Week 1

Some review material

How to succeed in this course

- Show up to lectures **&** tutorials
  - More material to cover than lecture time available
- Work on assignments evenly and collaborate
  - “Fill your partners in” and make sure you all understand *everything*.
- Compiler warnings!
  - In the past, automatic 10% penalty on assignments.

- SVN
  - `svn add` ; do a clean checkout and build (from scratch) before you submit your assignments
- Read assignments **<u>carefully</u>** ; lots of corner cases & design decisions to make
- Read the documentation
- Keep things modular
  - Make this part of your initial design
- Use the tools available to you & be **proactive** in learning them
  - Good for industry as well
- Design documents
  - More than line-by-line descriptions of your code
  - Explain the design (how/why); don't regurgitate the code

Architecture Review

CPU

- The Program Counter (PC)
- The Stack Pointer (SP)
- Data Registers
- Flow of normal execution
  - Memory address and load/store instructions
- Interrupts!

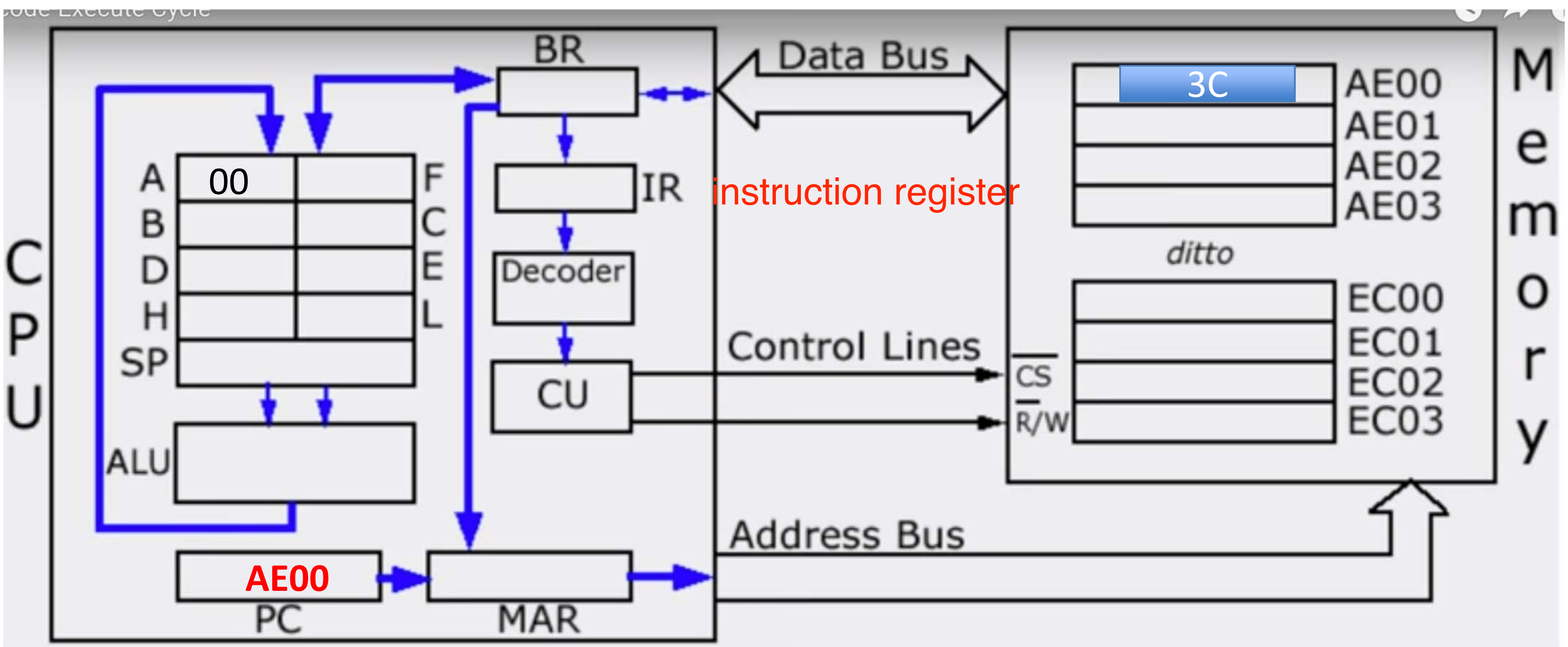
interrupts
1. hardware: (i.e. Ctrl C)
   + handled by interrupt handler
2. software: (sigaction)

fetch decode execute cycle

CPU

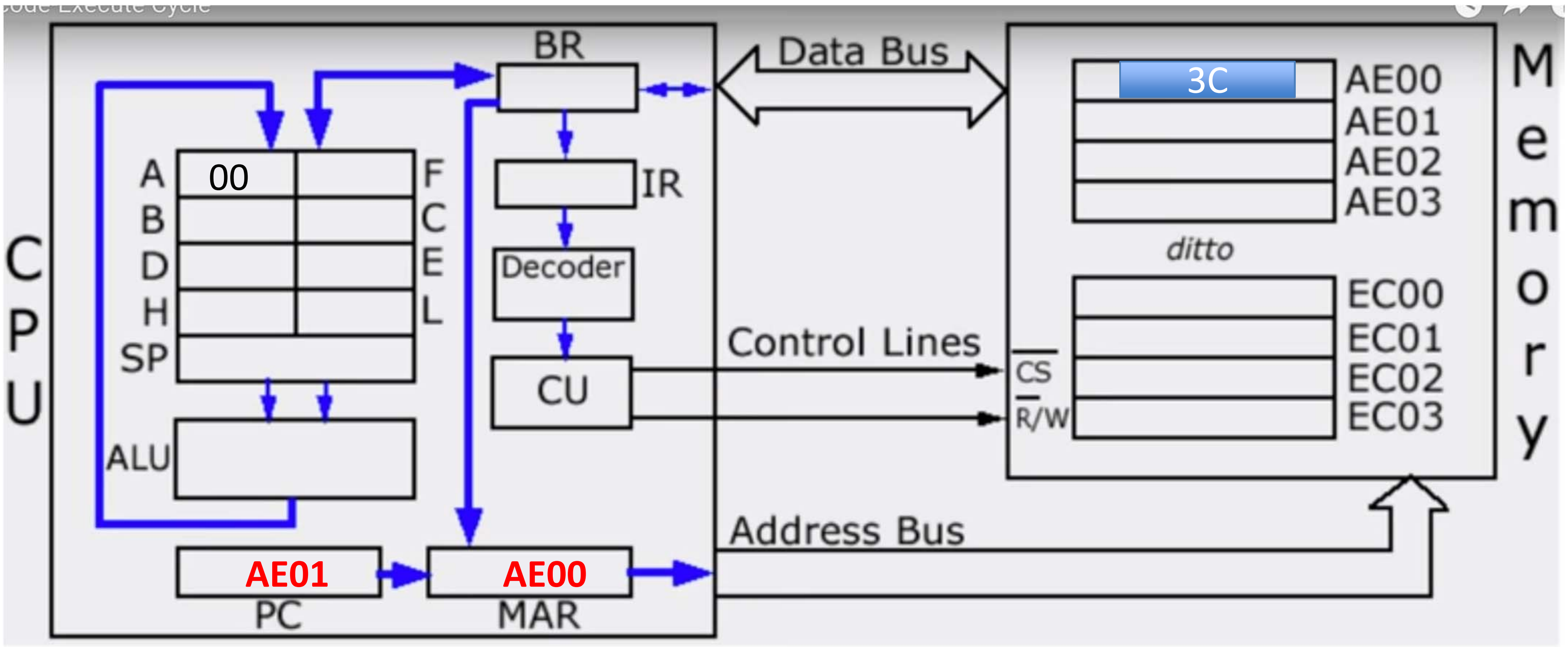
increment the value of A

INC A 0011 1100 3C



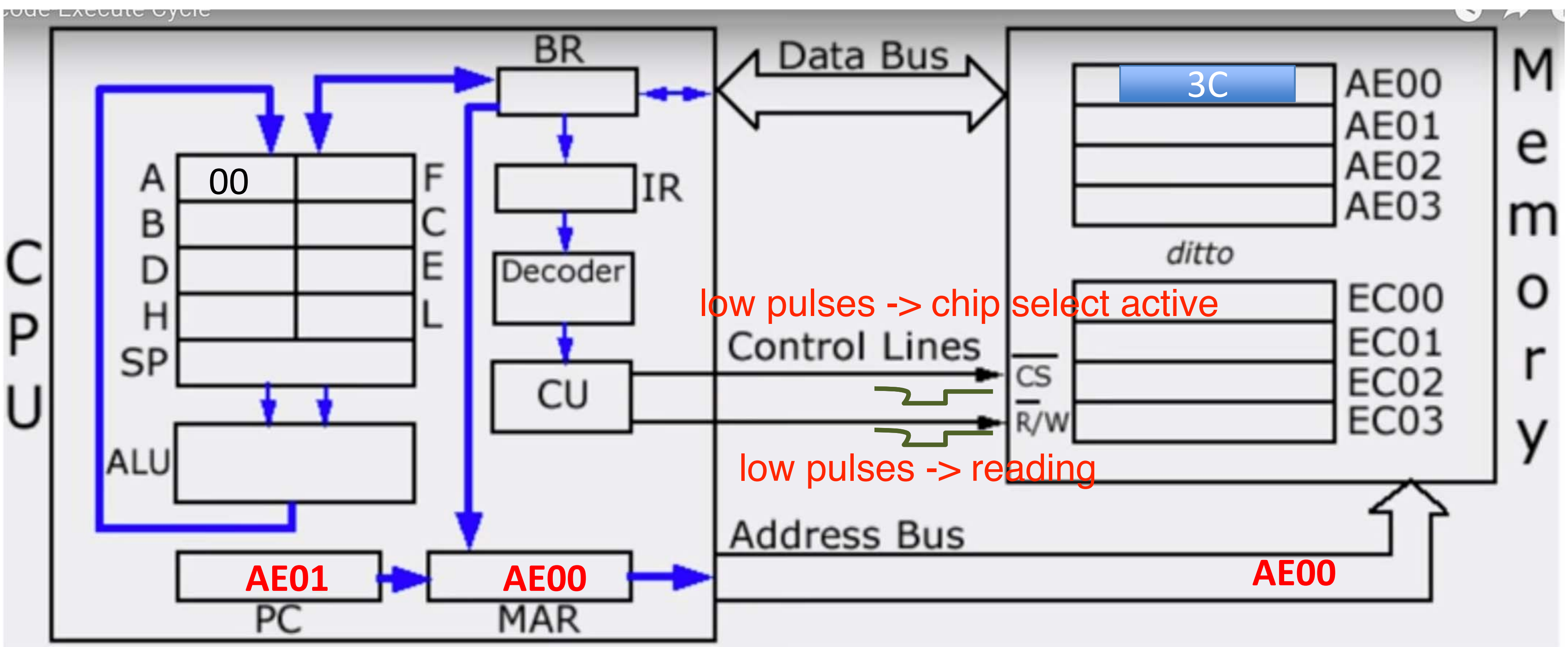
CPU

INC A   0011 1100   3C



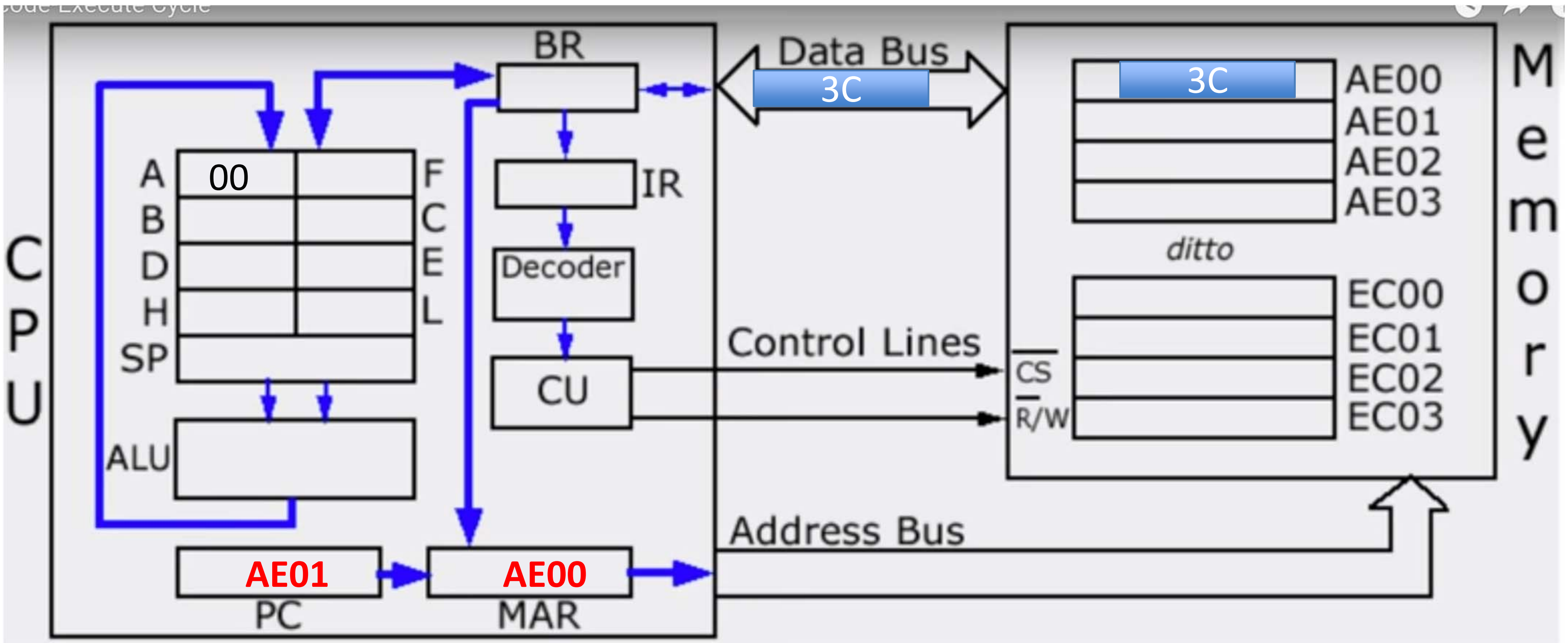
CPU

INC A 0011 1100 3C



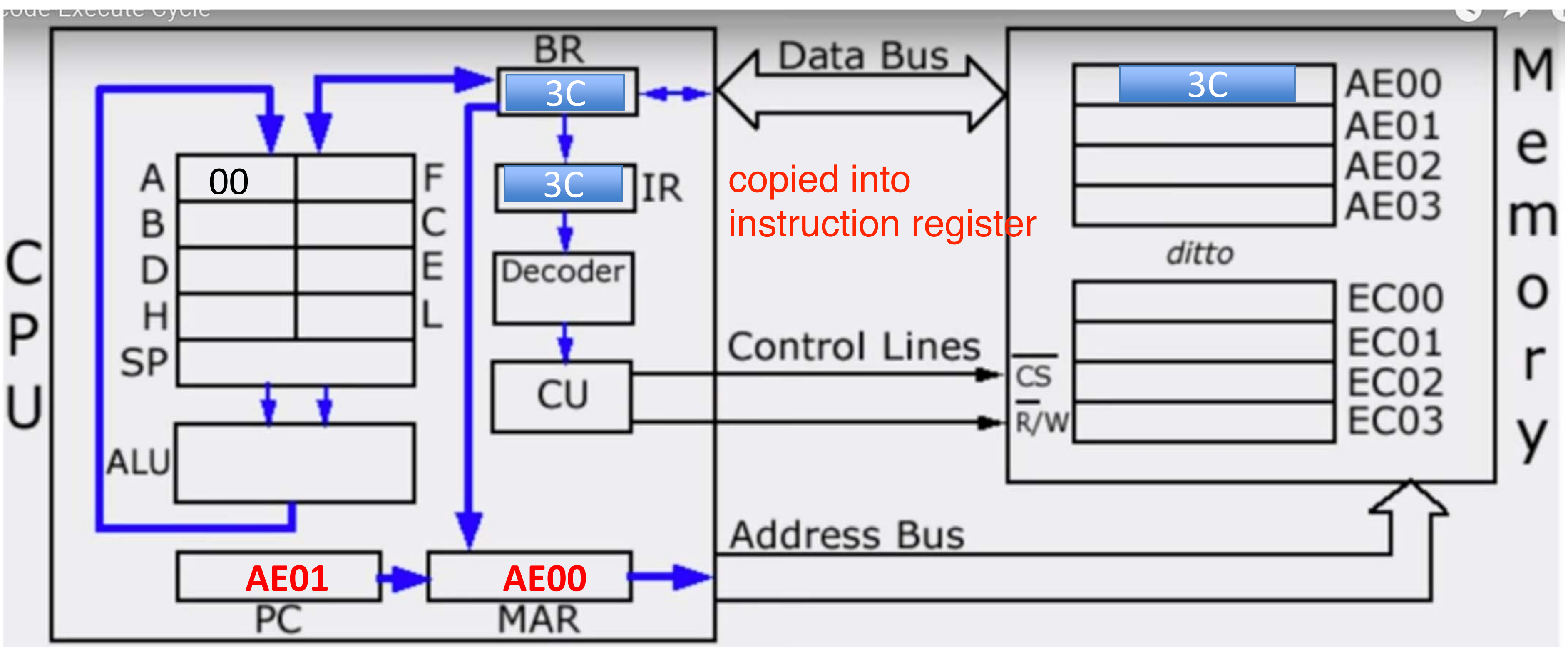
CPU

INC A 0011 1100 3C



CPU

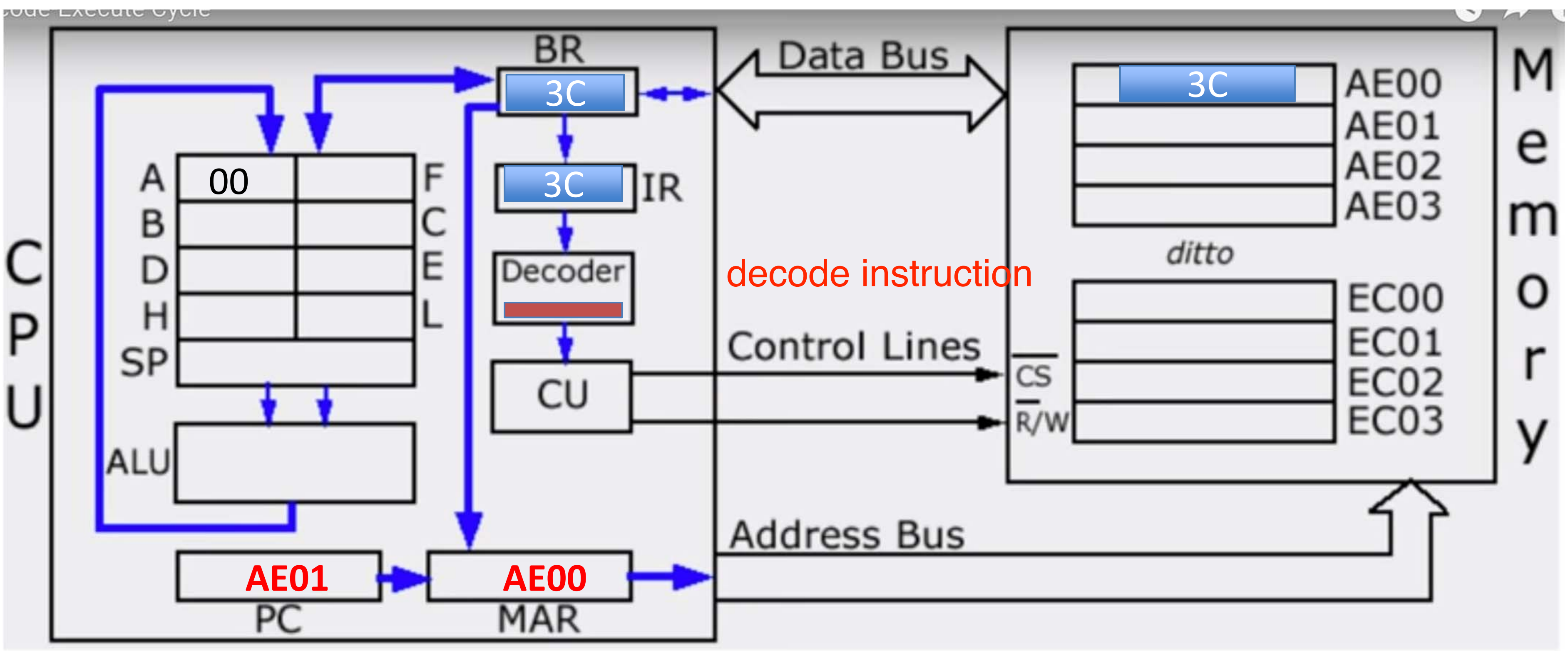
INC A   0011 1100   3C



End of FETCH

CPU

INC A   0011 1100   3C

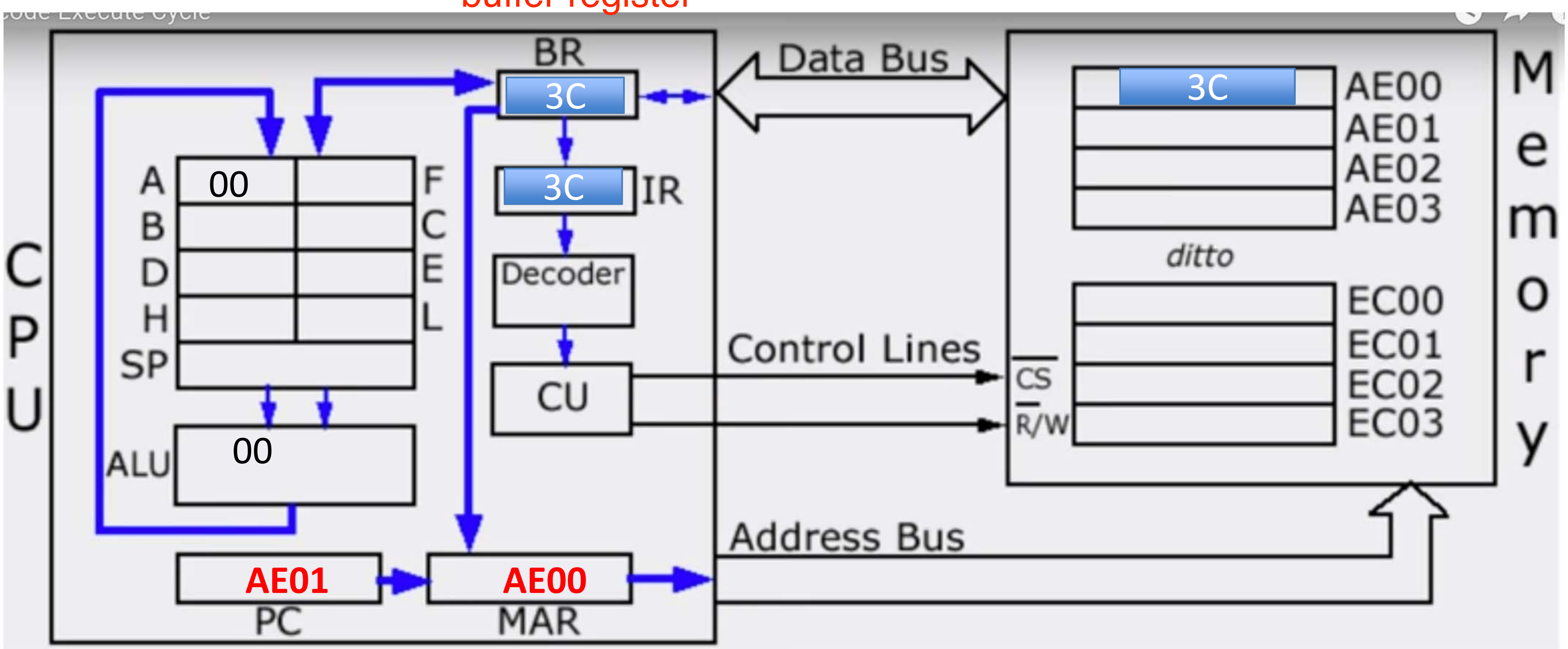


DECODE

CPU

INC A 0011 1100 3C

buffer register



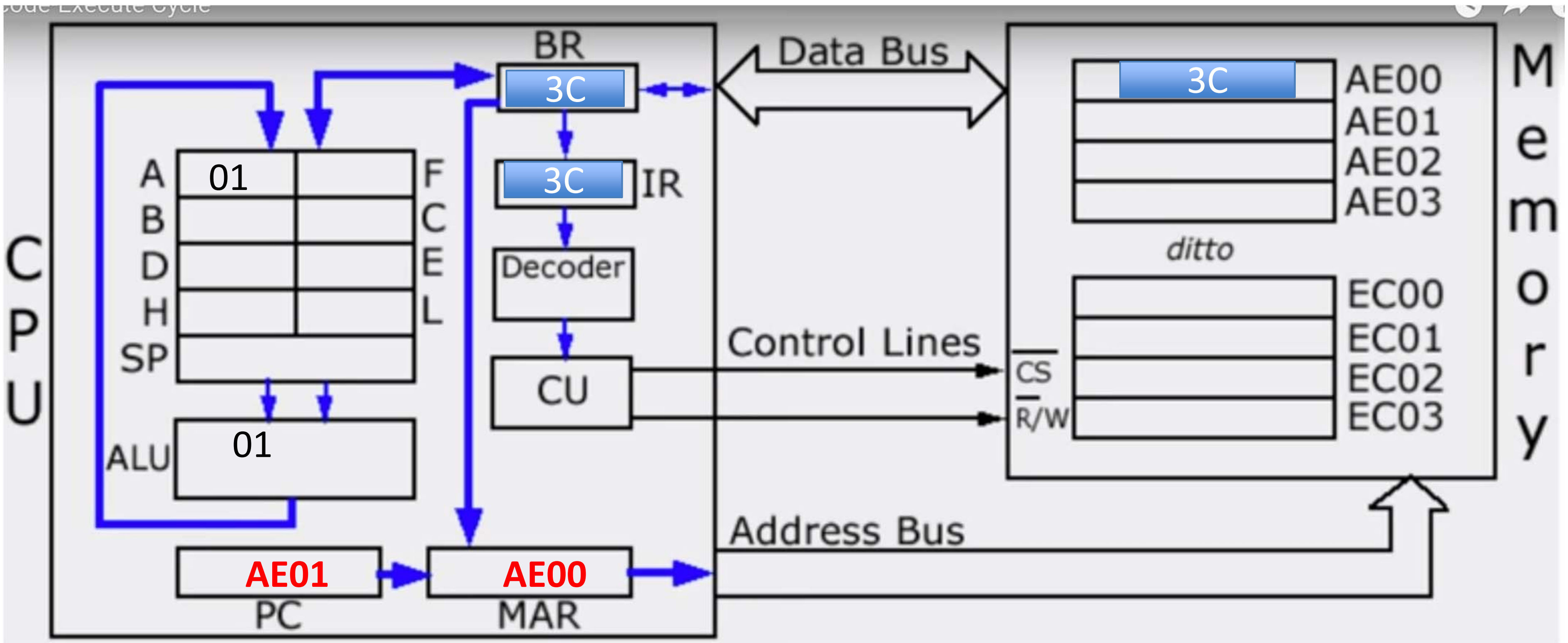
memory addr. register -> buffers PC value since PC incremented…

EXECUTE

bring content of register A, increment
and store back to register A

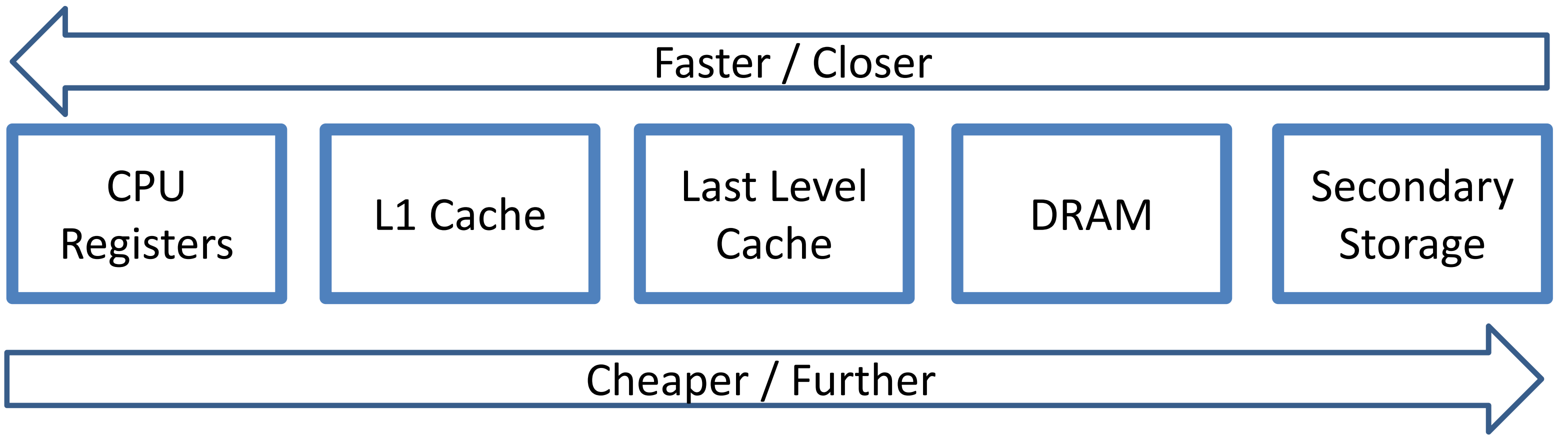
CPU

INC A   0011 1100   3C



EXECUTE

Memory Hierarchy and Trade-off



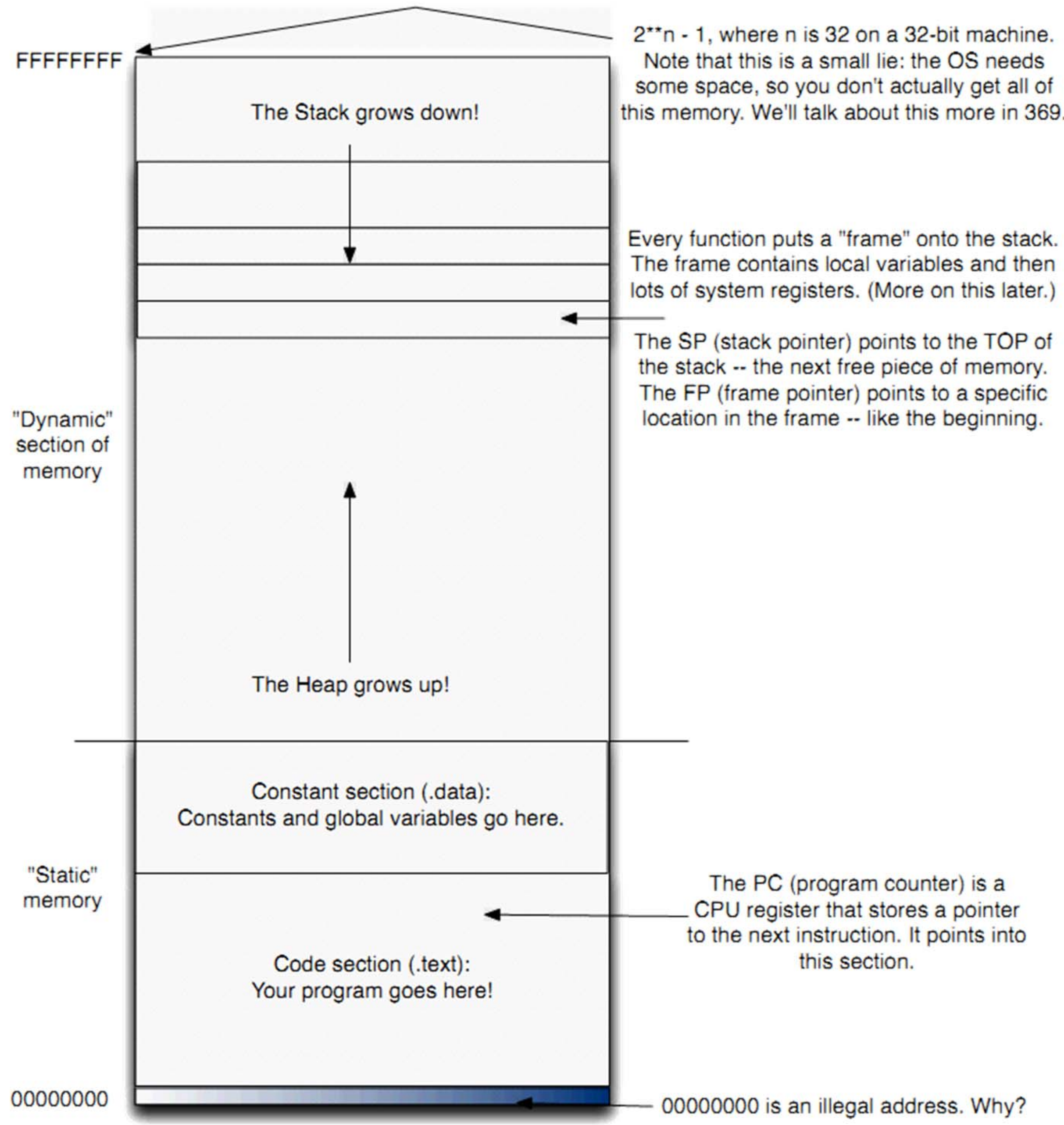
- Can’t have the fastest memory, largest capacity, and be the cheapest…
- OS must do smart things to efficiently use different types of memory (Caching)

OS optimizes memory usage

Memory

- Program sees linear address space, segmented
  - Code
  - Data
  - Stack
  - Heap
- Where does the OS go? OS in ram, inaccessible by other programs
- Do programs share the same space?

separate program have separate part of memory


FFFFFFFF
2**n - 1, where n is 32 on a 32-bit machine. Note that this is a small lie: the OS needs some space, so you don't actually get all of this memory. We'll talk about this more in 369.
The Stack grows down!
Every function puts a "frame" onto the stack. The frame contains local variables and then lots of system registers. (More on this later.)
The SP (stack pointer) points to the TOP of the stack -- the next free piece of memory. The FP (frame pointer) points to a specific location in the frame -- like the beginning.
"Dynamic" section of memory
The Heap grows up!
Constant section (.data):
Constants and global variables go here.
"Static" memory
The PC (program counter) is a CPU register that stores a pointer to the next instruction. It points into this section.
Code section (.text):
Your program goes here!
00000000
00000000 is an illegal address. Why?

Stack Frame of Function Call

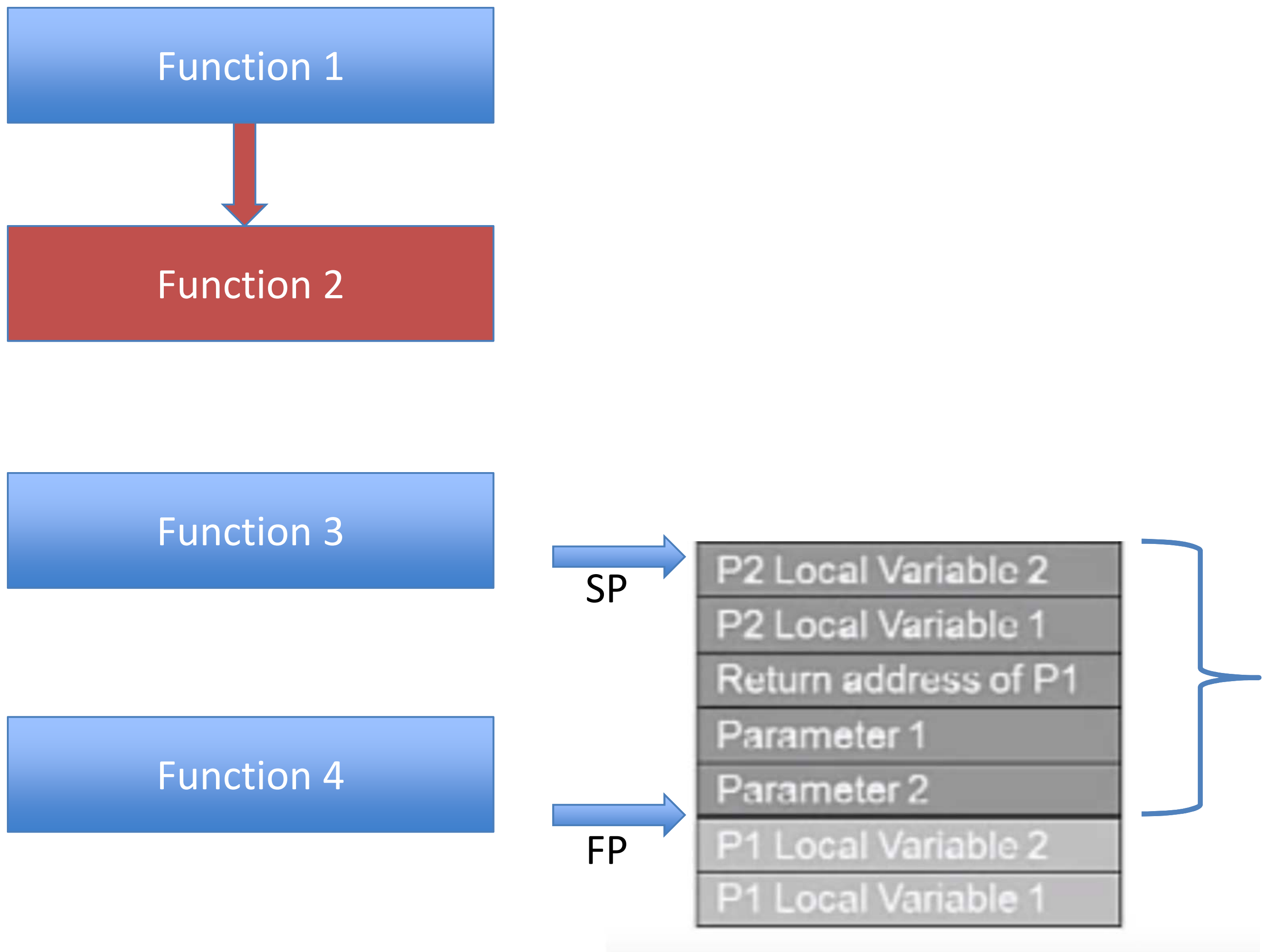
Function 1

Function 2

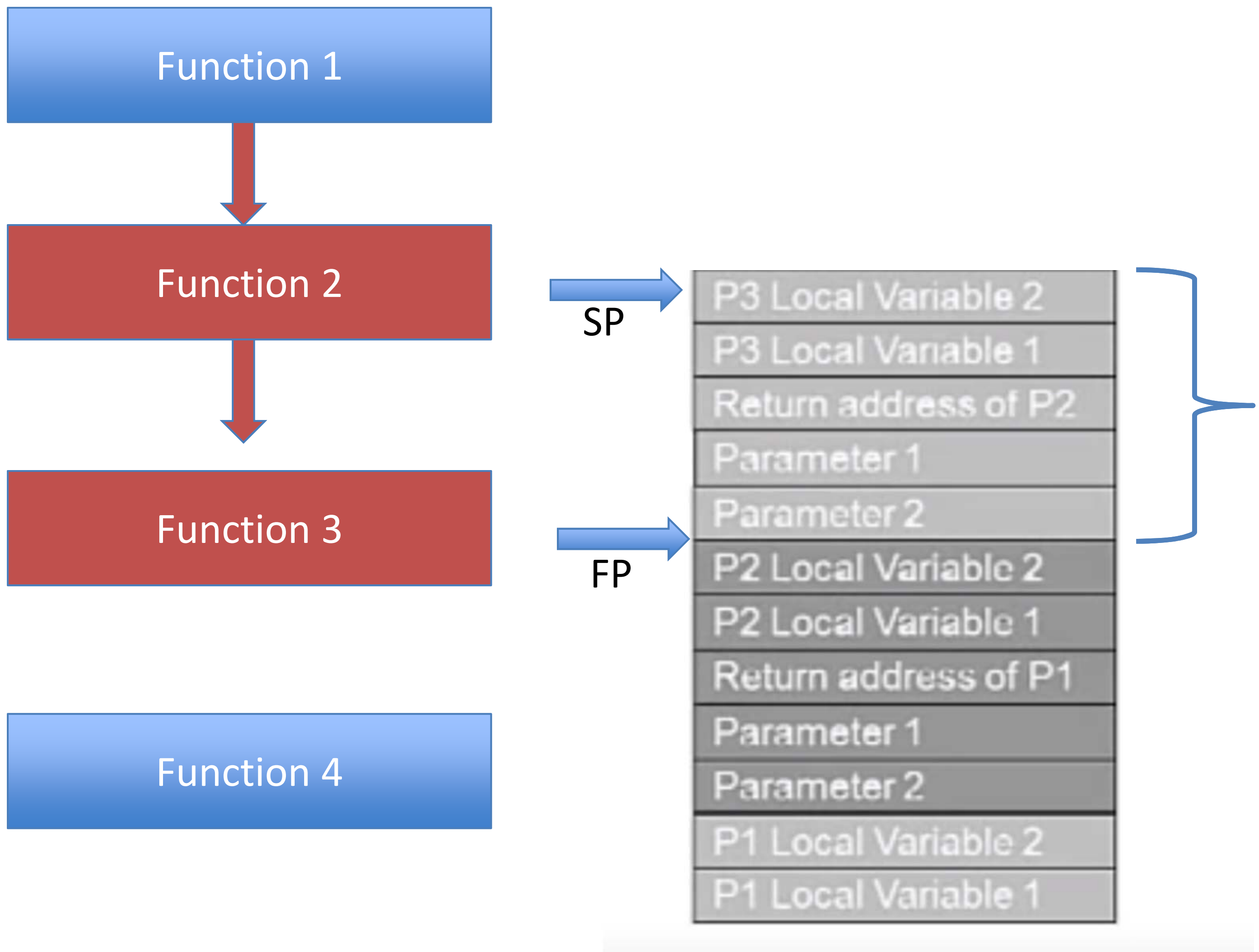
Function 3

Function 4

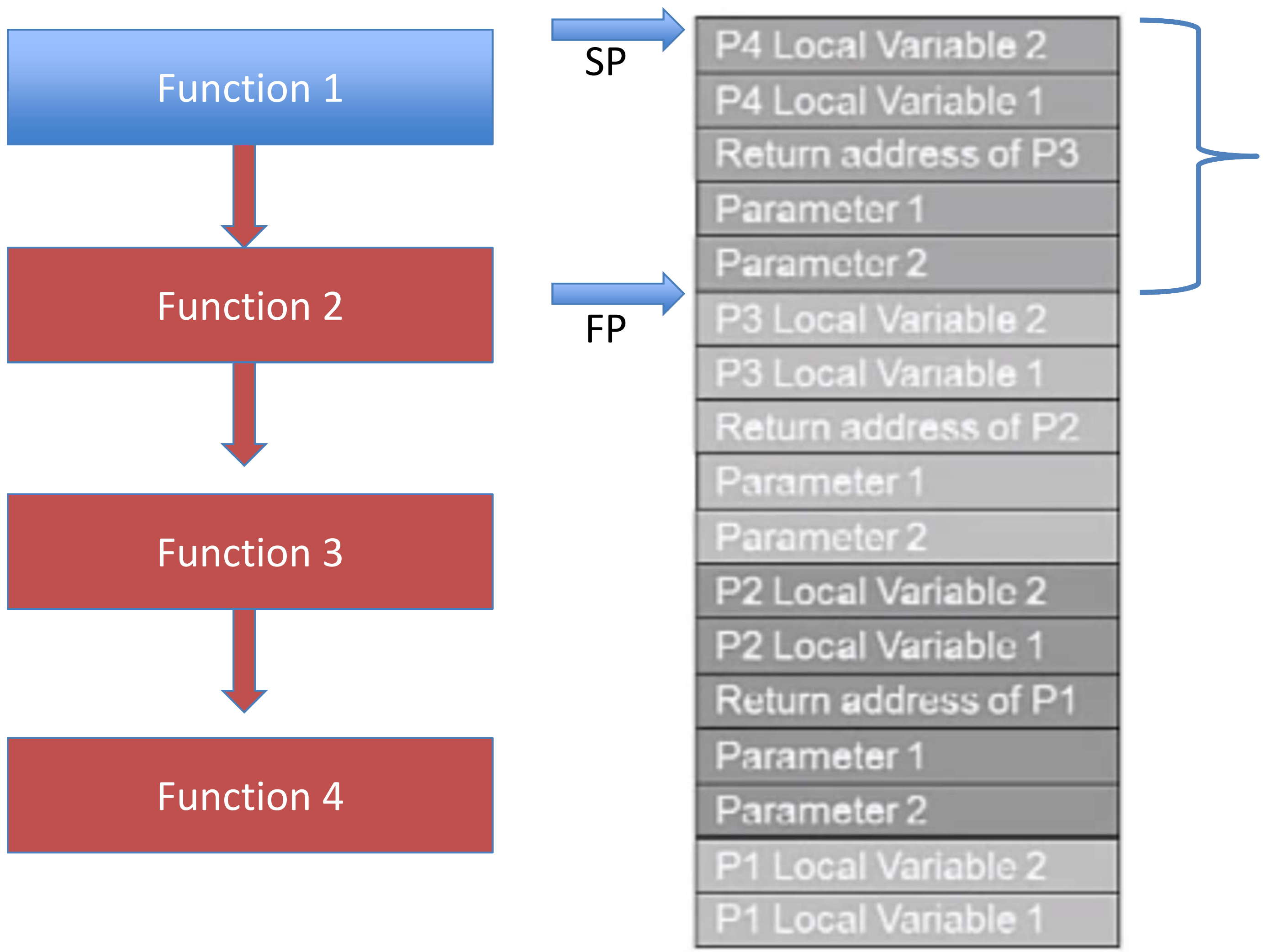
Stack Frame of Function Call



Stack Frame of Function Call

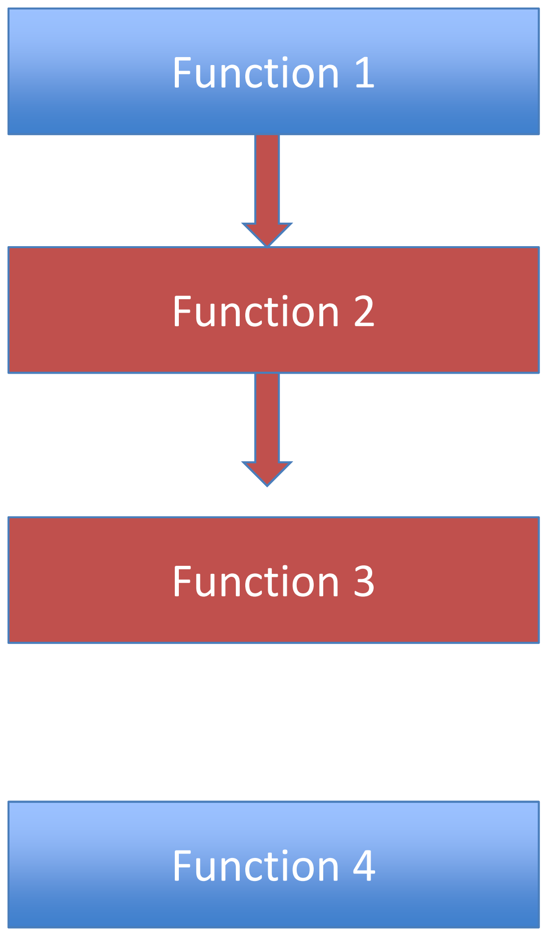


Stack Frame of Function Call

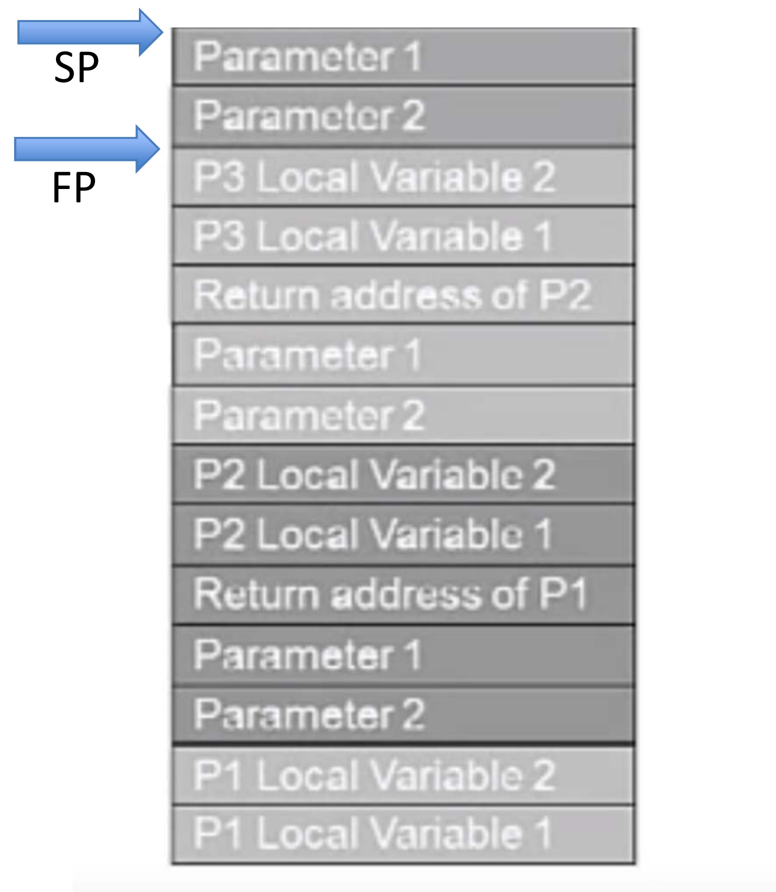


Returning

Stack Frame of Function Call



arguments to function 4
cleaned up by function 3

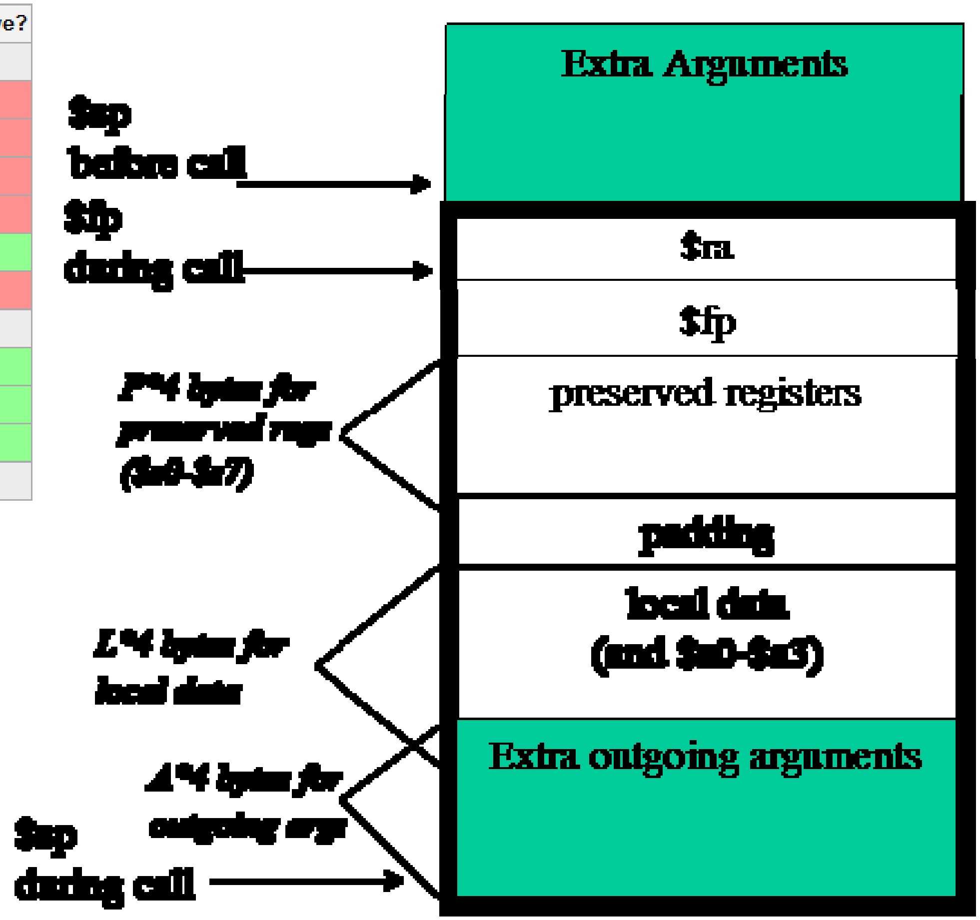


Stack Frames

Registers for O32 Calling Convention

Name	Number	Use	Callee must preserve?
$zero	$0	constant 0	N/A
$at	$1	assembler temporary	No
$v0–$v1	$2–$3	values for function returns and expression evaluation	No
$a0–$a3	$4–$7	function arguments	No
$t0–$t7	$8–$15	temporaries	No
$s0–$s7	$16–$23	saved temporaries	Yes
$t8–$t9	$24–$25	temporaries	No
$k0–$k1	$26–$27	reserved for OS kernel	N/A
$gp	$28	global pointer	Yes
$sp	$29	stack pointer	Yes
$fp	$30	frame pointer	Yes
$ra	$31	return address	N/A

- First 4 arguments: $a0-$a3
- Return value (or pointer to it): $v0
- Return address: $ra
- Frame pointer: $fp



http://www.cs.ucsb.edu/~franklin/30/spim/BookCallConvention.htm

C REVIEW

Some C Review!

- Go through these slides (and try the exercises…) at home!
- Brush up / learn what you don’t know now!
  - Assignments are work-intensive enough as it is…
- Topics: Bit manipulations, pointers, argument-passing, arrays, pointer arithmetic, memory allocation, error handling, etc.

Pointers

- Every variable has a memory address
  - Can be accessed with “address of” operator : &
- Pointers are variables that store memory addresses
  - int x = 42;
  - int *x_ptr = &x;
  - int *heap_ptr = (int *)malloc(sizeof(int));
- The value a pointer refers to can be accessed with *
  - This is “dereferencing”
    - int y = *x_ptr;

NULL

- NULL is the “0” value for addresses.
  – It’s a good idea to initialize pointers to NULL.
    - Much easier to catch bugs!
  – It’s often used as an error value, too.

Pass by Value / Reference

- C only allows one value (which may be a struct) to be returned.
- If variables are passed into a function **by value**, any changes to them will not be seen outside the function.
  - Why? A copy of each parameter is made on the stack, and changes are made to the copy.
- If pointers are passed into a function, any changes made to the values they point to will be seen -- this is passing **by reference**.
  - Note that the pointers themselves are still passed by value!

Arrays

- Arrays contain multiple variables of the same type.
- Each element can be accessed with [] notation.

```
int x_arr[10];
for (i = 0; i < 10; i=i+1)
  x_arr[i] = i;
```

- Arrays are ... almost the same as pointers.

  After "int *x_ptr = x_arr;" x_ptr[i] is just like x_arr[i]

  - Differences:
    - sizeof(x_ptr) = 4 (sizeof(int*)), whereas sizeof(x_arr) = 40 (10*sizeof(int))
    - You can't change an array var. to point to a different array by default
  - Note: arrays are passed to a function as a **pointer**, **not** an array-typed variable

Pointer Arithmetic

- Pointers are just values, so you can manipulate them.
- If x is an array, this is true:

  x[5] == *(x + 5)
- The key? Constants added to pointers are "scaled" by the size of the type. Adding 5 to an (int *) adds 5 * sizeof(int).
- And also, strangely, this is true (on most systems):
  - 5[x] == x[5]

Pointers and Structs

- Structs are one "aggregate" structure in C.
  - A struct can contain multiple variables in a single
  - package.
- Structs have a syntactic quirk:
  - If you have a struct variable, use "."

    struct mystruct s= ...

    s.myfield = 6;
  - If you have a struct pointer, use "->"

    struct mystruct *s_ptr = ...

    s_ptr->myfield = 6;

    (*s_ptr).myfield = 6;

Allocating Memory

- malloc allocates memory from the heap
  - It allocates by byte, so it requires a size
  - Its return value must be typecast
    int *heap_ptr = (int *)malloc(sizeof(int) * 4);
- Don't forget to "free" memory you "malloc"!
- Remember to use "kernel" versions of the calls if you're working inside the kernel
  - Instead of malloc, kmalloc
  - Instead of free, kfree

Stack Allocation

- Heap allocation isn't always necessary
- Also might cause a memory leak (if not careful…)

```
int foo() {
      struct mystruct z;
      z.x = 1;
      return funcwithmystruct(&z);
}   ….. NOT

int foo() {
      struct mystruct* z = malloc(sizeof(struct mystruct));
      int rval = -1;
      z->x = 1;
      rval = funcwithmystruct(z);
      free(z);
      return rval;
}
```

Stack versus Heap trade-off

- Stack allocation is “easy,” but stack sizes are limited. (1-4MB for a “regular” system, and only **4KB** for a kernel thread running on sys161)
  - This means any array or struct with more than a handful of elements should be heap allocated.
  - Additionally, **no recursion** in kernel threads!
- Heap allocation is “harder,” but gets around these limitations. Why is it harder?
  - Have to remember to free any malloc/calloc’d mem.!
  - Can’t free a memory location more than once!

Don’t Leak Memory!

- Make sure to free memory you allocate
- This example shows an error case

```
struct mystruct* sys_mystruct() {
    struct mystruct* first;
    first = malloc(sizeof(struct mystruct));
    if( first == NULL ) {
        return -1;
    }
    first.other = malloc(sizeof(struct otherstruct));
    if ( first->other == NULL ) {
        return -1;
    }
    return first;
}
```

didnt free first should allocation for otherstrut fail

More C Quirks to Remember

- Uninitialized variables always initialize
  - … have undetermined value (and C won’t complain)
- Array bounds
- Runtime exceptions
  - … don’t exist!
  - Instead, functions return, e.g., “-1” or “0”
- Type casts
  - … are not checked at runtime! (can cast char to int*)
  - “Dangerous,” but you’ll need to do it sometimes.
- Memory can be corrupted without the program crashing: check your bounds!

C Error Messages

- Segmentation Fault:
  - A pointer has accessed a location in memory that is not in a segment you own.
  - Maybe an infinite loop: overran an array?
  - Forgot to initialize a pointer and dereferenced it?
  - Adding two pointers that shouldn't be?
  - Note: segfaults can be sporadic, since you have to step outside the (rather large) segment to get one.
- Bus Error:
  - A pointer is not properly aligned.
  - Bad casting? Bad pointer arithmetic?

General Tips

- Simplify whenever possible

```
struct mystruct myarray[10][10];
        is better than
struct mystruct **myarray;
```

- Declare all functions ahead of time
- Use a test-oriented **incremental** development strategy
  - Test first and frequently

C: bit manipulation

- Sometimes we need to alter bits in a byte or word of memory directly
  - A 32-bit int is a very compact way to represent 32 different boolean values
- C provides bitwise boolean operators
  - “&” : AND
  - “|” : OR
  - “~” : NOT (or complement)
  - “^” == XOR (exclusive OR)

Practice with bit ops

a	0110 1001
b	0101 0101
~a	
~b	
a & b	
a | b	
a ^ b	

Bit Masks

- A mask is a bit pattern that indicates a set of bits in a word
  - E.g., 0xFF would represent the least signficant byte of a word   1byte = _ _ 1111 1111 (least sig byte is 0xFF)
  - For a mask of all 1's, the best way is ~0
    - Portable, not dependent on word size
    - For 32-bit machines, 0xFFFFFFFF will work
    - You may also see -1 used (2's complement, -1 is a bit pattern with all bits set to 1)

Practice with bit masks

- Given an integer x, write C expressions for:
  - Set n-th bit of y:
    - int y |= 1 << n
  - L.s.b unchanged, toggle all other bits of y:
    - int y ^= 0xfff0

Practice with bit masks

- Given an integer x, write C expressions for:
  - Least significant byte of x, all other bits set to 1:
    - int y = ____
  - Complement of the l.s.b. of x, all other bytes unchanged:
    - int y = ____
  - All but l.s.b. of x, with l.s.b. set to 0
    - int y = ____

Bit Shifting

- x << k : shift the bits of x by k bits to the left, dropping the k most significant bits and filling the rightmost (least significant) k bits with 0

- Example: 6 << 1 = 12

Before: 00000000 00000000 00000000 00000110

After: 00000000 00000000 00000000 00001100

Equivalent to multiplying by 2^k

Bit Shifting

- Shifting is *non circular*
- E.g 3,758,096,384 << 1

- Before: 11100000 00000000 00000000 00000000
- After : 11000000 00000000 00000000 00000000

- What if k is >= size of object? (e.g., for int’s, on 32-bit machine, k >= 32)
    - UNDEFINED! Don’t assume the result will be 0

Bit Shifting

- x >> k   right shift, logical or arithmetic
  - logical right shift - fill left end with k 0’s (unsigned types)
  - arithmetic right shift (care about signed bit) - fill left end with k copies of the most significant bit
    - C does not define when arithmetic shifts are used! Typically used for signed data, but not portable

- Example -2,147,483,552 >> 4

- Before: 10000000 00000000 00000000 01100000
- Arithm: 11111000 00000000 00000000 00000110
- Logical: 00001000 00000000 00000000 00000110

Exercise 1

In groups (max 3)