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 **carefully** ; 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!

CPU

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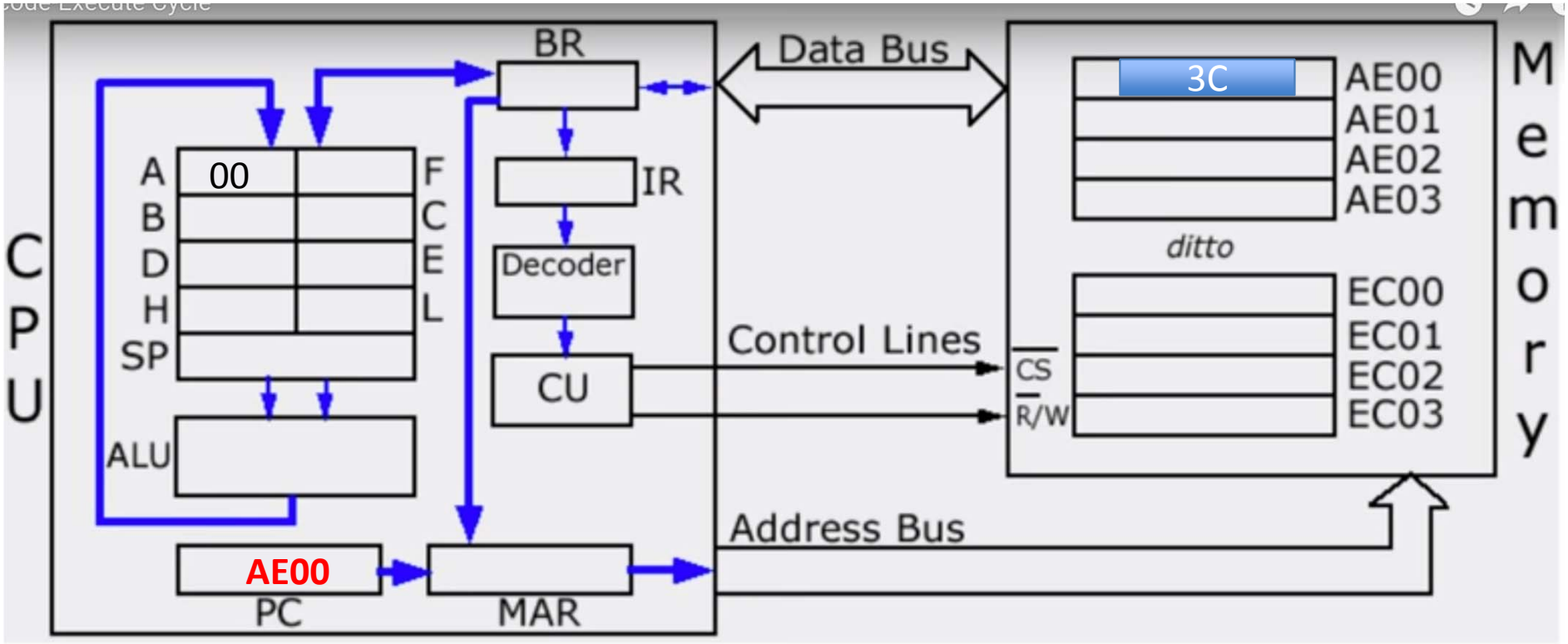

CPU

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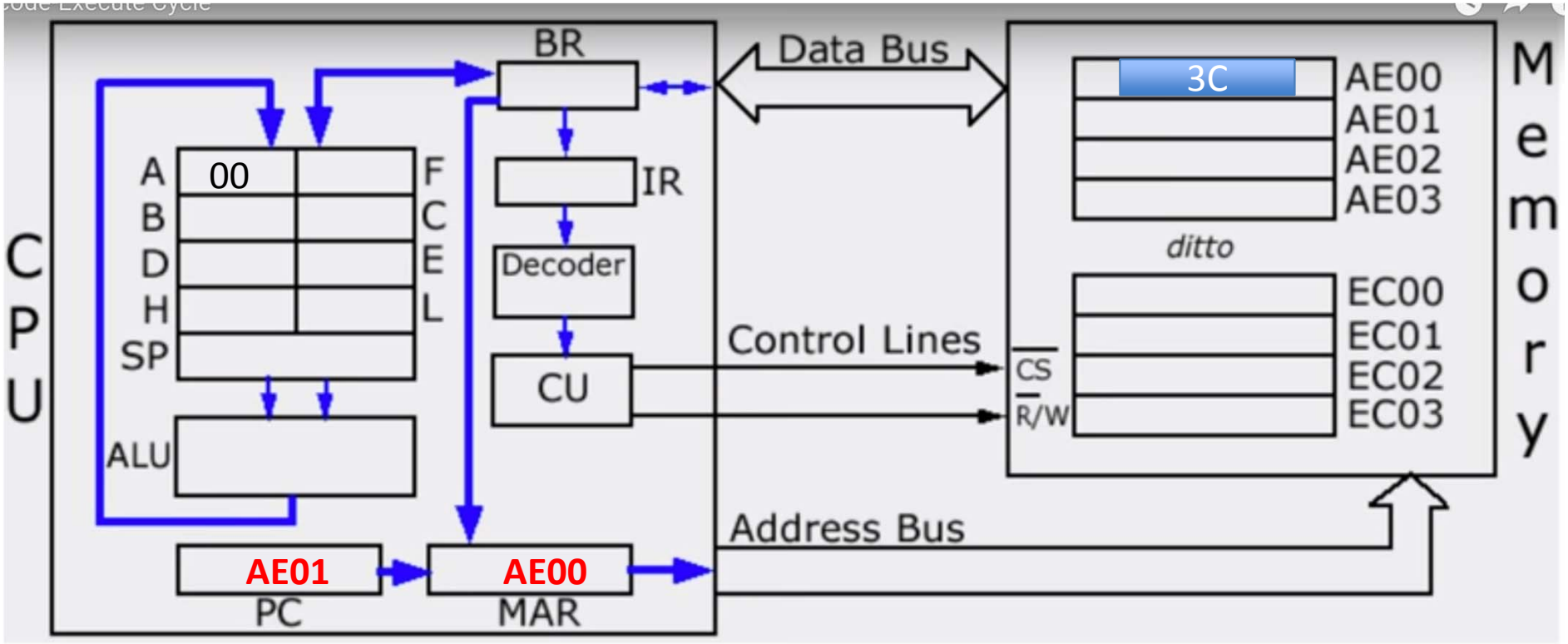

CPU

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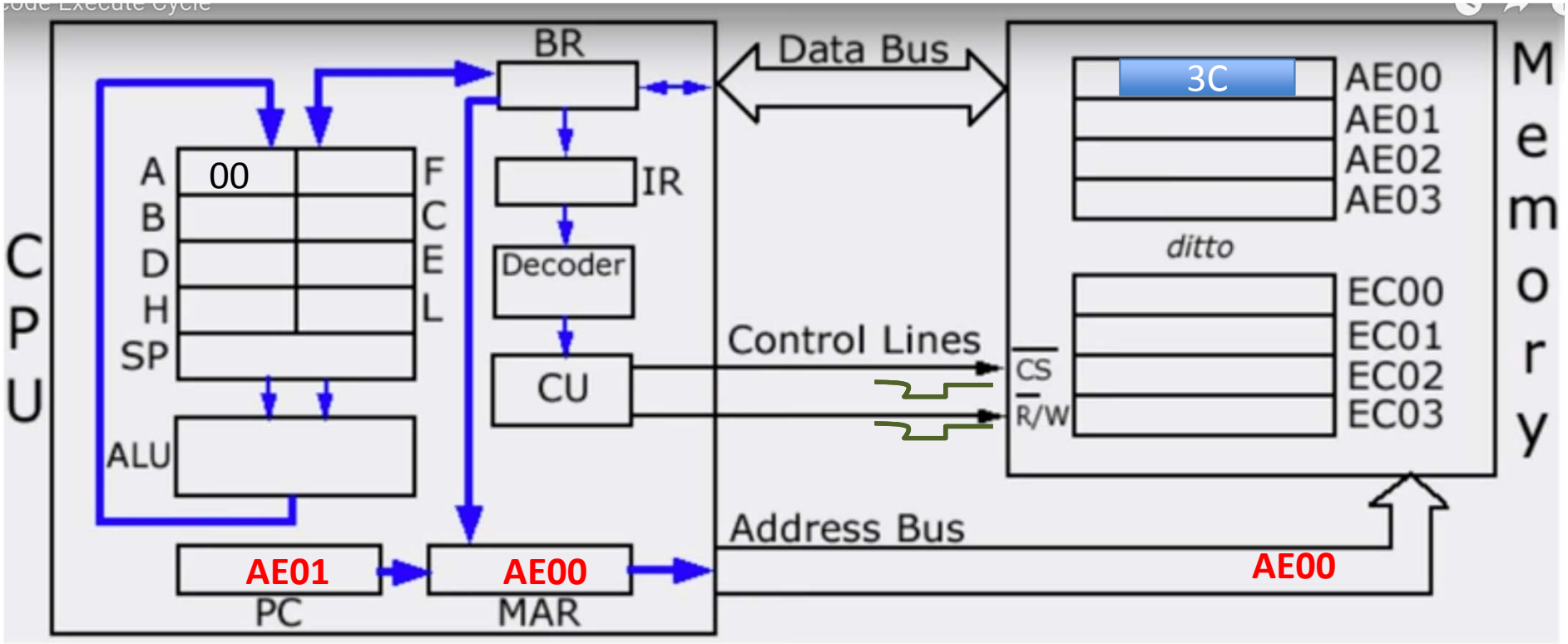

CPU

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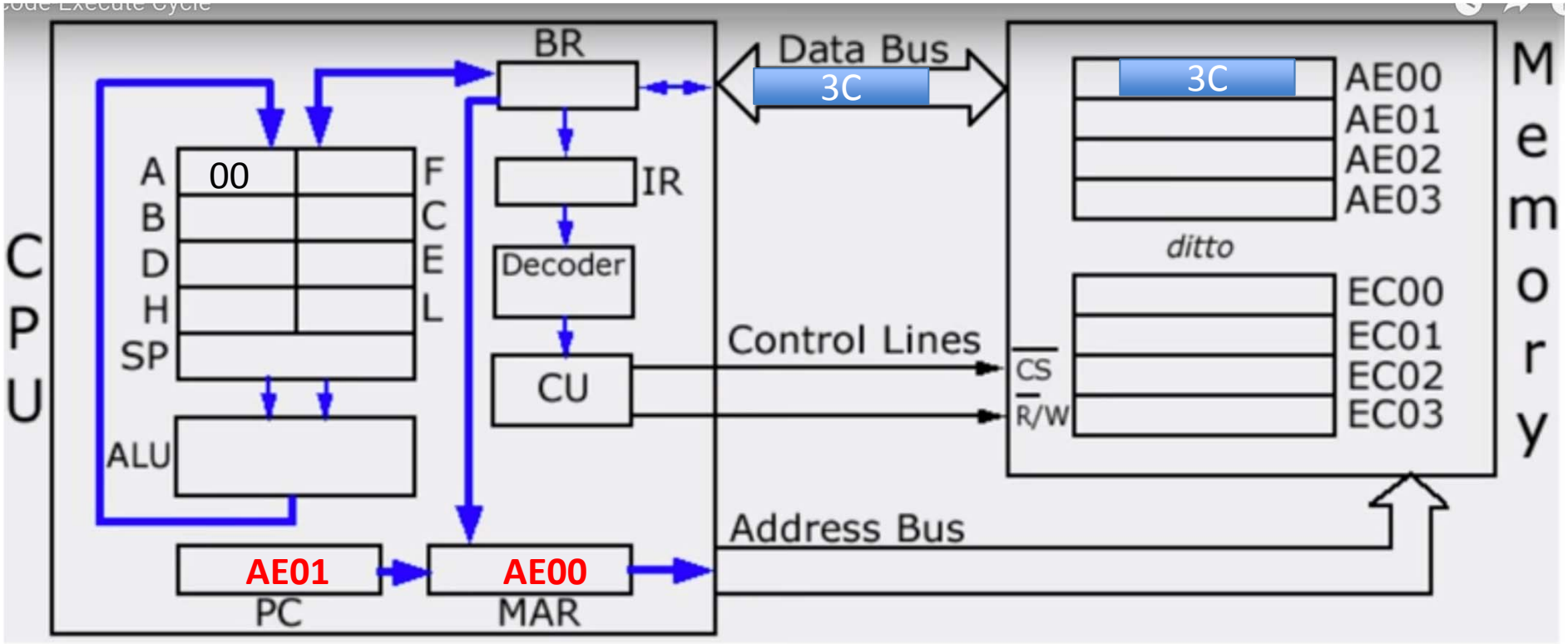

CPU

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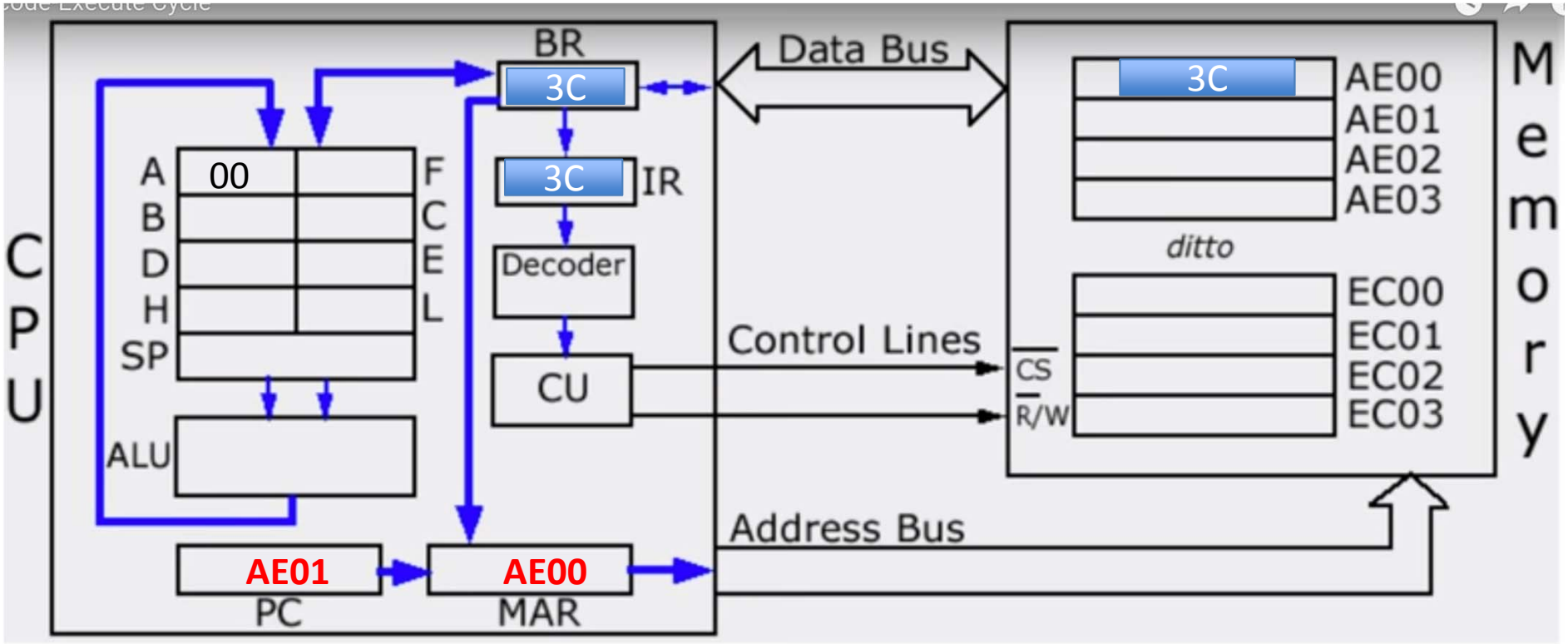

End of FETCH

CPU

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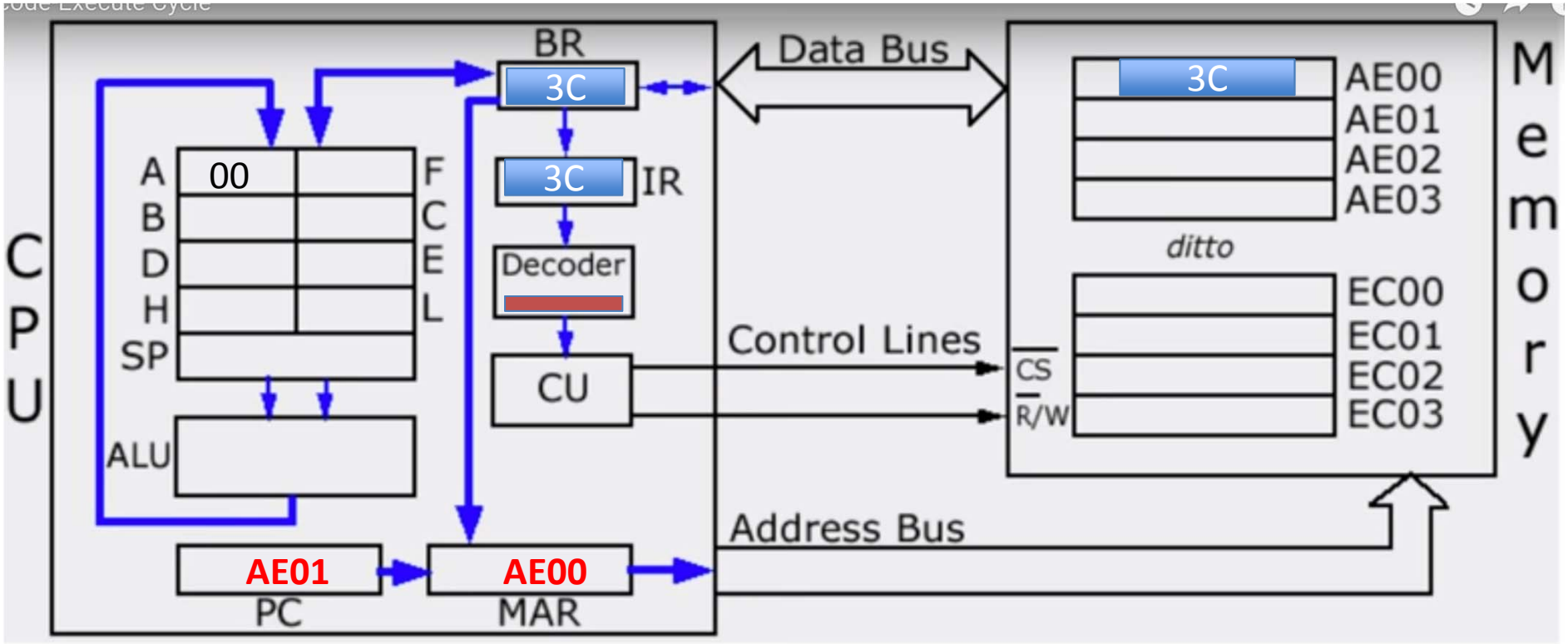

DECODE

CPU

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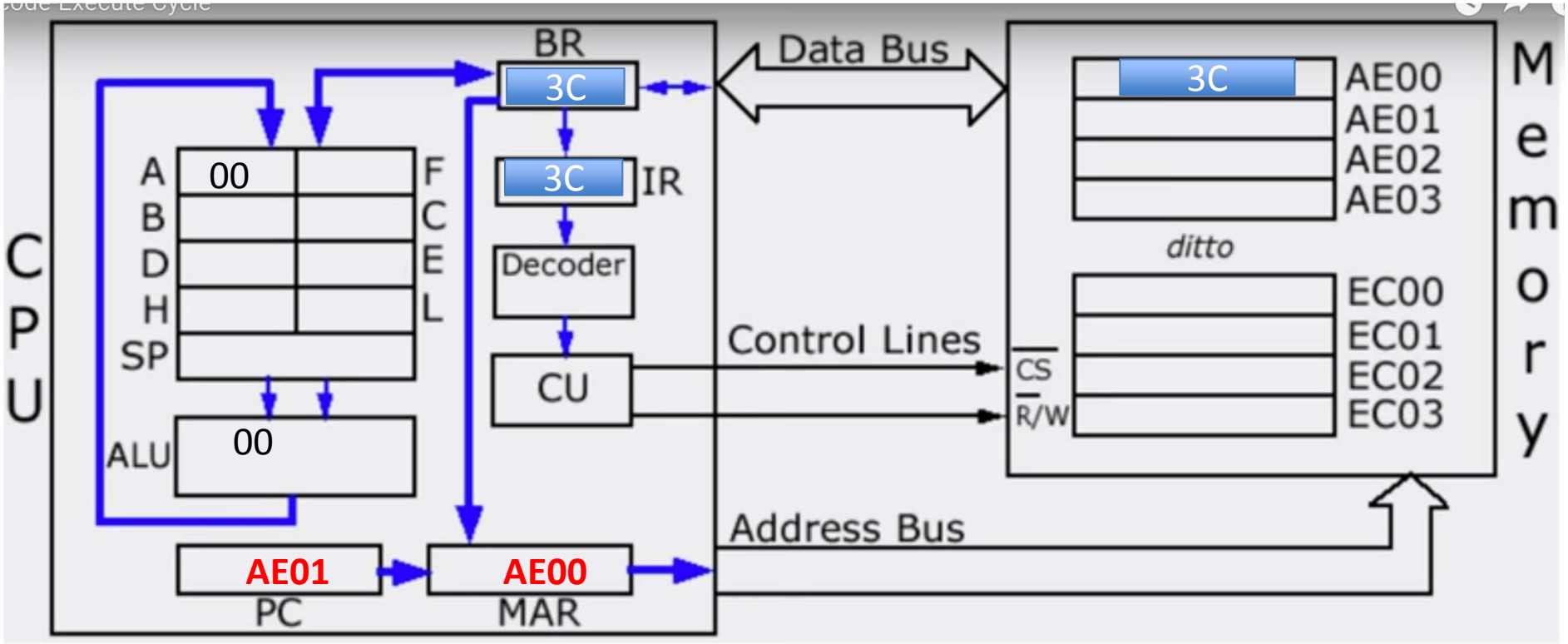

EXECUTE

CPU

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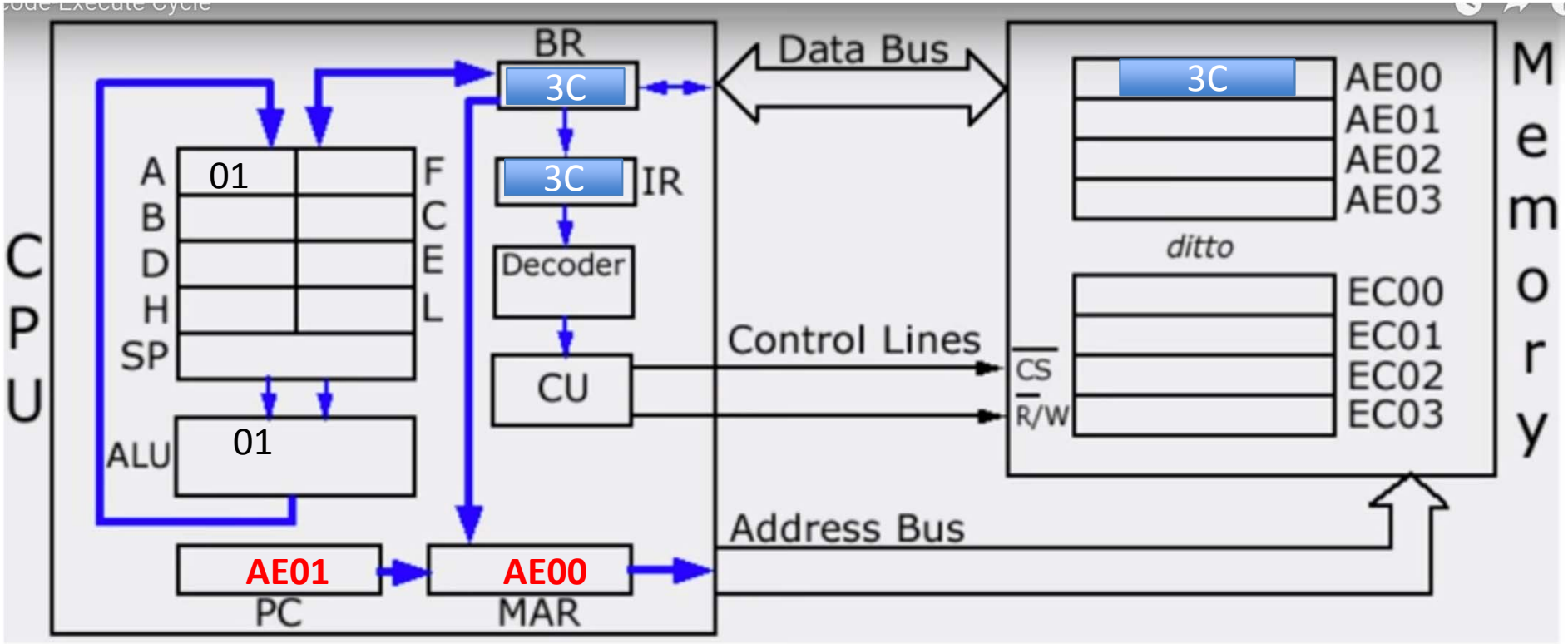
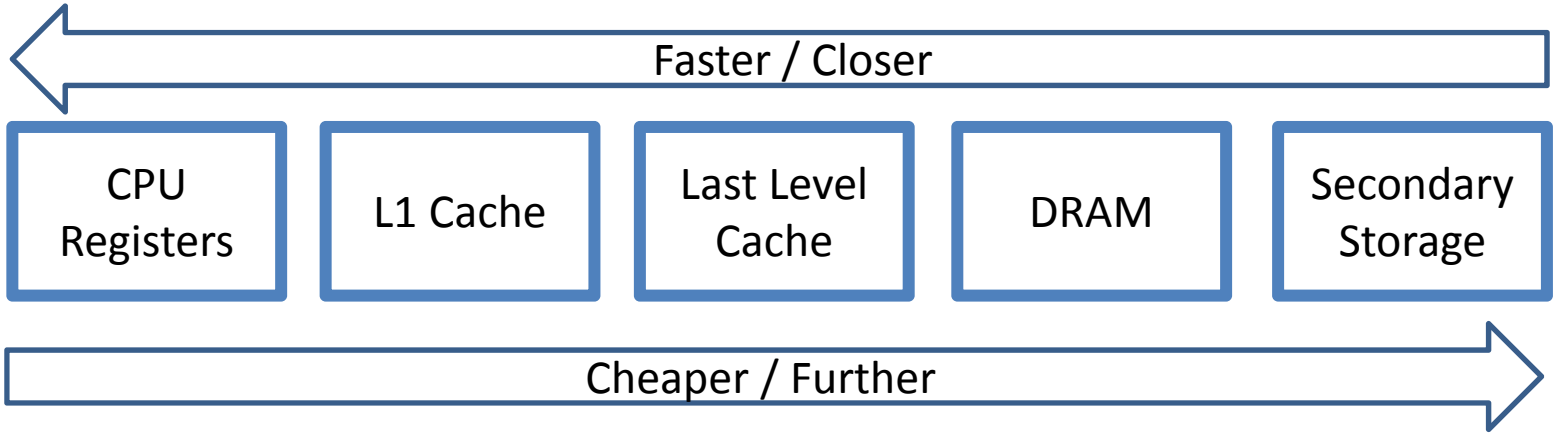


EXECUTE

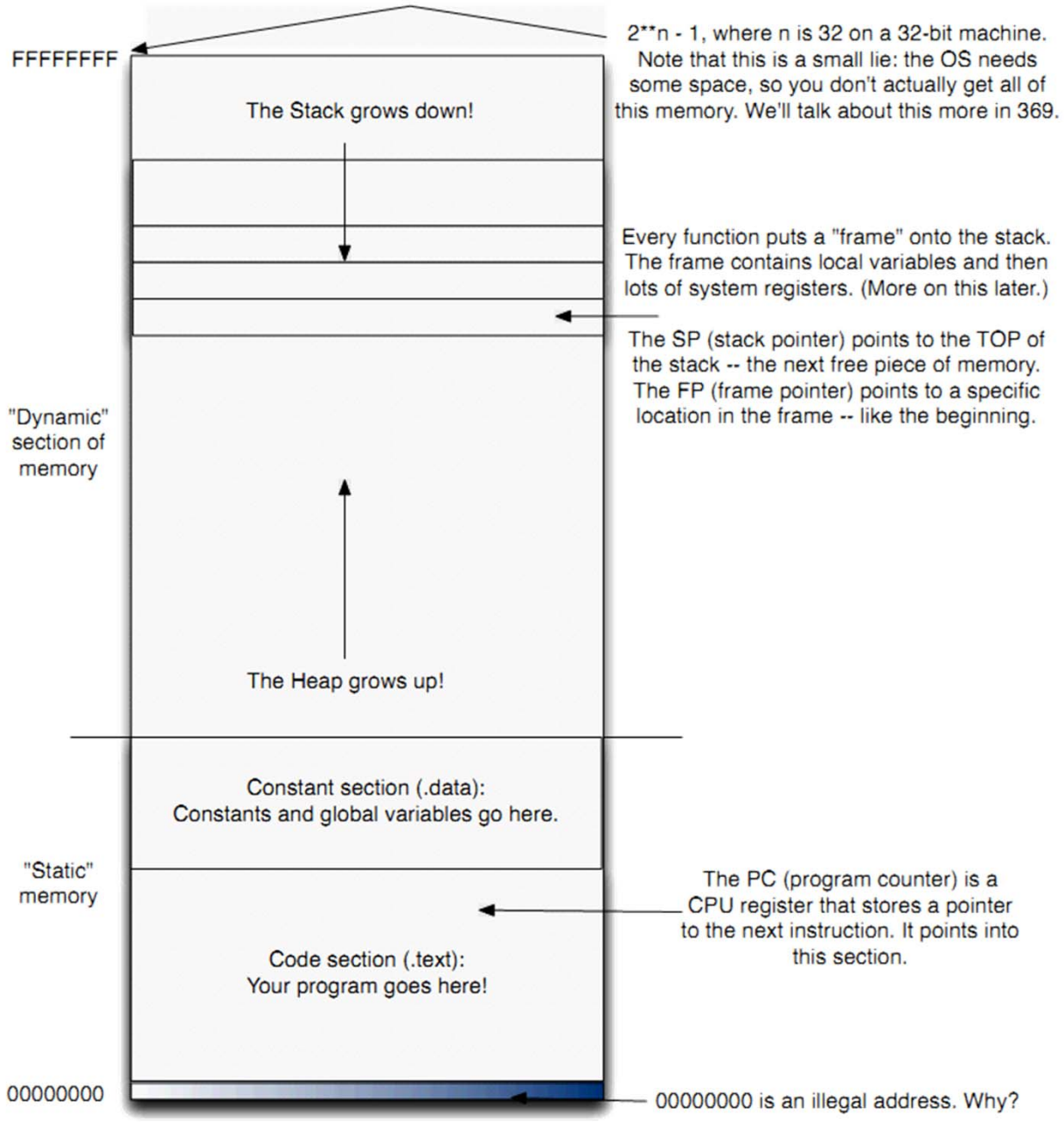
Memory Hierarchy and Trade-off



- 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)

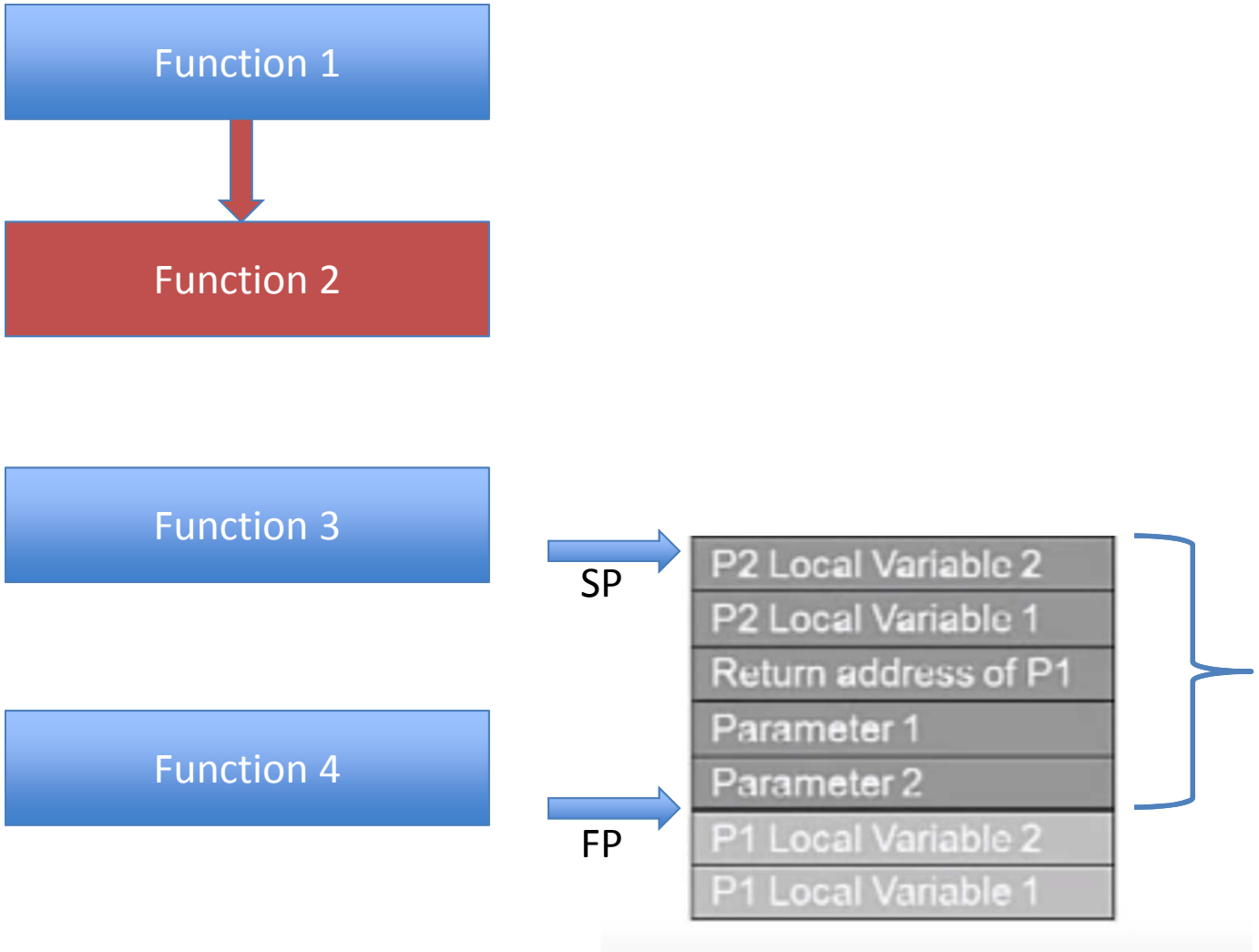
Memory

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

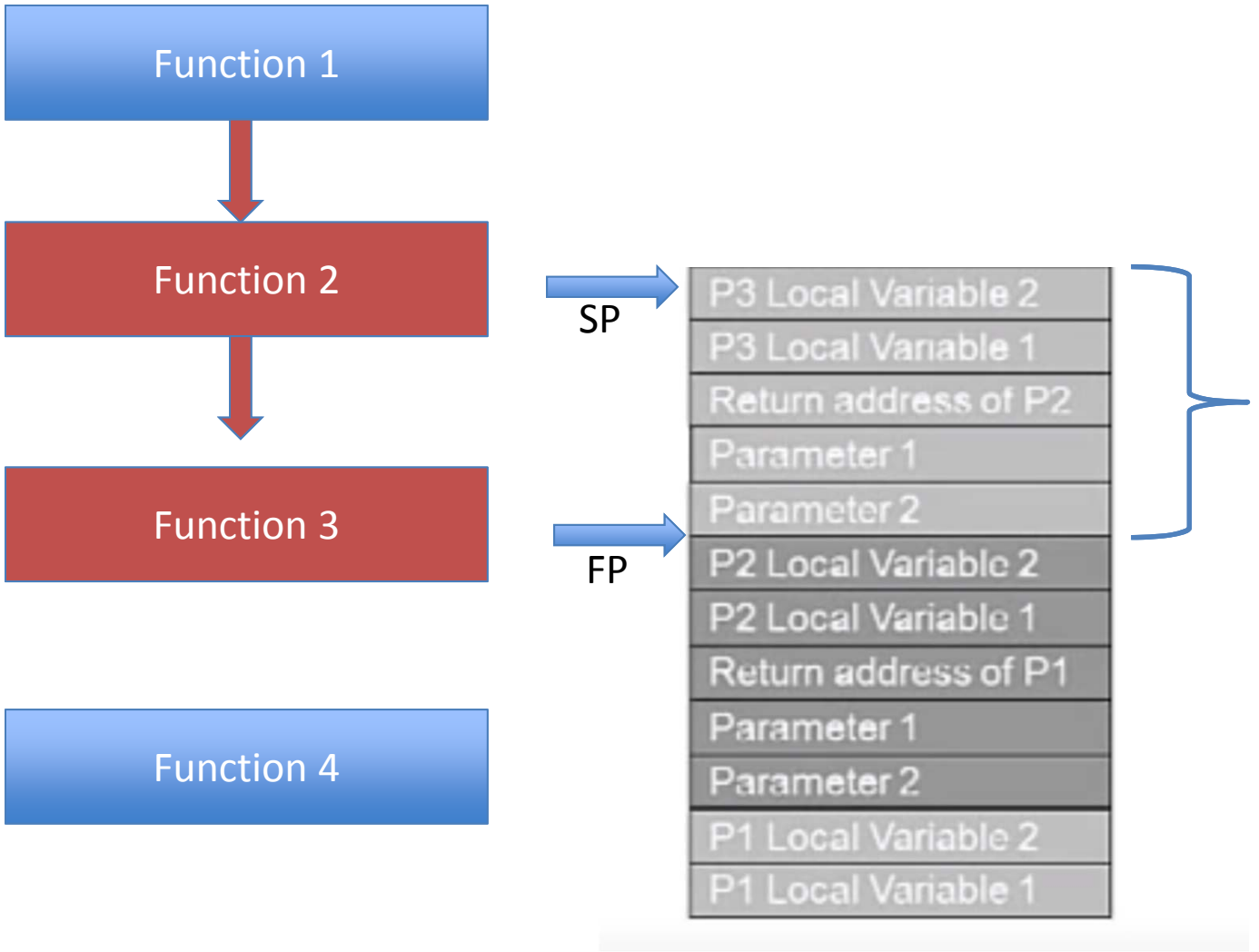

FFFFFFFF
2**n - 1, where n is 32 on a 32-bit machine. Note that this is a small lie: the OS needs some space, so you don't actually get all of this memory. We'll talk about this more in 369.
The Stack grows down!
Every function puts a "frame" onto the stack. The frame contains local variables and then 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

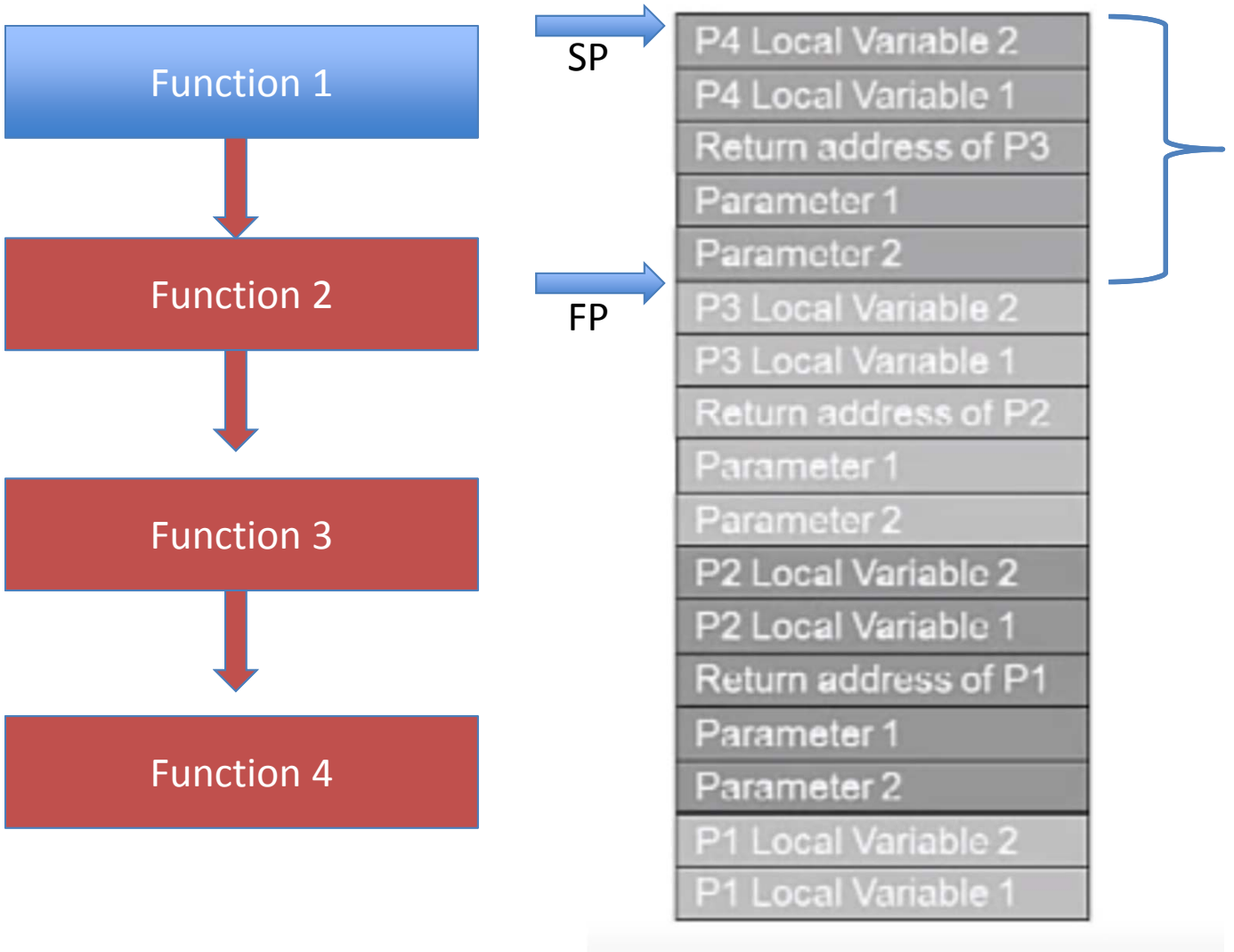
Stack Frame of Function Call



Stack Frame of Function Call

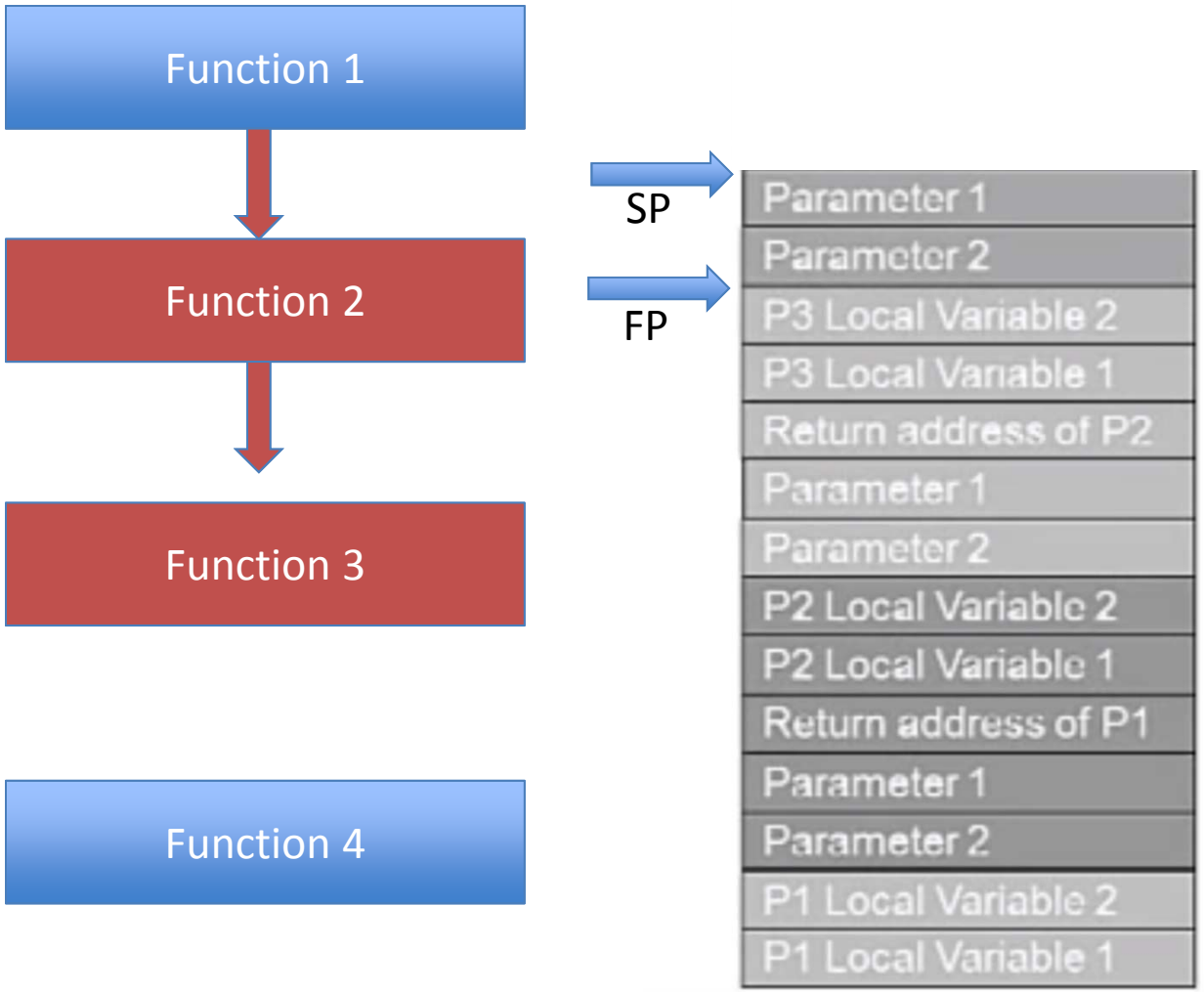


Stack Frame of Function Call



Stack Frame of Function Call

Returning

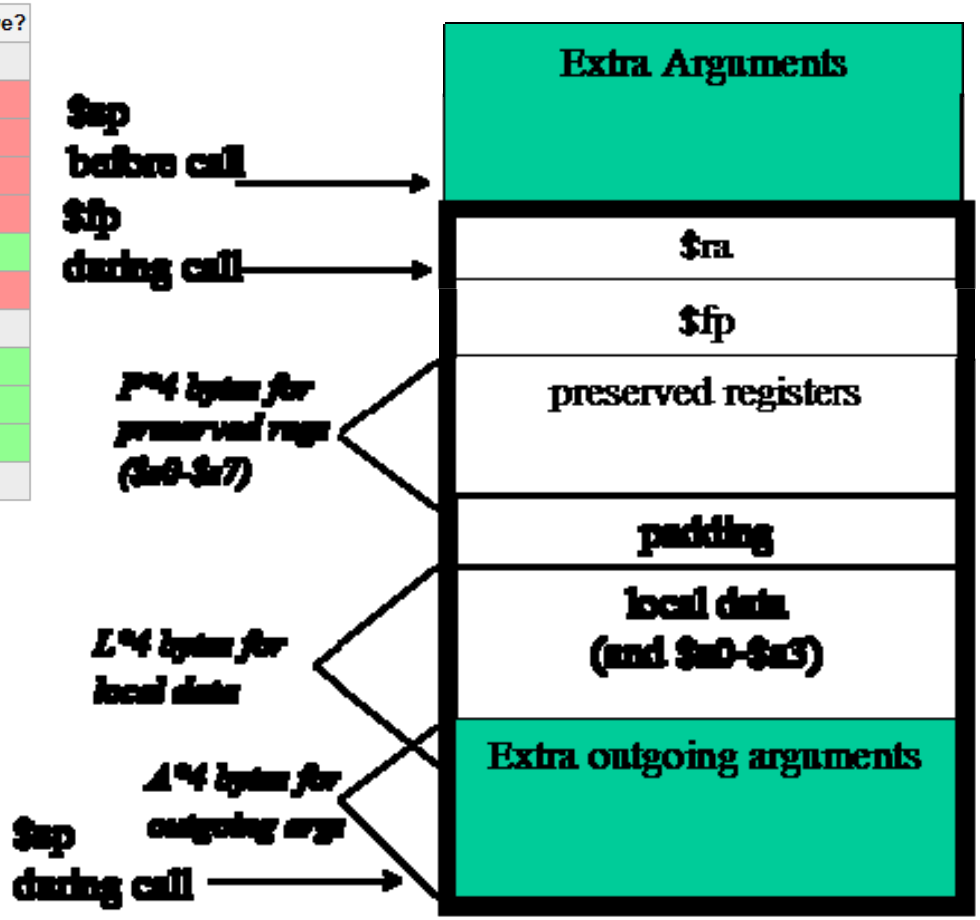


Stack Frames

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
  - 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;
}
```

More C Quirks to Remember

- Uninitialized variables
  - … 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
  - 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

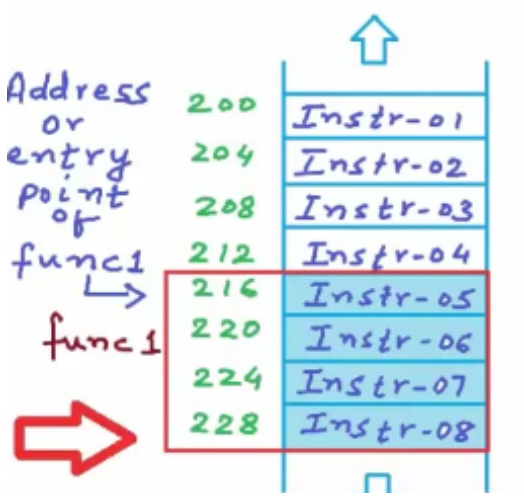
- x >> k right shift, logical or arithmetic
  - logical right shift - fill left end with k 0's (unsigned types)
  - arithmetic right shift (care about signed bit) - fill left end with k copies of the most significant bit
    - C does not define when arithmetic shifts are used! Typically used for signed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

Function pointers

- Pointer store addresses
- Functions are a set of instructions
- Functions start at a memory address
- Function pointer = address of a function



How to declare function pointers?

```c
//Function Pointers in C/C++
#include<stdio.h>
int Add(int a,int b)
{
    return a+b;
}
int main()
{
    int c;
    int (*p)(int,int);
    p = &Add;
    c = (*p)(2,3); //de-referencing and executing the function.
    printf("%d",c);
}
```

How to declare function pointers?

```c
//Function Pointers in C/C++
#include<stdio.h>
void PrintHello()
{
    printf("Hello\n");
}
int Add(int a,int b)
{
    return a+b;
}
int main()
{
    void (*ptr)();
    ptr = PrintHello;
    ptr();
}
```

Quiz

- What is the difference between the following two?

- int (*p) (int, int);
- int *p   (int, int);

Why use function pointers?

- Sample use case:

```
void makePizza(void) { }

void bakeCake(void) { }

iWantPizza = 1;
...
if (iWantPizza)
   makePizza();
else
   bakeCake();
/* want to call the same function again... */
if (iWantPizza)
   makePizza();
else
   bakeCake();

..

/* alternative */
void (*makeFood)(void) = iWantPizza ? makePizza : bakeCake;

makeFood();
/* want to call the same function again... */
makeFood();
```

Function pointers

- Visibly cleaner code
- Change one function pointer instead of changing all the explicit function calls