CSE 351
SECTION 10

THE END *...ALMOST*

3/7/12

Agenda

- Virtual Memory
- Final Review
  - Assembly
  - Calling Conventions
  - Malloc/Free
  - Caching
- Questions, Evaluations

Virtual Memory

- Used for 3 things
  - Efficient use of main memory (RAM)
    - Use RAM as cache for parts of virtual address space
      - Some non-cache parts stored to disk
      - Some (unallocated) non-cached parts stored nowhere
    - Keep only active areas of virtual address space in memory
      - Transfer data back and forth as needed
  - Memory management
    - Each process gets the same full, private linear address space
  - Memory protection
    - Isolates address spaces
    - One process can't interfere with another's memory since they operate in different address spaces
    - User process cannot access privileged information
      - Different sections of address spaces have different permissions

Address Spaces

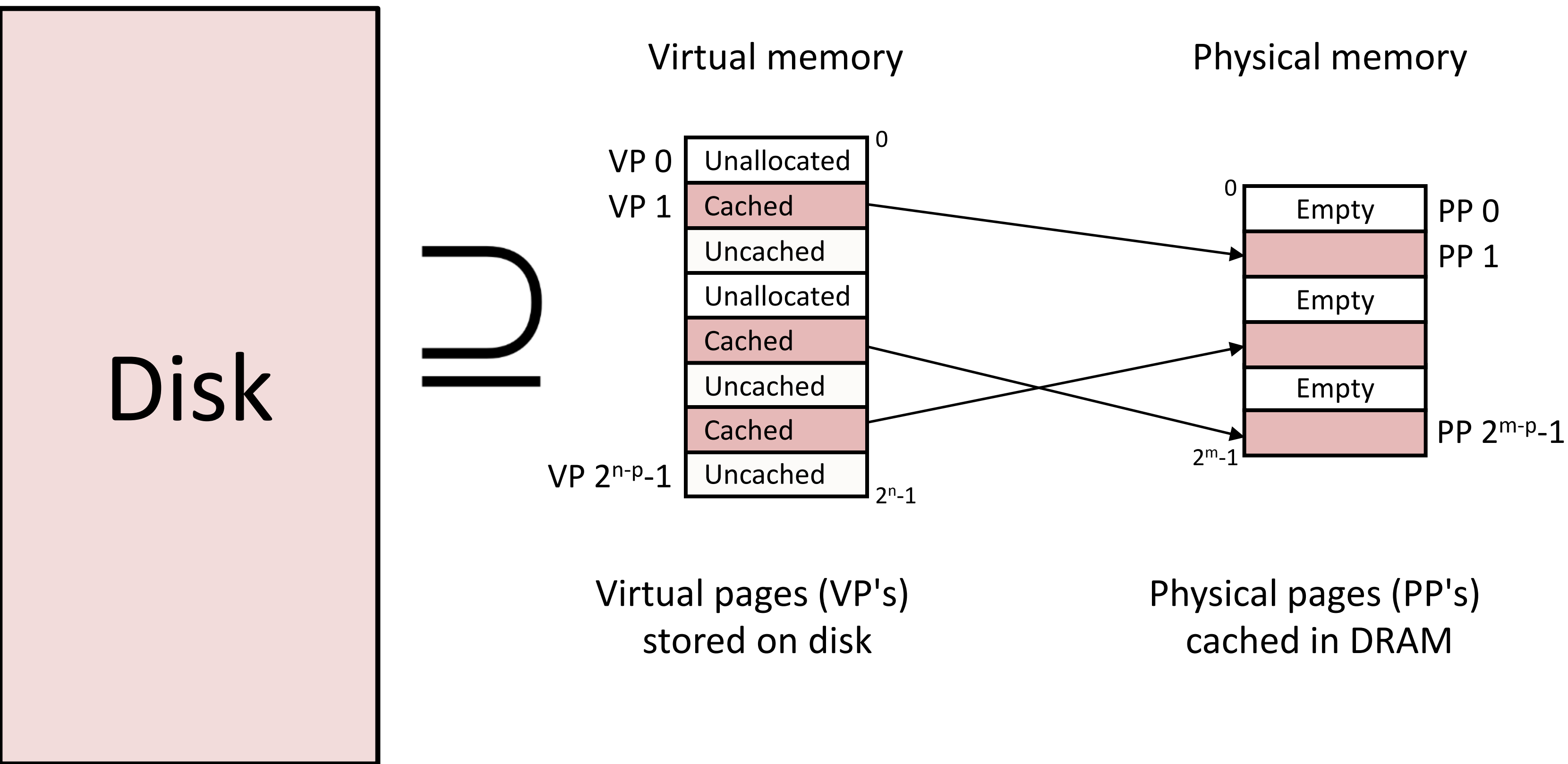
- Virtual address space: Set of $N = 2^n$ virtual addresses
  $\{0, 1, 2, 3, \ldots, N-1\}$

- Physical address space: Set of $M = 2^m$ physical addresses ($n >> m$)
  $\{0, 1, 2, 3, \ldots, M-1\}$

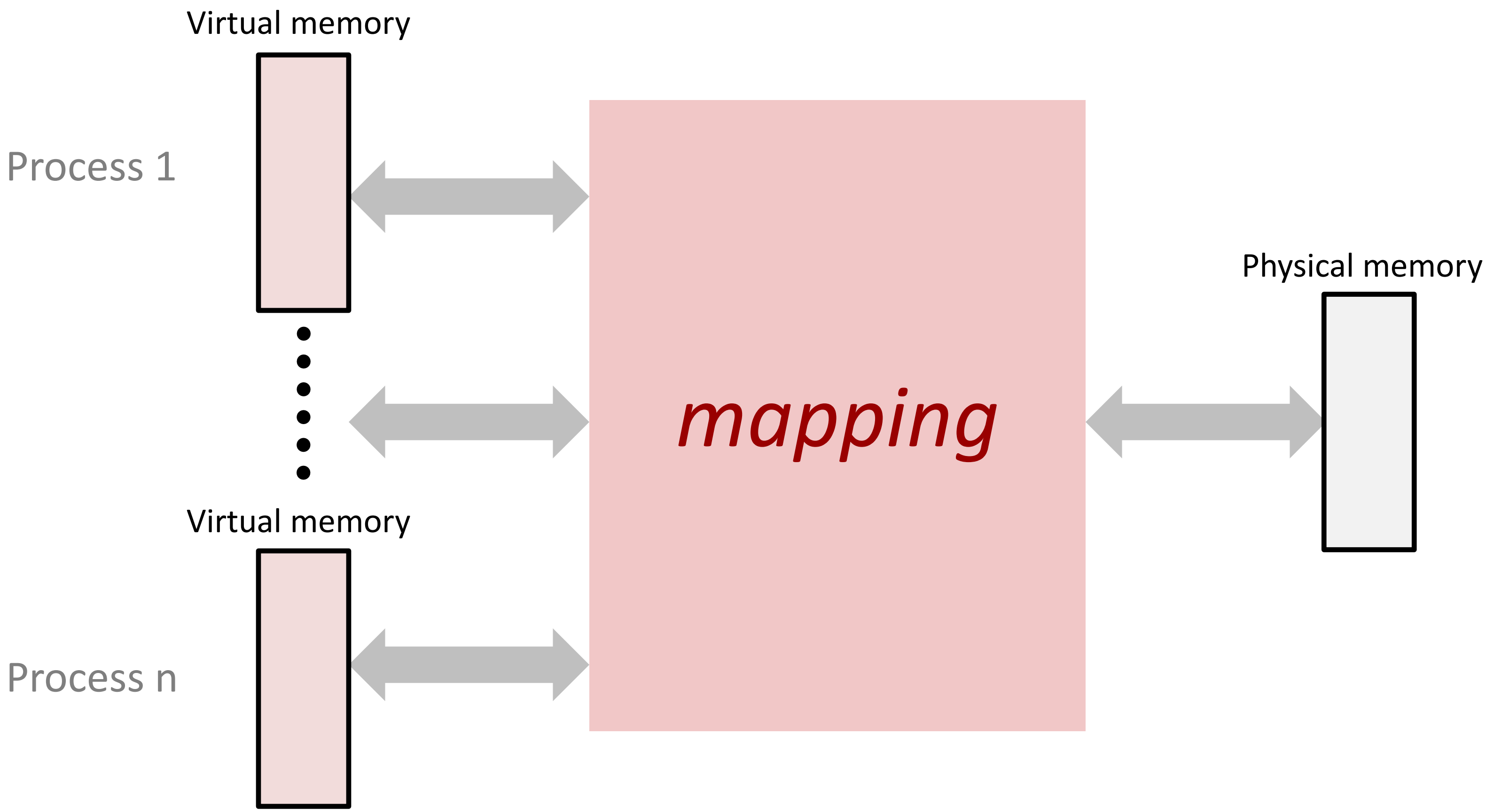
- Every byte in main memory:
  one physical address, one (or more) virtual addresses

VM as a Tool for Caching

- *Virtual memory:* array of $N = 2^n$ contiguous bytes
  - think of the array (allocated part) as being stored on disk
- Physical main memory (DRAM) = cache for allocated virtual memory
- Blocks are called pages; size = 2^p



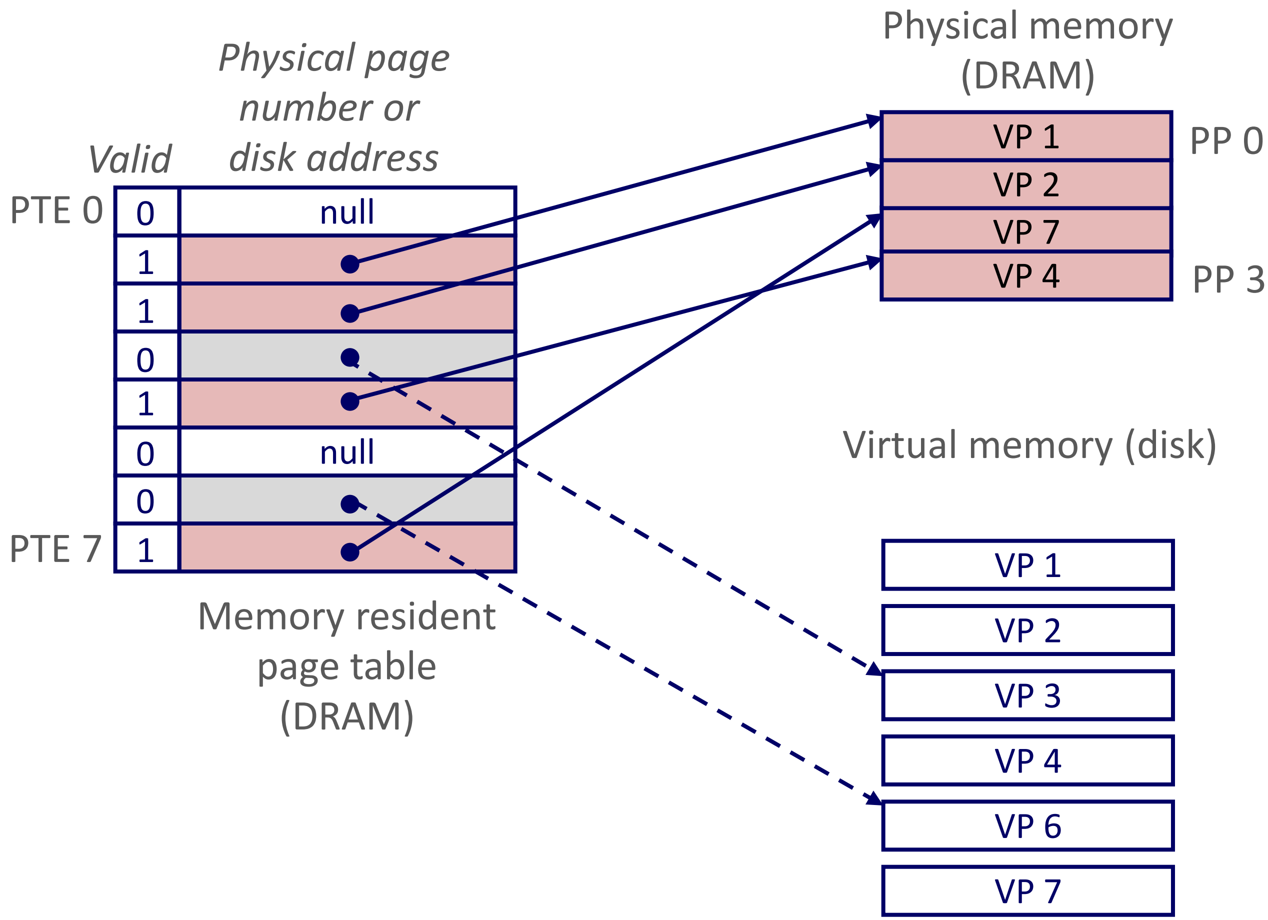
Virtual Memory



- Each process gets its own private memory space

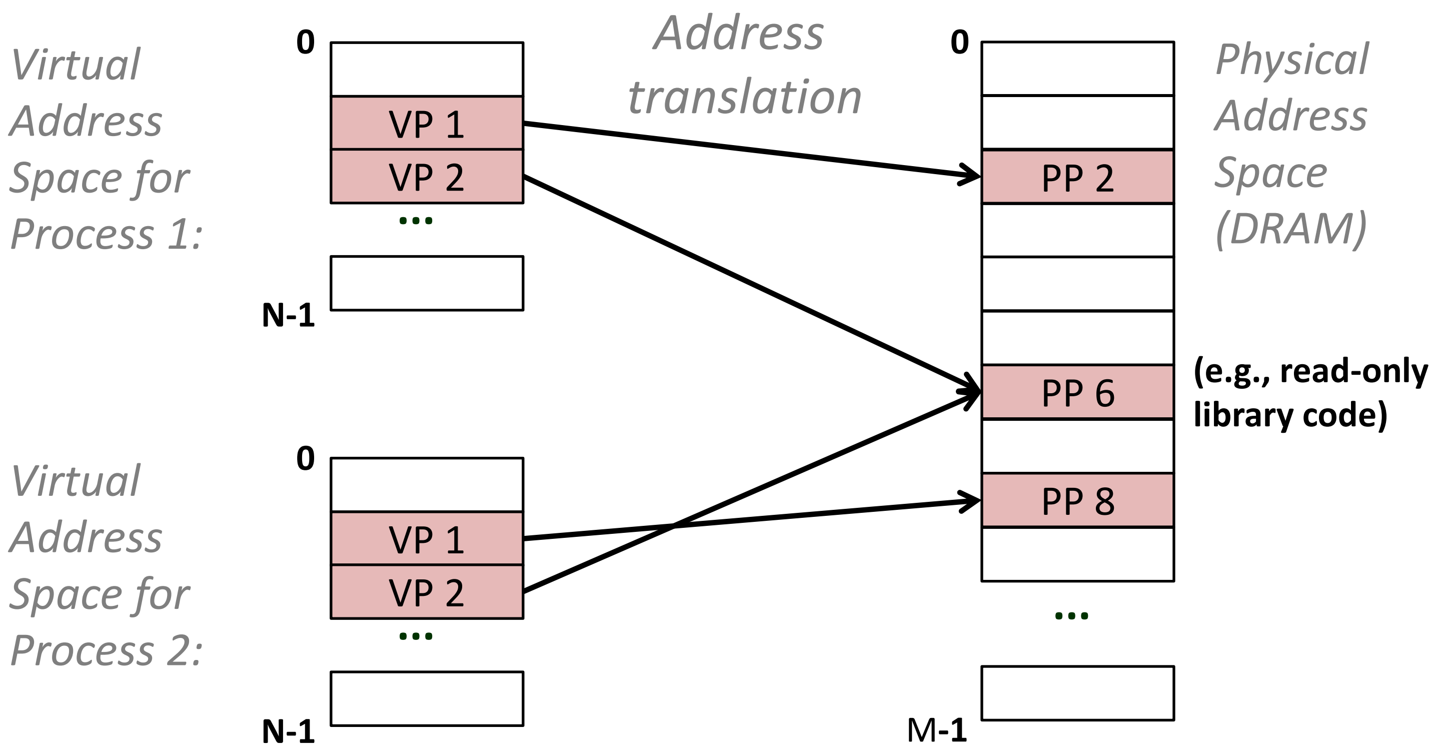
Address Translation: Page Tables

- A *page table* is an array of page table entries (PTEs) that maps virtual pages to physical pages. Here: 8 VPs



VM as a Tool for Memory Management

- Memory allocation
  - Each virtual page can be mapped to any physical page
  - A virtual page can be stored in different physical pages at different times
- Sharing code and data among processes
  - Map virtual pages to the same physical page (here: PP 6)



VM as a Tool for Memory Protection

- Extend PTEs with permission bits
- Page fault handler checks these before remapping
  - If violated, send process SIGSEGV signal (segmentation fault)
  - SUP bit indicates whether processes must be running in kernel (supervisor) mode to access it

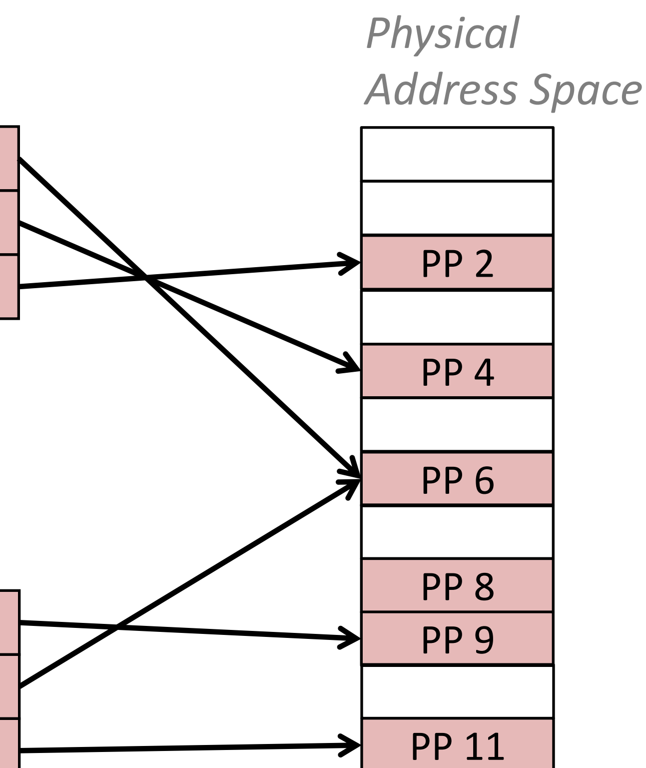
Process i:

	SUP	READ	WRITE	Address
VP 0:	No	Yes	No	PP 6
VP 1:	No	Yes	Yes	PP 4
VP 2:	Yes	Yes	Yes	PP 2

⋮

Process j:

	SUP	READ	WRITE	Address
VP 0:	No	Yes	No	PP 9
VP 1:	Yes	Yes	Yes	PP 6
VP 2:	No	Yes	Yes	PP 11



Final Review

Assembly – Things to Remember

- `.text` always goes before your code
- `.globl` *<label>* when you want your function to be used by other modules (i.e. public)
- `pushq %rbp` and `movq %rsp,%rbp` when entering a function
- `popq %rbp` and `ret` at the end of your function
- Size suffixes must be used when the length can not be implicitly determined
  - To be safe, always use them! (e.g. `movq`, `cmpb`, etc.)
- If you need to allocate stack space to store data, the space must be a multiple of 16.
  - E.g. `sub $32, %rsp` at the start, then `add $32, %rsp` at the end of the function
- Register names used must match size suffix of instruction
  - E.g. To use the lower byte stored in rax with `cmpb`, you must use %al, not %rax.
- Dereferencing
  - `cmpb (%rdi),%sil`
    - Compares 1 byte in memory stored at the address in rdi with the lower byte in the rsi register

Assembly – More Things

- Read only data – data that will not change

```
        .section .rodata
    mystring:
        .string "Hello world"
```

  - Access the pointer to the start of the string using `$mystring`
- Labels really act like pointers to instructions or data
  - `jmp loop` is really saying the next instruction lives at the address where the loop label points to
- Data segment

```
  .data
  my_array: .zero 512
```

  - Allocates 512 bytes for my_array and initializes to zero

x86-64 Calling Conventions

- First six arguments passed in registers
  - rdi, rsi, rdx, rcx, r8, r9
- Callee saved registers
  - rbx, rbp, r12, r13, r14, r15
  - Function being called must save the values in the registers before using them, and restore them before returning.
- Caller saved registers
  - r10, r11
  - Calling function must save these registers if it wants to keep the values in them
- Return value stored in rax

Malloc/Free

- Use `malloc` when you want to want to dynamically allocate something
  - e.g. the size of a data structure is only known at runtime
  - Data allocated on the heap

```
p=(int*)malloc(n*sizeof(int));
```

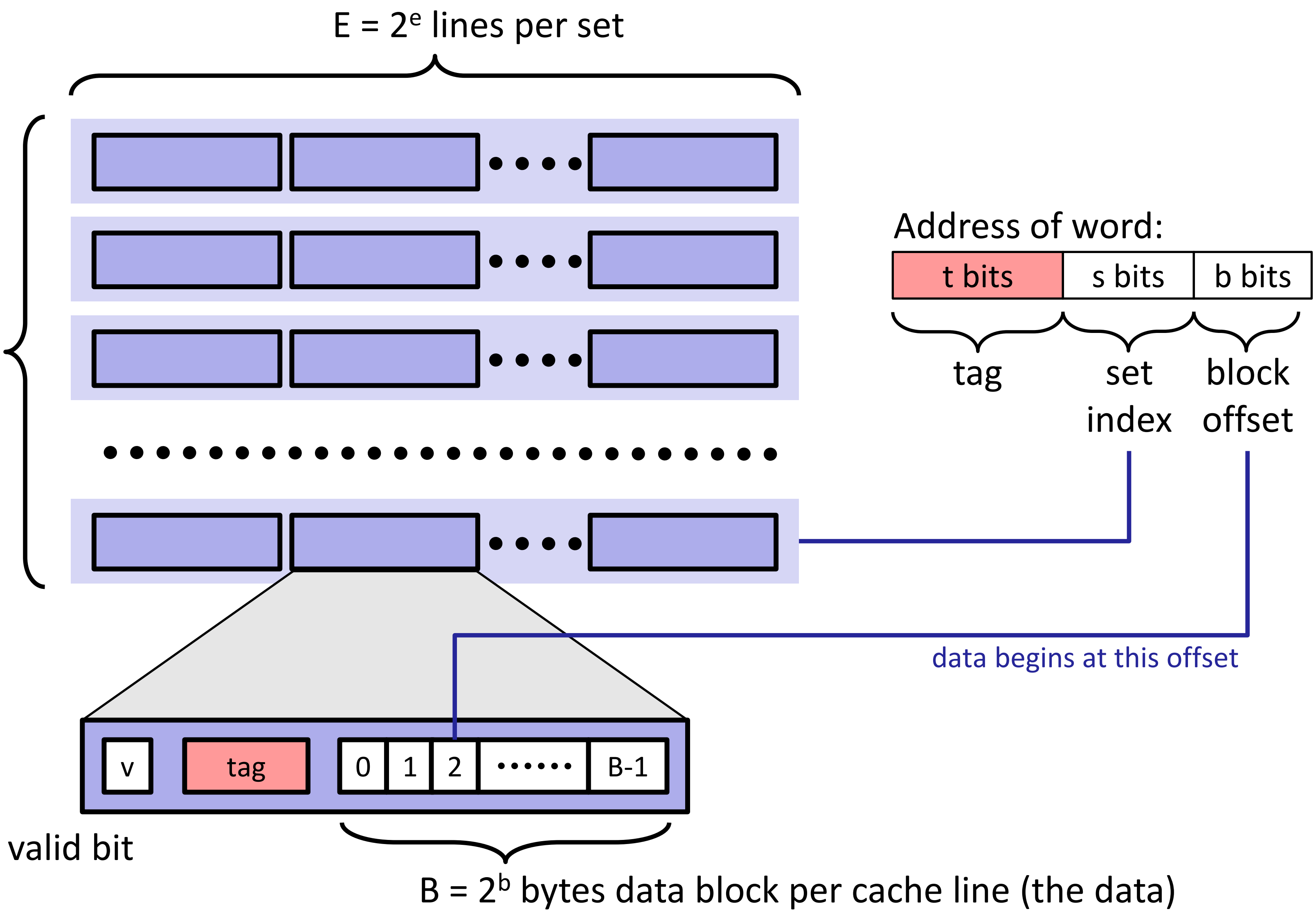
- Data allocated with `malloc` must be `free`'d when finished with it

```
free(p);
```

Caching

- Exploits temporal and spatial locality
  - Temporal locality: recently referenced items likely to be referenced again in the near future
  - Spatial locality: items with nearby addresses tend to be referenced close together in time
- Organized into lines and sets
- Number of lines per set is the associativity
  - E.g. 2-way associative means 2 lines per set
- Line consists of valid bit, tag, data block

Caching


E = 2e lines per set
Address of word:
t bits
s bits
b bits
tag
set index
block offset
data begins at this offset
v
tag
0
1
2
B-1
valid bit
B = 2b bytes data block per cache line (the data)

Suggestions (Not a comprehensive list!)

- Review all lecture and section slides
- Be able to write both assembly and C code to the level we've covered
  - Practice writing code at home. Pick some functionality (like perhaps atoi) and code it in both C and assembly.
  - All code you write on the final should be able to be compiled
  - Have a solid understanding of pointers
  - Have a solid understanding of how the stack works
- Be able to convert a C function into assembly and vice versa
- Understand data representation (2's complement, endianness, signed/unsigned, floating point, etc.)
- Know the x64 calling conventions

QUESTIONS? COMMENTS?

GOOD LUCK ON THE FINAL AND
THANKS FOR A GREAT QUARTER!