Midterm Review

CS140 Winter 2020

Admin

- When is it?
  - Midterm **in class** Wednesday Feb 12
- What resources can I use?
  - Open note, can print lecture slides
  - No textbook or electronics
- How much of my grade does it count for?
  - 50% of overall grade is: `max( midterm > 0 ? final : 0, (midterm + final)/2 )`

Content

- Processes & Threads
- Concurrency
- Scheduling
- Virtual Memory (HW/OS)
- Synchronization
- Linking
- Memory Allocation (Monday)

Themes

- Memory models
    - Sequential consistency
- Races
    - Implementing locks
    - Producer/consumer
- Design tradeoffs
    - Using the past to predict the future
- Uniprocessor vs. multiprocessor

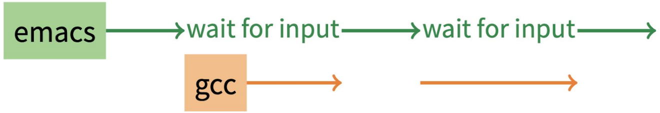
Processes & Threads

Processes

- Process
  - An instance of a program running
  - Has its own view of the machine: address space, open files
- Process control block **(PCB)**
  - Stores information about the process, including:
    - State (running, ready, waiting)
    - Registers
    - Virtual memory mappings
    - Open files
  - `struct thread` in pintos

Processes

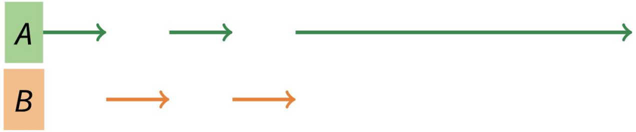
- Why?
  - Higher throughput*



  - Lower latency*

Running *A* then *B* requires 100 sec for *B* to complete

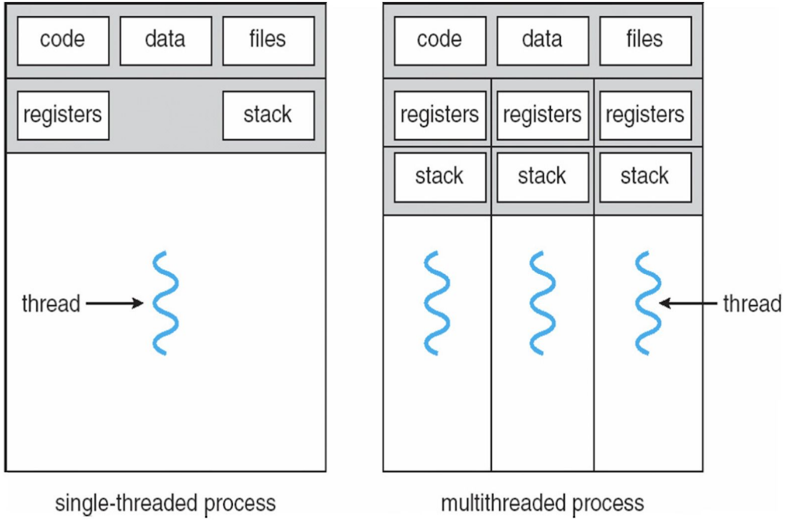
Running *A* and *B* concurrently makes *B* finish faster



*potentially

Threads

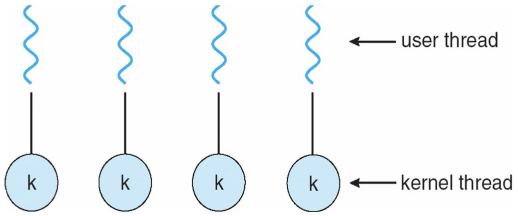
- Thread
  - Schedulable execution context
  - Allows one process to use multiple CPUs
  - Lighter-weight than process



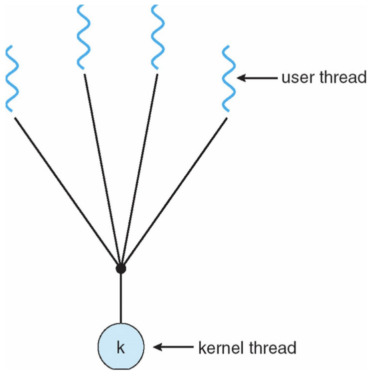
Kernel vs. User Threads

- Kernel threads
  - Pro: control
    - Scheduling
    - Priority
  - Con: heavy-weight
    - All operations go through kernel
    - More memory/features than needed

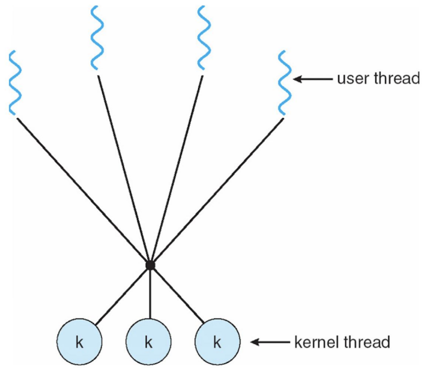
- User threads
  - Also known as “green threads”
  - Pro: more lightweight and flexible
  - Con: control
    - IO on one thread blocks all



1 user thread : **1** kernel thread



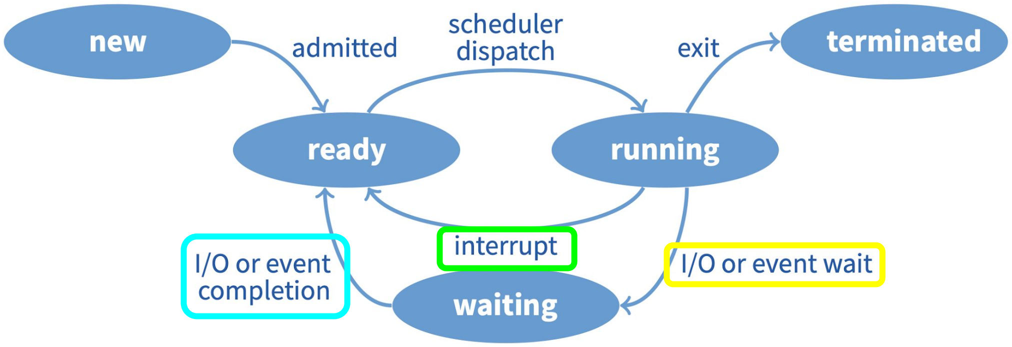
n user threads : **1** kernel thread



n user threads : **m** kernel threads

Context Switching

- **Context switch**
  - Change which process is running
- How?
  - Save registers of current thread
  - Restore registers of next thread
  - Return into next thread
- When?
  - State change
    - Blocking call
    - Device interrupt (e.g. disk access completed, packet arrived on network)
  - Can **preempt** when kernel gets control*
    - Traps: system call, page fault, illegal instruction
    - Periodic timer interrupt

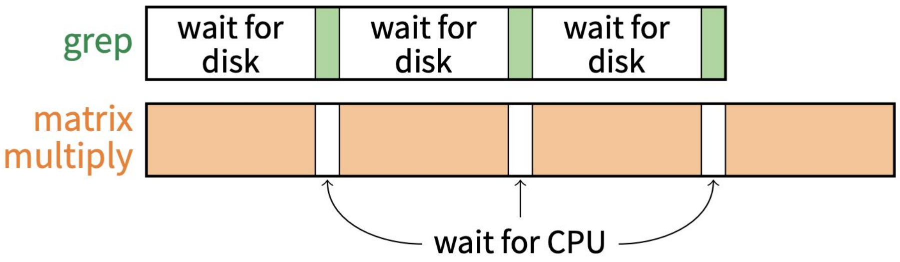


*unless non-preemptive (thread executes until blocking call)

Scheduling

Scheduling

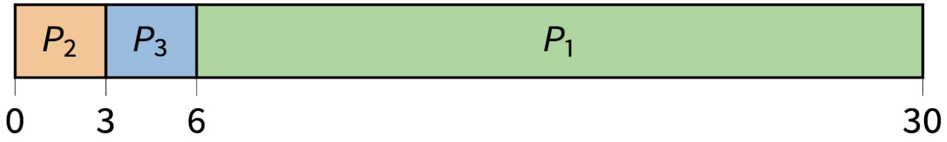
- Problem
  - Given a list of runnable processes, **which do we run?**
- Goals
  - Throughput
  - Turnaround time
  - Response time
  - CPU utilization
  - Waiting time
- Context switch costs
  - CPU time in kernel
  - Indirect costs



Scheduling Algorithms

- First come first serve

- Shortest job first



- Round-robin
- Priority scheduling
- MLFQS (multilevel feedback queues)

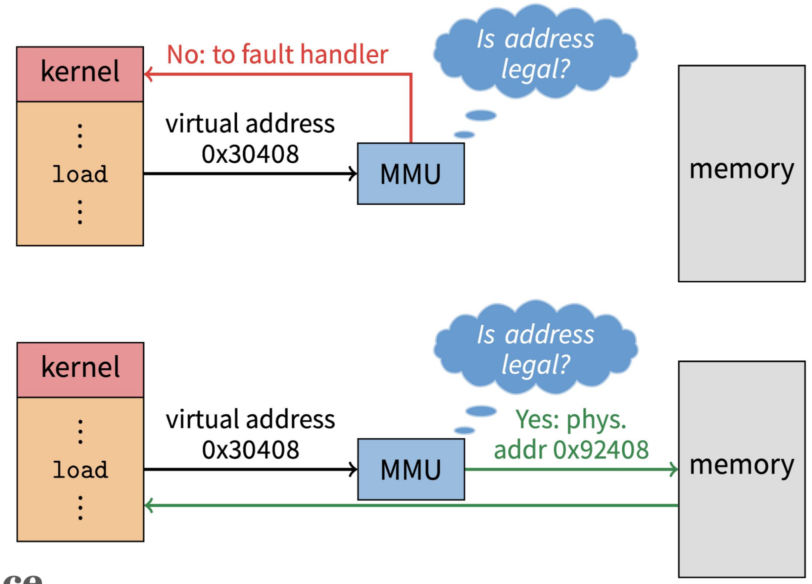
Multiprocessor Scheduling

- Problem
  - Given a list of runnables processes, which do we run and **which CPUs do we run them on?**
- Considerations
  - Load balancing
  - Minimize direct/indirect costs
- Approaches
  - Affinity scheduling
    - Keep process on same CPU
  - Gang scheduling
    - Schedule related processes/threads together

Virtual Memory

Virtual Memory HW

- Problem
  - Want multiple processes to co-exist
  - How should processes interface with memory?
- Issues with using physical addresses
  - Protection
  - Transparency
  - Resource exhaustion
- Solution
  - Give each program its own **virtual address space**
  - **Memory Management Unit (MMU)**
    - translates between physical and virtual addresses



How to Map Memory

- Base + bound
  - Physical address = virtual address + base
- Segmentation
  - Divide memory into segments, each of which has a base + bound
- Demand Paging
  - Divide memory into small, equal-sized pages
  - Each process has its own **page table**
    - Multilevel
    - Translation Lookaside Buffer (**TLB**) caches recently used translations
  - Any process can have any page, idle pages stored on disk, paged in when used
  - Eviction?
    - Least recently used: use past to predict future

Considerations

- Fragmentation
  - Inability to use free memory
  - **External** fragmentation (e.g. segmentation)
    - Many small holes between memory segments
  - **Internal** fragmentation (e.g. paging)
    - Unused memory within allocated segments
- Speed
  - Disk much slower than memory
  - 80/20 rule
    - Hot 20 in memory = “working set”
- Local or global page allocation
- Thrashing
  - Working set can’t fit in memory

Concurrency

Memory Model

- Sequential consistency
  - As if all operations were executed in some sequential order
  - Downsides
    - Thwarts hardware/compiler optimizations (e.g. prefetching/reordering)
  - Requirements
    - Maintain program order on individual processors
    - Ensure write atomicity

Preventing Races

- Define **critical section**
- Requirements to fake SC?
  - Mutual exclusion
  - Progress
  - Bounded waiting
- How to meet requirements?
  - **Synchronization primitives**
    - Locks, semaphores, condition variables
- What if sharing data with interrupt handler?
  - Uniprocessor: disable interrupts
  - Multiprocessor: disable interrupts + spinlock

Synchronization

Memory System Properties

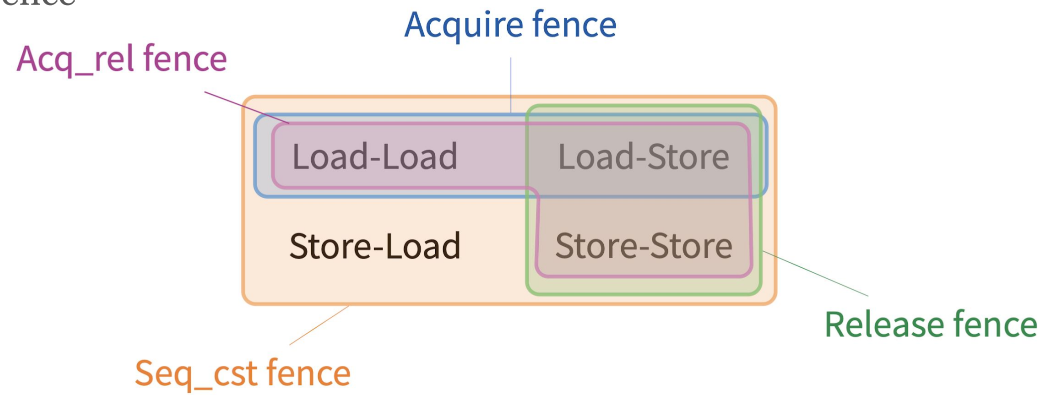
- Coherence
    - Concerns access to a single memory location
        - If A writes `x=1` and B writes `x=2`, all processes should see the same ordering
    - MESI/MOESI multicore cache coherence
        - Modified, Exclusive, Shared, Invalid, Owned
- Consistency
    - Concerns ordering across multiple memory locations
        - If `x=1,y=2`, A reads x,y and B writes `x=3,y=4`, could A ever see `x=1,y=4`?
    - Sequential consistency matches our intuition

Considerations

- Amdahl's law
  - Ultimate limit on parallel speedup if part of task must be sequential
- Necessary conditions for **data race**
  - Multiple threads access the same data
  - At least one of the accesses is a write
- *There is no such thing as a benign data race*
- Necessary conditions for **deadlock**
  - Limited access (mutual exclusion)
  - No preemption
  - Multiple independent requests (hold and wait)
  - **Circularity in graph of requests**
    - A holds mutex `x`, wants mutex `y`; B holds `y`, wants `x`

Memory Ordering and Fences

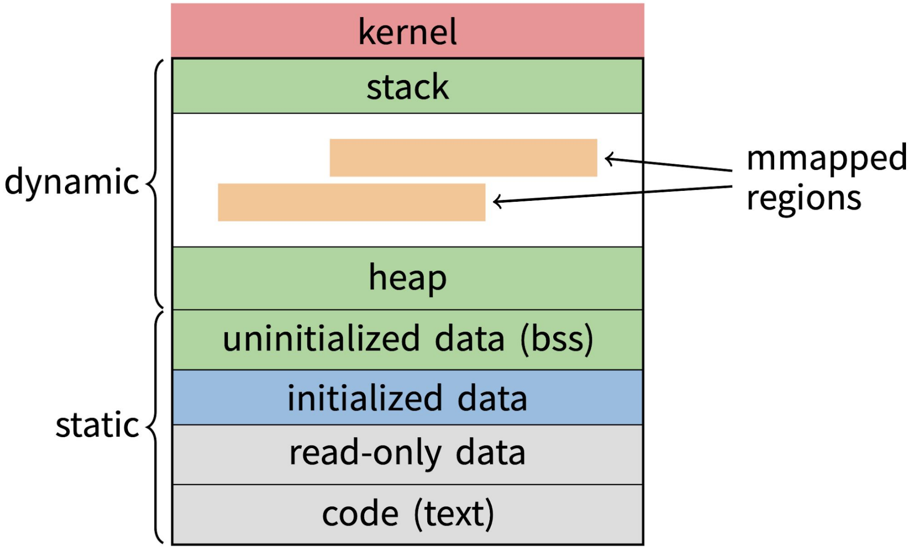
- What if we don't need sequential consistency?
  - Weaker consistency models
  - Atomics, lock-free data structures, read-copy update, MCS spinlock, futex
- *X*-*Y* fence
  - operations of type *X* sequenced before the fence happen before operations of type *Y* sequenced after the fence



Linking

Components of Memory

- Heap
  - Allocated and laid out at runtime by malloc
- Stack
  - Allocated at runtime, layout by compiler
- Global data/code
  - Allocated by compiler, layout by **linker**
- Mmapped regions
  - Managed by programmer or linker



Program Lifecycle

- Source code → program running
- Compiler/Assembler
  - Generates one **object file** for each source file (e.g. main.c → main.o)
    - References to other files are incomplete (e.g. printf is in stdio.o)
- **Linker**
  - Combines all object files into **executable** file
- OS Loader
  - Reads executables into memory

Linker

- Goal
  - Object files → executable
- How
  - Pass 1
    - Coalesce like segments
    - Construct global symbol table
    - Compute virtual address of each segment
  - Pass 2
    - Fix addresses of code and data using global symbol table

Object Files

main.c

```
extern float sin();
extern printf(), scanf();

main() {
  double x, result;
  printf("Type number: ");
  scanf("%f", &x);
  result = sin(x);
  printf("Sine is %f\n",
         result);
}
```

main.o

text section

```
0   main:
    ...
30  call printf
    ...
52  call scanf
    ...
60  call sin
    ...
86  call printf
```

data section

```
0   _s1: "Type number: "
14  _s2: "%f"
17  _s3: "Sine is %f\n"
```

symbols

```
main    T[0]
_s1     D[0]
_s2     D[14]
_s3     D[17]
```

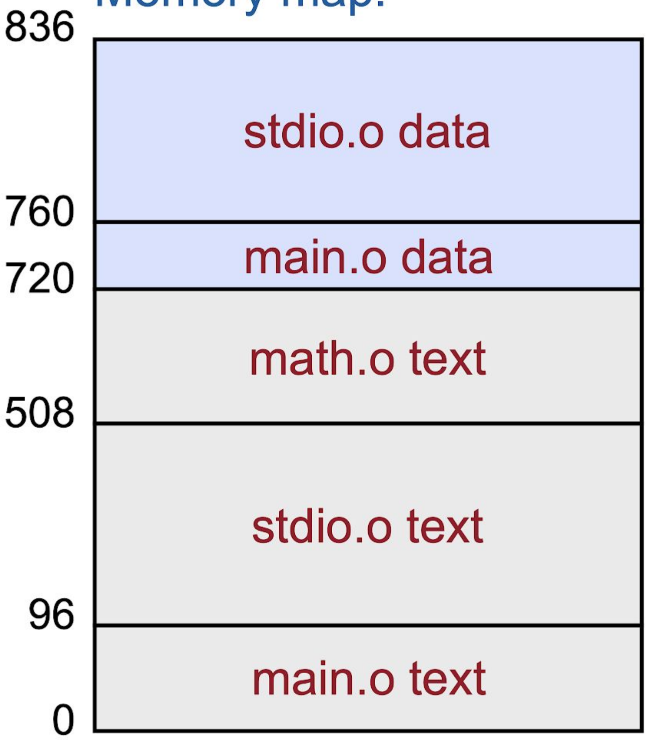
relocation

```
printf  T[30]
printf  T[86]
scanf   T[52]
sin     T[60]
_s1     T[24]
_s2     T[54]
_s3     T[80]
```

"Store the final location of sin at offset 60 in the text section"

Pass 1

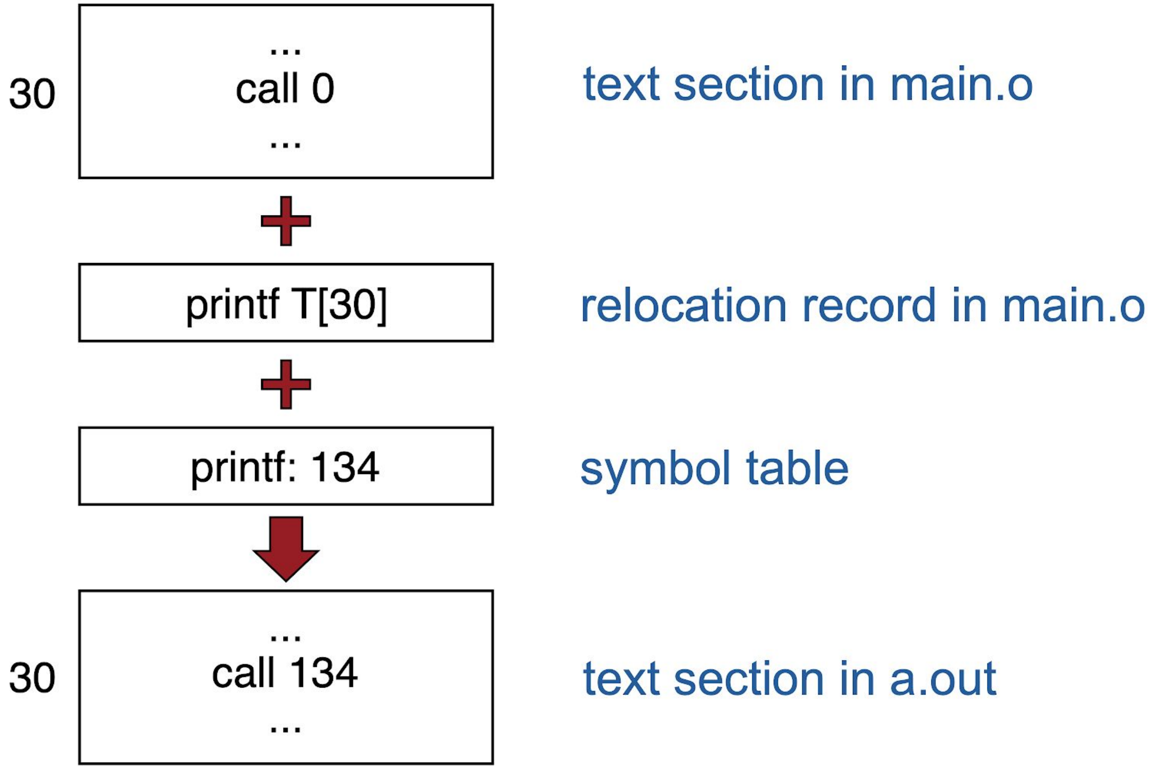
Memory map:



Symbol table:

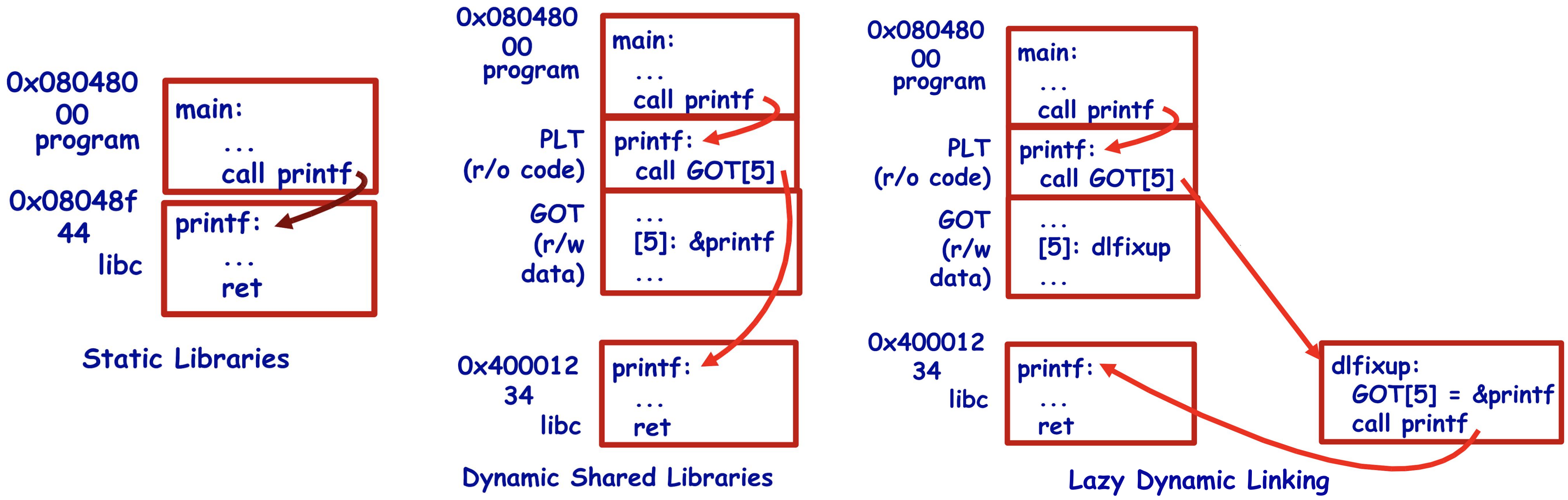
Name	File	Sec	Offset	Addr
main	main.o	T	0	0
_s1	main.o	D	0	720
_s2	main.o	D	14	734
_s3	main.o	D	17	737
printf	stdio.o	T	38	134
scanf	stdio.o	T	232	328
stdin	stdio.o	D	0	760
stdout	stdio.o	D	8	768
sin	math.o	T	0	508

Pass 2


30
...
call 0
...
text section in main.o
printf T[30]
relocation record in main.o
printf: 134
symbol table
30
...
call 134
...
text section in a.out

Shared Libraries & Dynamic Linking

- Keep a single shared copy of common libraries in memory



[Unsolicited] Advice

Advice

- Old exams won't necessarily cover the same material or have the same format
- Understand core themes
  - Identify races in code
  - Identify pros/cons of new approaches
  - Given a workload, be able to select a good approach
- Notice what is/isn't specified in a question (and state assumptions!)
  - Sequential consistency
  - Uniprocessor vs. multiprocessor
- Rely on notes for facts
  - Might be time-constrained
  - Create a cheat sheet instead of printing all lecture slides (or both?)
- Deep understanding of most material > cursory understanding of all

Good luck!