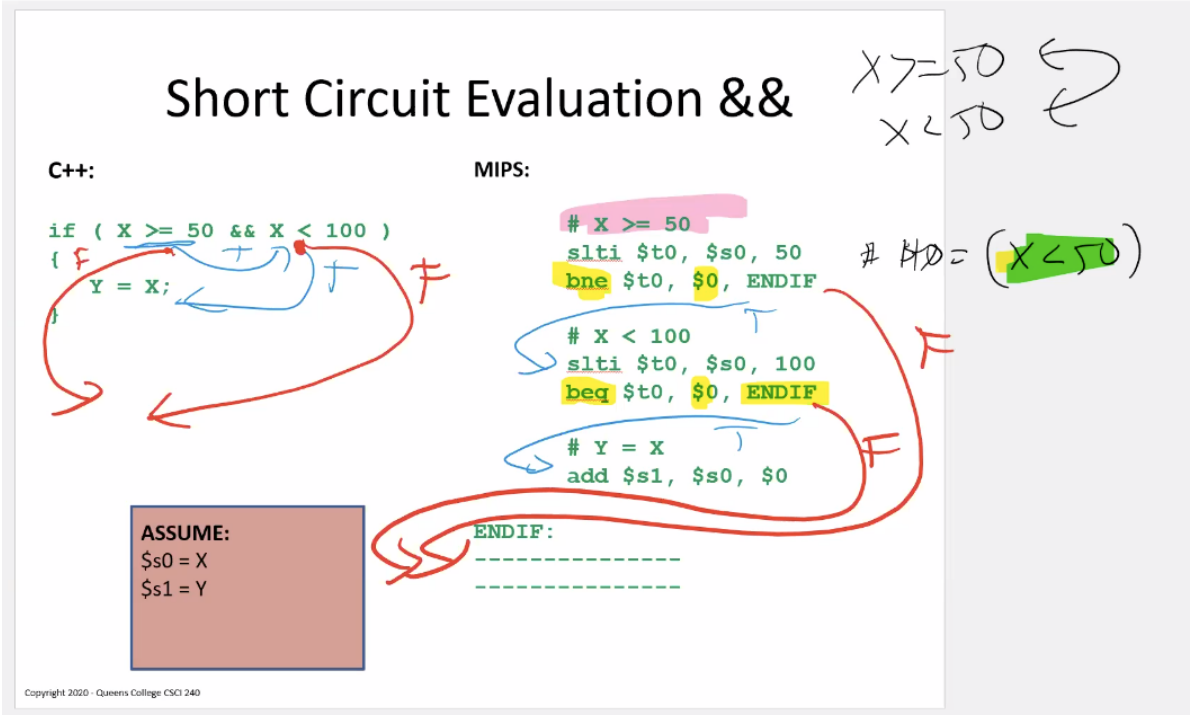


Do While Loop

1. Execute Loop Body Once
2. At end of loop body, test condition
3. If condition passes
    1. jump to first instruction inside loop body
4. If condition fails
    1. continue to next instruction outside loop body

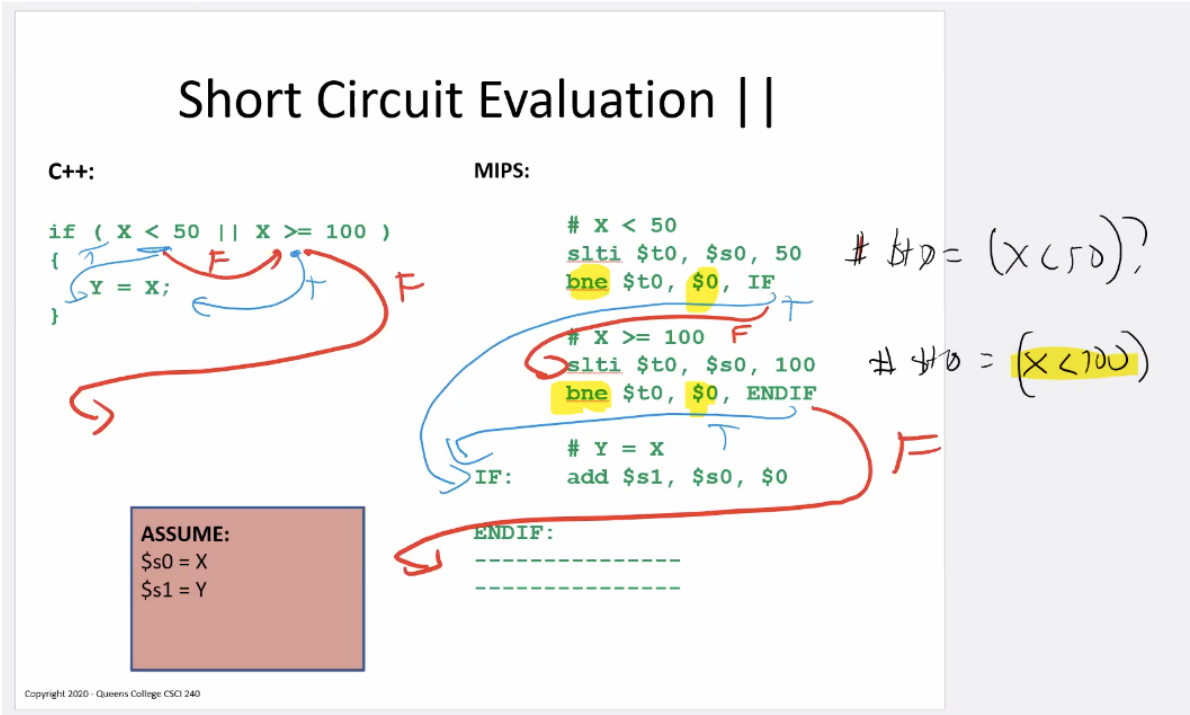


Short Circuit Evaluation &&



Think of it as double negatives, if X < 50 == true, that means it's not >= 50, so endif

Short Circuit Evaluation ||



Exercise - Guess a Number

```
,data
Str1: ,asciiz "Guess #"
Str2: .asciiz "Congrats"
Str3: .asciiz "Wrong"
SECRET: .word 42

.text
main:
    #load Secret into $s0
    la $t0, SECRET
    lw $s0, 0($t0)

Guess: #print string "guess"
    li $v0, 4
    la $a0, Str1
    syscall

    #read int input into s1
    li $v0, 5
    syscall
    move $s1, $v0

    #compare input to secret, if eq, goto win
    beq $s0, $s1, WIN

    #print wrong!
    li $v0, 4
    la $a0, Str3
    syscall
```

```
    #goto guess
    j GUESS

WIN: #print congrats
    li $v0, 4
    la $a0, Str2
    syscall
    #End program
    li $v0, 10
    syscall
```

5/4 - Data Structures

Addressing Modes

An addressing mode is a method of addressing (locating) operands for an instruction

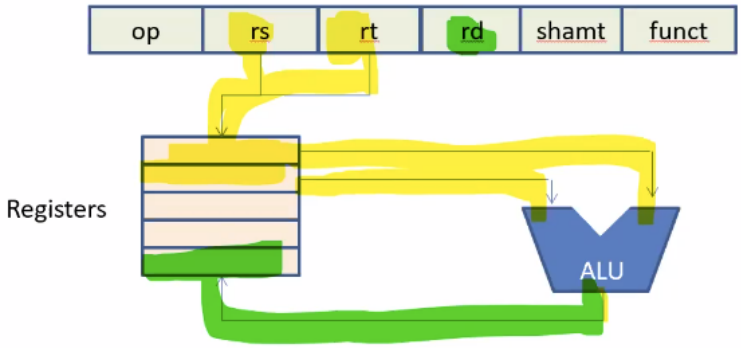
MIPS supports:

- Register Addressing
- Immediate Addressing
- Base Displacement Addressing

Register Addressing

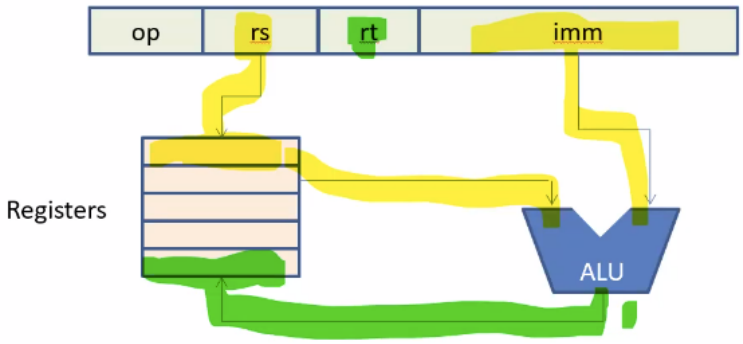
Register Addressing

- Operands are stored in a register
- Must retrieve from register before using
- Example: add $t0, $s0, $s1

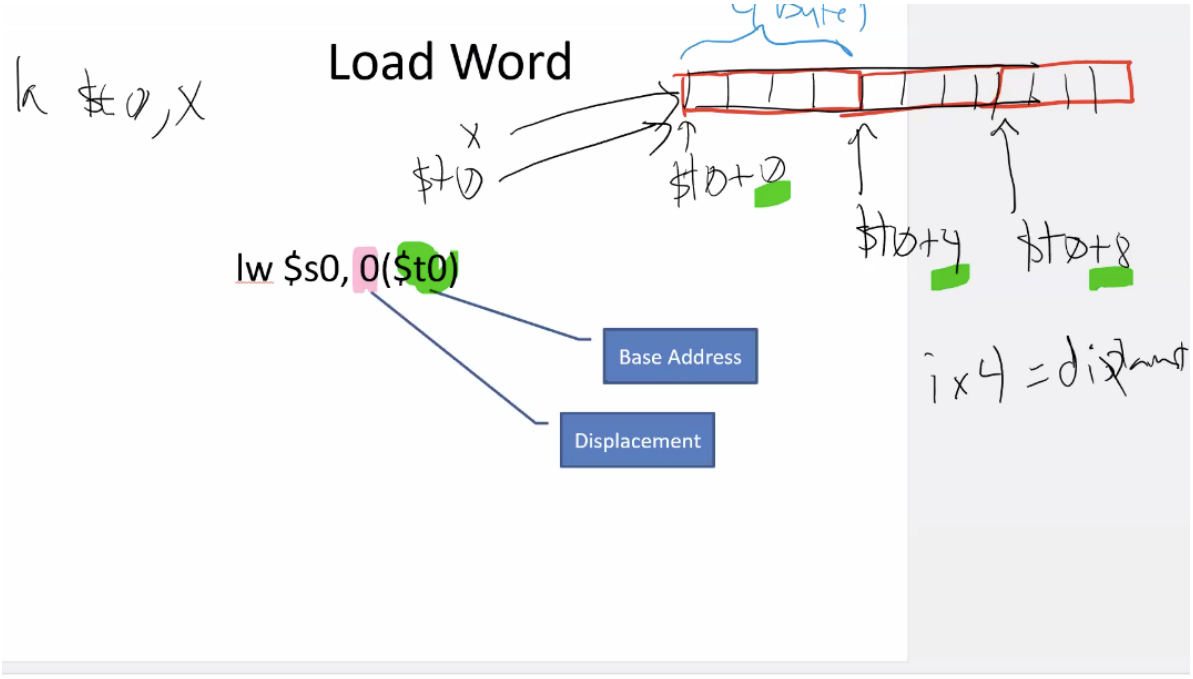


Immediate Addressing

- Operand is an immediate value
- Value is part of the instruction
- Example: addi $t0, $s0, 5

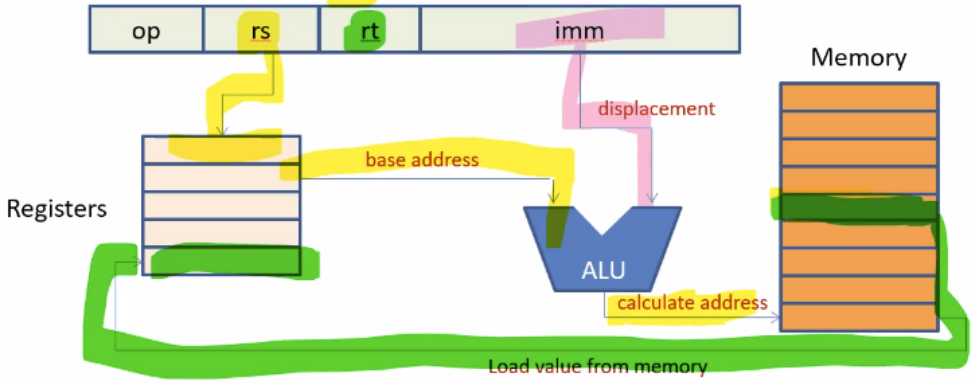


Base Displacement Addressing



Base Displacement Addressing

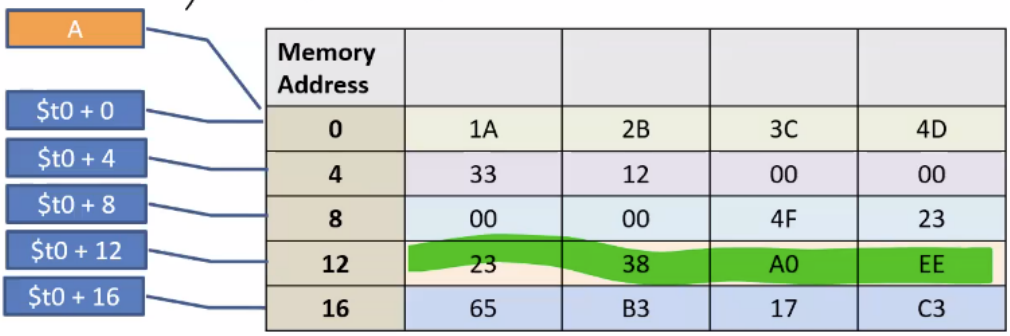
- Operand is a memory location
- Memory address is a base + displacement (must calculate address)
- Must load value from memory
- Example: lw $s0, 0($t0)



Loading values from memory

la $t0, A #$t0 = address of A

lw $s0, 12($t0)



Memory Address				
0	1A	2B	3C	4D
4	33	12	00	00
8	00	00	4F	23
12	23	38	A0	EE
16	65	B3	17	C3

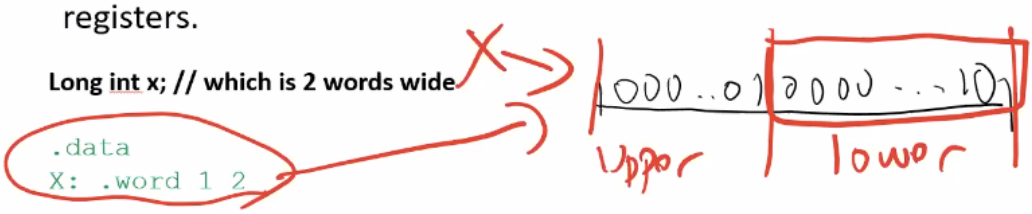
Exercise: How to retrieve value stored at memory address 12 in terms of A?

Long data type - 64bit value

Long data type - 64 bit values

- For a variables larger than 1 word (32 bits), label refers to first word of variable
- Need several **lw** statements to load variable into several registers.

Long int x; // which is 2 words wide



```
.data
X: .word 1 2
```

```
.text
# load x into registers $s0 and $s1
la $t0, x # $t0 = &x
lw $s0, 0($t0) # $s0 = upper word of x
lw $s1, 4($t0) # $s1 = lower word of x. 4 is offset into x.
```

Arrays

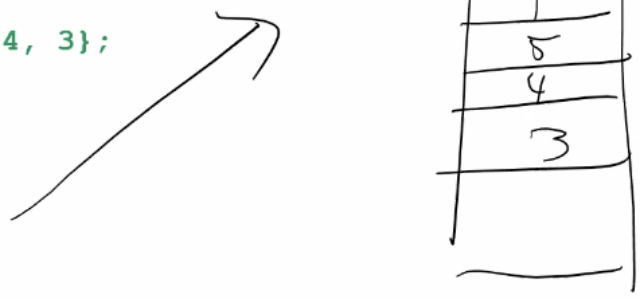
Arrays

C++:

```
int a[5] = {2, 1, 5, 4, 3};
```

MIPS:

```
.data
a: .word 2 1 5 4 3
```



```
.text
   la $t0, a          # $t0 = &a
   lw $s0, 0($t0)     # a[0]
   lw $s1, 4($t0)     # a[1]
   lw $s2, 8($t0)     # a[2]
```

Arrays

What about A[i]?

MIPS:

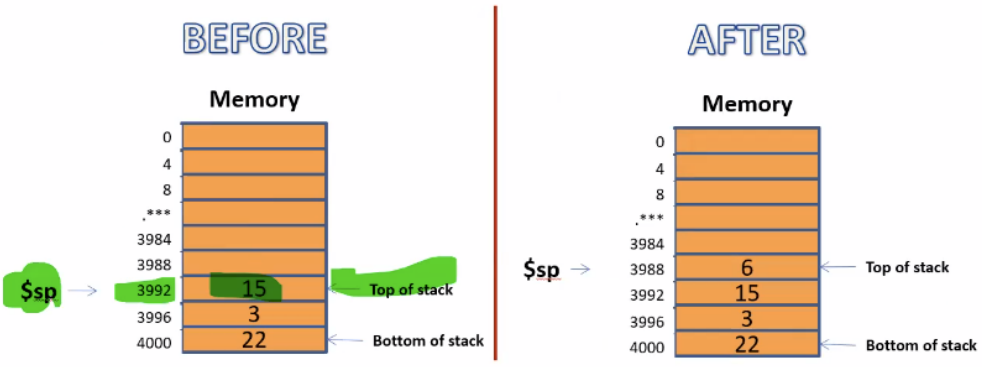
```
# $s0 = &a
# $s1 = i
# $s2 = a[i]

la $s0, a           # base address
sll $t0, $s1, 2     # $t0 = i * 4
add $t1, $s0, $t0   # $t1 = address of a[i]
lw $s2, 0($t1)      # load a[i]
```

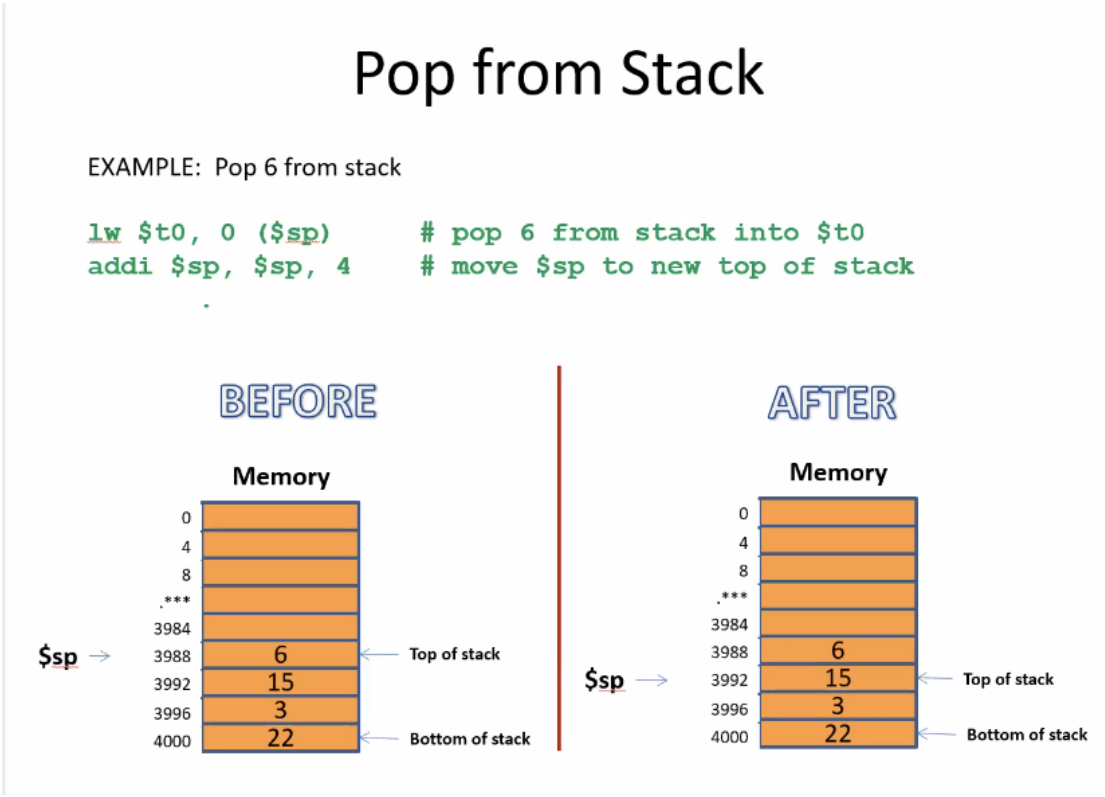
Stack Memory

Pushing onto Stack

EXAMPLE: Push 6 onto stack

```
li $t0, 6           # $t0 = 6
addi $sp, $sp, -4   # $sp -=4
sw $t0, 0($sp)      # push $t0 onto stack.
```





Exercise - SumArray

```
.data
A: .word 5 4 3 2 1 #array 5,4,3,2,1
Str: .asciiz "The sum is:"

.text
main:
#set $s0 to beginning of A
la $s0, A
#(index = $s1) initialize $s1=0
li $s1, 0
#(Sum = $s3) initialize $s3=0
li $s3, 0

LOOP:
#while index < 5
slti $t0, $s1, 5 #$t0 = (index <5)?
beq $t0, $0, ENDLOOP #if condit not met, endloop
#load A[index] into $s2
sll $t0 $s1, 2 #$t0 = i*4
add $t1, $s0, $t0 #$t1 = address of a[i]
lw $s2, 0($t1) #load a[i]
#add $s2 to Sum
add $s3, $s3, $s2 #s3 = s3+s2
#increment index
add $s1, $s1, 1 #s1 = s1 + 1
#goto top of loop
j LOOP

ENDLOOP:
```

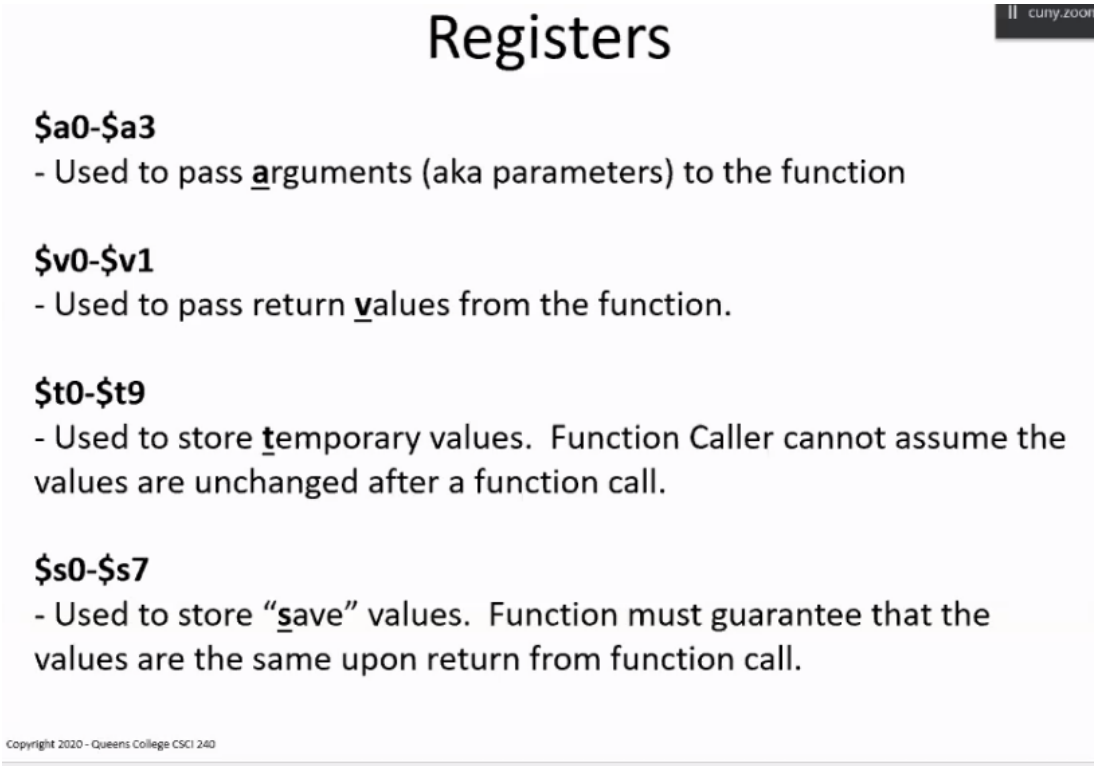
```
#print str "sum is"
li $v0, 4
la  $a0, Str
syscall
#Print int stored in $s3
li $v0, 1
move $a0, $s3
syscall
```

5/9 Functions

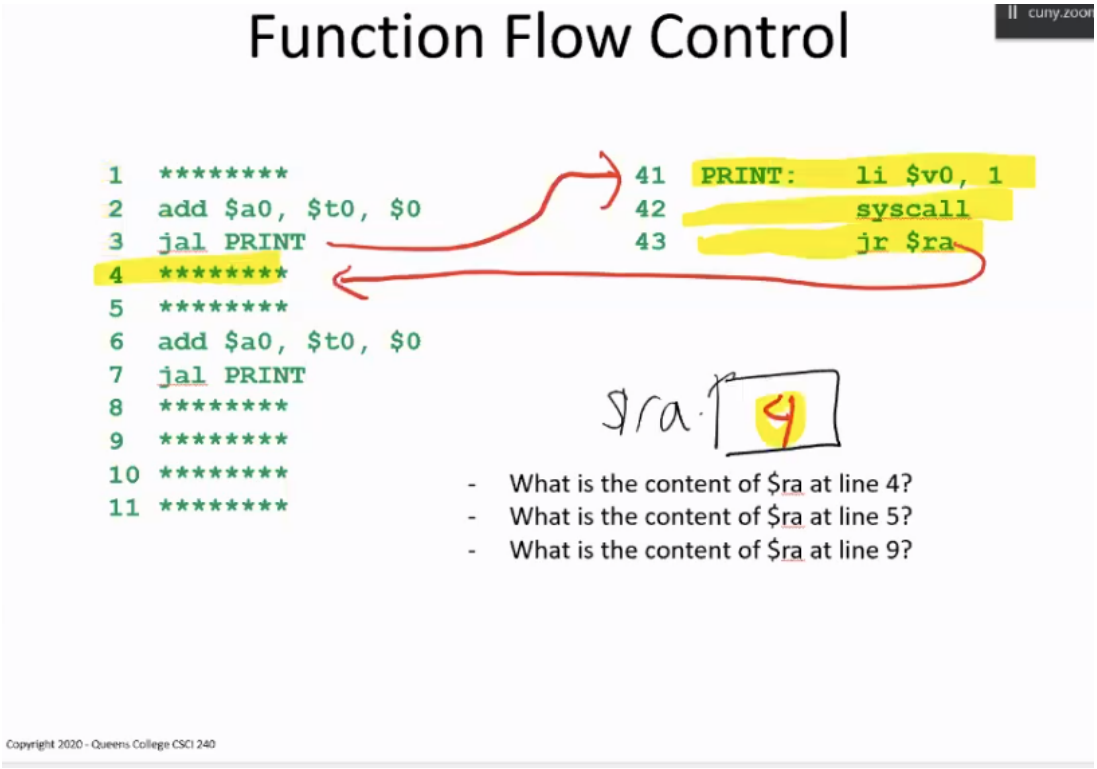
jal - jump and link jumps to memory address indicated in the instruction label and saves the address of the next instruction into $ra ($31)

jr - jump register - jumps to the address in the register used by this instruction.

Registers



Function Flow Control



PrintArray

```
.data
A: .word 5 4 3 2 1

.text
main:
#set $s0 to beginning of Array A
la $s0, A
#(index = $s1) initialize $s1=0
li $s1, 0
#(Sum = $s3) Initialize $s3=0
li $s3, 0

LOOP:
#while index < 5
slti $t0, $s1, 5 #t0 = (index < 5)?
beq $t0 $0, ENDLOOP #if index =5, break

#load A[index] into $a0
sll $t0, $s1, 2 #to = 1*4
add $t1, $s0, $t0 #t1 = address a[i]
lw $a0, 0($t1) #load a[i]

#call PRINT function
jal PRINT
#increment index
addi $s1, $s1, 1 #s1=s1+1
#goto top of loop
j LOOP

ENDLOOP:
#end program
li $v0, 10
```

```
syscall
PRINT:
#print integer stored in $a0
li $v0, 1
syscall #note, a0 has already been filled in before print
#return
jr $ra
```

5/11 Palindrome, High Low

Palindrome

> Exercise
>
> Palindrome.asm
>
> A program that prints contents of an integer array forward and backward.
>
> 1) Set initial index to zero
> 2) Select value at A[index]
> 3) Call print function to print char value
> 4) Push A[index] onto stack
> 5) Increment index
> 6) Repeat steps 3-5 for all items in array
> 7) Print all char values in stack

```
.data
A: .word 76 73 86 69
.text
main:
# Set $s0 to beginning of Array A
La $s0, A   # $s0 = address of A
#(index = $s1)  Initialize $s1=0
Li $s1, 0   # $s1 = 0

LOOP1:  #while index < 4
Slti $t0, $s1, 4            # $t0 = (index < 4)?
beq $t0, $0, ENDLOOP1       # If condition not met, break loop
    #load A[index] into $a0
sll $t0, $s1, 2         # $t0 = i * 4
add $t1, $s0, $t0    # $t1 = address of a[i]
lw $a0, 0($t1)      # load a[i]
```

```
#call PRINT function
Jal PRINT
#increment Stack pointer
addi $sp, $sp, -4   # $sp -=4
#push A[index] onto stack
sw $a0, 0($sp)      # push $a0 onto stack.

#increment index
Addi $s1, $s1, 1        # i++
#goto top of LOOP1
J LOOP1

ENDLOOP1:   # Initialize $s1=0
Li $s1, 0   # $s1 = 0

LOOP2:  #while index < 4
Slti $t0, $s1, 4            # $t0 = (index < 4)?
beq $t0, $0, ENDLOOP2       # breaks loop if condition not met.
#print character stored in top of stack via PRINT function
Lw $a0, 0($sp)      # $a0 = character on top of stack
Jal PRINT

#decrement Stack pointer
Addi $sp, $sp, 4        # moves stack pointer
#increment index
Addi $s1, $s1, 1        # i++
#goto top of LOOP2
J LOOP2

ENDLOOP2:
    #end program
    Li $v0, 10  # 10 = syscode for exit
    syscall

PRINT:  #print character stored in $a0
    Li $v0, 11  # 11 = syscode for PRINT Character
    syscall
    #return
    Jr $ra
```

HighLow

```
.data
STR1: .asciiz “Guess a number”
STR2: .asciiz “Congratulations”
STR3: .asciiz “Higher”
STR4: .asciiz “Lower”
SECRET: .word 42

.text
main:
# Load SECRET into $s0
La $t0, SECRET
```

```
lw $s0, 0($t0)
GUESS:  # Load String “Guess a number” into $a0
La $a0, STR1
    # Call PRINT function
Jal PRINT
    # Capture input into $s1
Li $v0, 5
syscall
move $s1, $v0

    # If SECRET = INPUT, goto WIN
Beq $s0, $s1, WIN
    # If SECRET < INPUT, goto LOW
Blt $s0, $s1, LOW
    # If SECRET > INPUT, goto HIGH
Bgt $s0, $s1, HIGH

WIN:    # Print Congratulations via function
    La $a0, Str2
    jal PRINT
    # End program
    Li $v0, 10
    syscall

HIGH:   # Print “Higher” via function
    La $a0, STR3
    jal PRINT
    # Goto GUESS
    J GUESS

LOW:    # Print “Lower” via function
    La $a0, STR4
    jal PRINT
    # Goto GUESS
    J GUESS

PRINT:  #print String address stored in $a0
Li $v0, 4
syscall
    #return
Jr $ra
```