CPU Scheduling

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Problem

- You are the cook at the state st. diner
  - customers continually enter and place their orders
  - Dishes take varying amounts of time to prepare
- What is your goal?
- Which strategy achieves this goal?

Multitasking Operating Systems

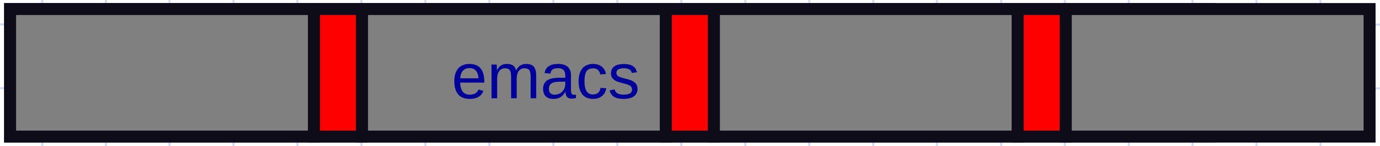
time sharing

the cpu among processes

Process Model

- Process alternates between CPU and I/O bursts
  - CPU-bound jobs: Long CPU bursts

  - I/O-bound: Short CPU bursts

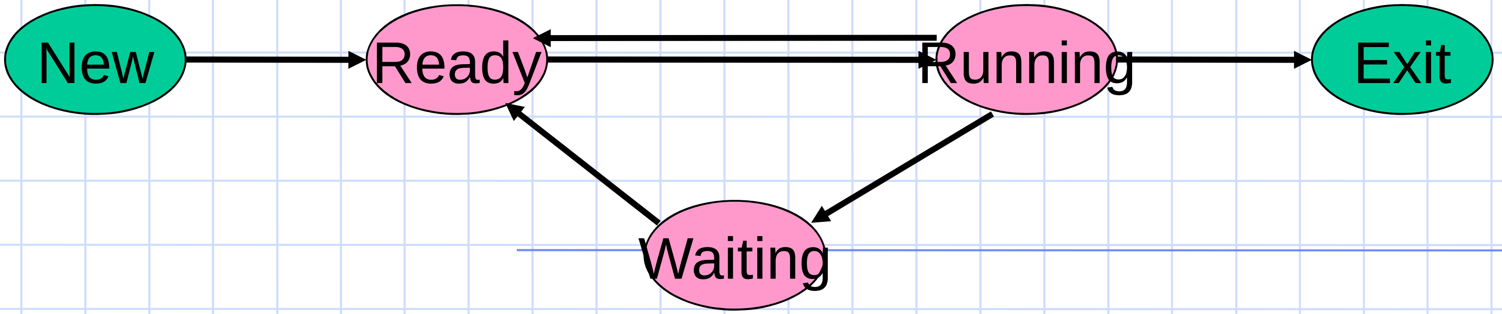


  - I/O burst = process idle, switch to another “for free”

CPU Scheduler

- Processes and threads migrate among queues
  - Ready queue, device wait queues, …
- Scheduler selects one from ready queue to run

- Which one?
  - 0 ready processes: run idle loop
  - 1 ready process: easy!
  - > 1 ready process: what to do?



multitasking

design decisions

algorithms

advanced topics

Goals

- What are metrics that schedulers should optimize for ?
  - There are many, the right choice depends on the context
- Suppose:
  - You own an (expensive) container ship and have cargo across the world
  - You own a sweatshop, and need to evaluate workers
  - You own a diner and have customers queuing
  - You are a nurse and have to combine care and administration

Scheduling Metrics

- Many quantitative criteria for evaluating scheduler algorithm:
  - CPU utilization: percentage of time the CPU is not idle
  - Throughput: completed processes per time unit
  - Turnaround time: submission to completion
  - Waiting time: time spent on the ready queue
  - Response time: response latency
  - Predictability: variance in any of these measures
- The right metric depends on the context

“The perfect scheduler”

- Minimize latency: response or job completion time
- Maximize throughput: Maximize jobs / time
- Maximize utilization: keep all devices busy
- Fairness: everyone makes progress, no one starves

Task Preemption

- Non-preemptive
  - Process runs until voluntarily relinquish CPU
    - process blocks on an event (e.g., I/O or synchronization)
    - process terminates
    - Process periodically calls the yield() system call to give up the CPU
  - Only suitable for domains where processes can be trusted to relinquish the CPU
- Preemptive
  - The scheduler actively interrupts and deschedules an executing process
  - Required when applications cannot be trusted to yield
  - Incurs some overhead

Other considerations

Uni vs. Multiprocessor

- Uniprocessor scheduling concerns itself with the selection of processes on a single processor or core
- Multiprocessor scheduling concerns itself with the partitioning of jobs across multiple CPUs or multiple cores

Best Effort vs. Real Time

Predictability:

- ABS in your car vs. navigation software
- heart rate monitor

Real time schedulers give strong predictability guarantee

Best effort schedulers provide no such guarantees

Most desktop Oses use best effort schedulers multitasking

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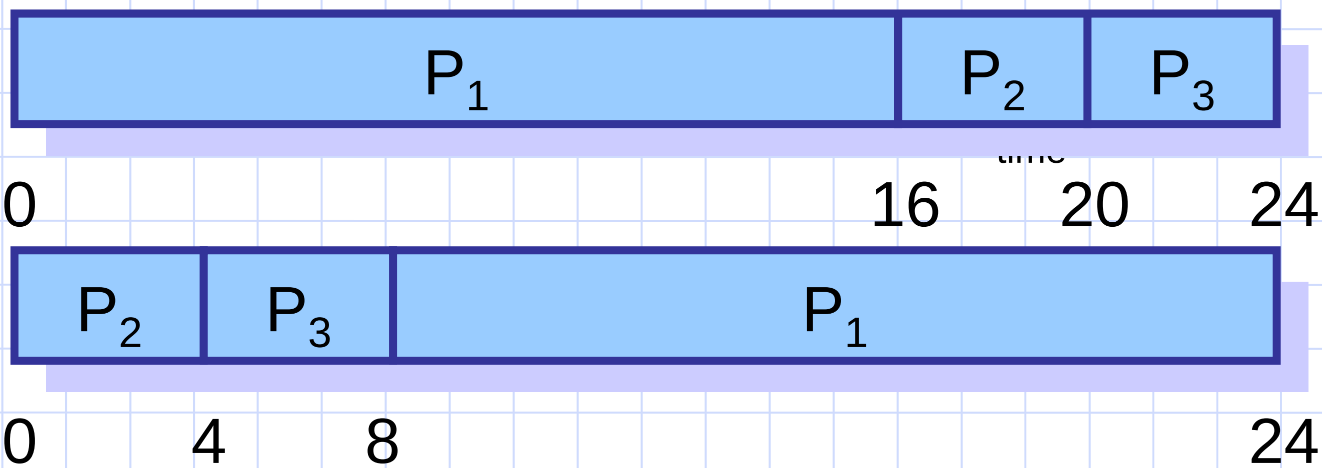
Scheduling Algorithms FCFS

- **First-come First-served (FCFS) (FIFO)**
  - Jobs are scheduled in order of arrival
  - Non-preemptive
- **Problem:**
  - Average waiting time depends on arrival order



- **Advantage:** really simple!

Scheduling Algorithms LIFO

- **Last-In First-out (LIFO)**
  - Newly arrived jobs are placed at head of ready queue
  - Improves response time for newly created threads
- **Problem:**
  - May lead to starvation – early processes may never get CPU

Round Robin

FCFS with preemption

- Often used for timesharing
- Ready queue is treated as a circular queue (FIFO)
- Each process is given a time slice called a *quantum*
- It is run for the quantum or until it blocks
- RR allocates the CPU uniformly (fairly) across participants.
- If average queue length is n, each participant gets 1/n

RR with Time Quantum = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

- The Gantt chart is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

0 20 37 57 77 97 117 121 134 154 162

RR: Choice of Time Quantum

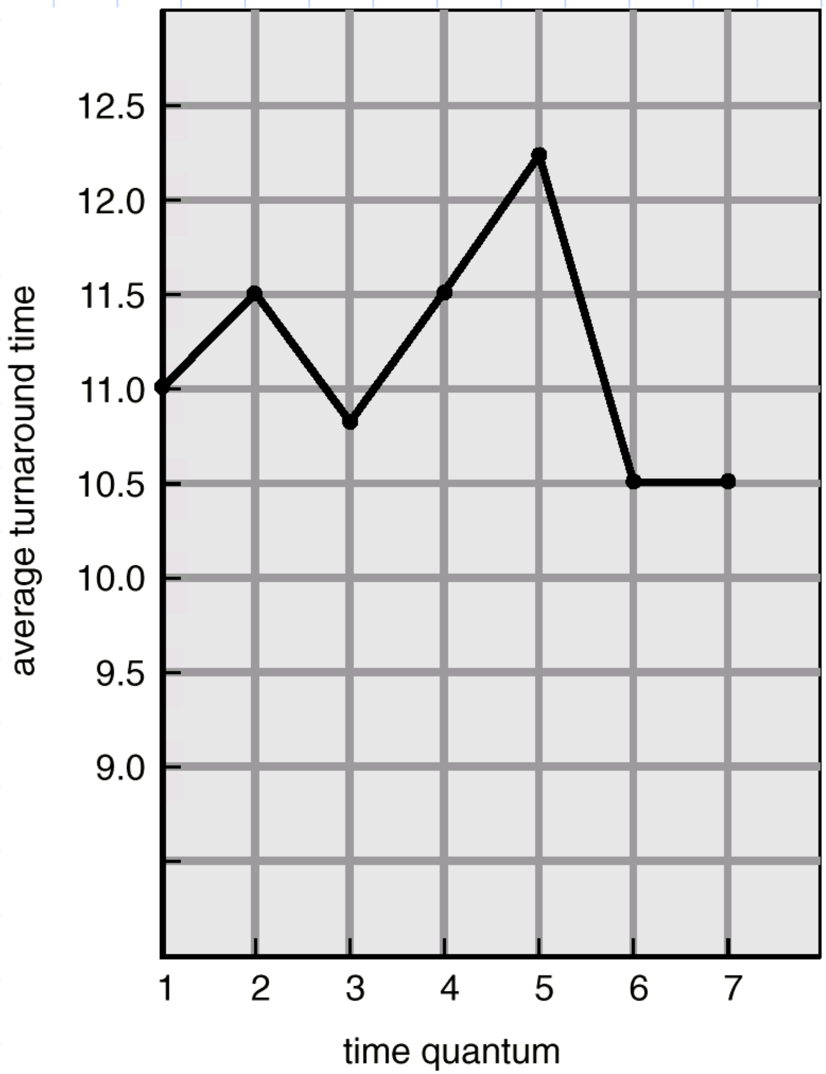
- Performance depends on length of the timeslice
  - Context switching isn't a free operation.
  - If timeslice time is set too high
    - attempting to amortize context switch cost, you get FCFS.
    - i.e. processes will finish or block before their slice is up anyway
  - If it's set too low
    - you're spending all of your time context switching between threads.
  - Timeslice frequently set to ~100 milliseconds
  - Context switches typically cost < 1 millisecond

Moral:

Context switch is usually negligible (< 1% per timeslice)

unless you context switch too frequently and lose all productivity

Turnaround Time w/ Time Quanta



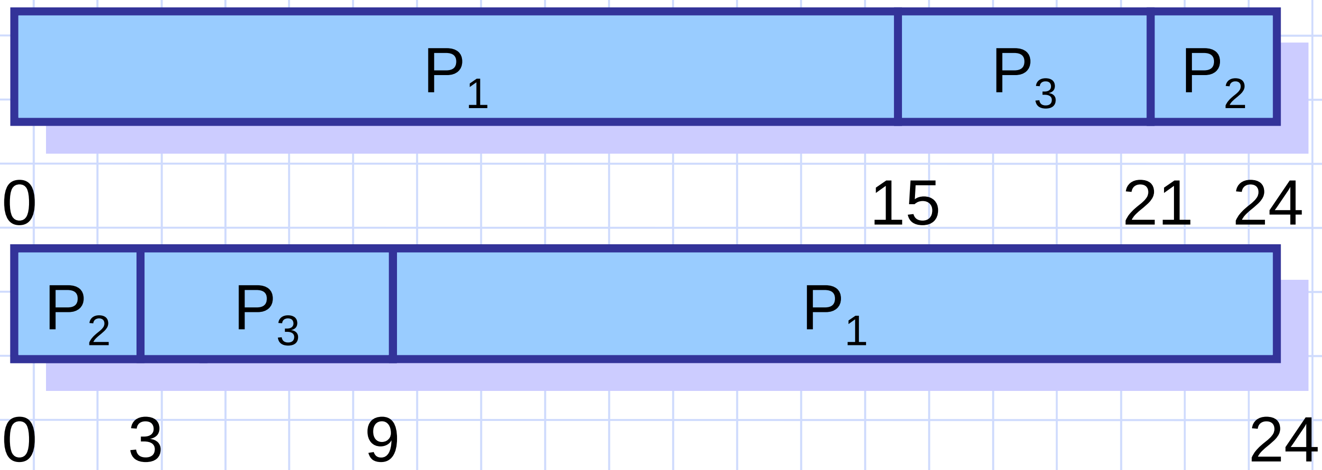
process	time
P_1	6
P_2	3
P_3	1
P_4	7

Problem Revisited

- You work as a short-order cook
  - Customers come in and specify which dish they want
  - Each dish takes a different amount of time to prepare
- Your goal:
  - minimize average time customers wait for their food
- What strategy would you use ?
  - Note: most restaurants use FCFS.

Scheduling Algorithms: SJF

- **Shortest Job First (SJF)**
  - Choose the job with the shortest next CPU burst
  - Provably optimal for minimizing average waiting time



- **Problem:**
  - Impossible to know the length of the next CPU burst

Shortest Job First Prediction

- Approximate next CPU-burst duration
  - from the durations of the previous bursts
    - The past can be a good predictor of the future
- No need to remember entire past history
- Use exponential average:

t_n duration of the n^{th} CPU burst

τ_{n+1} predicted duration of the $(n+1)^{st}$ CPU burst

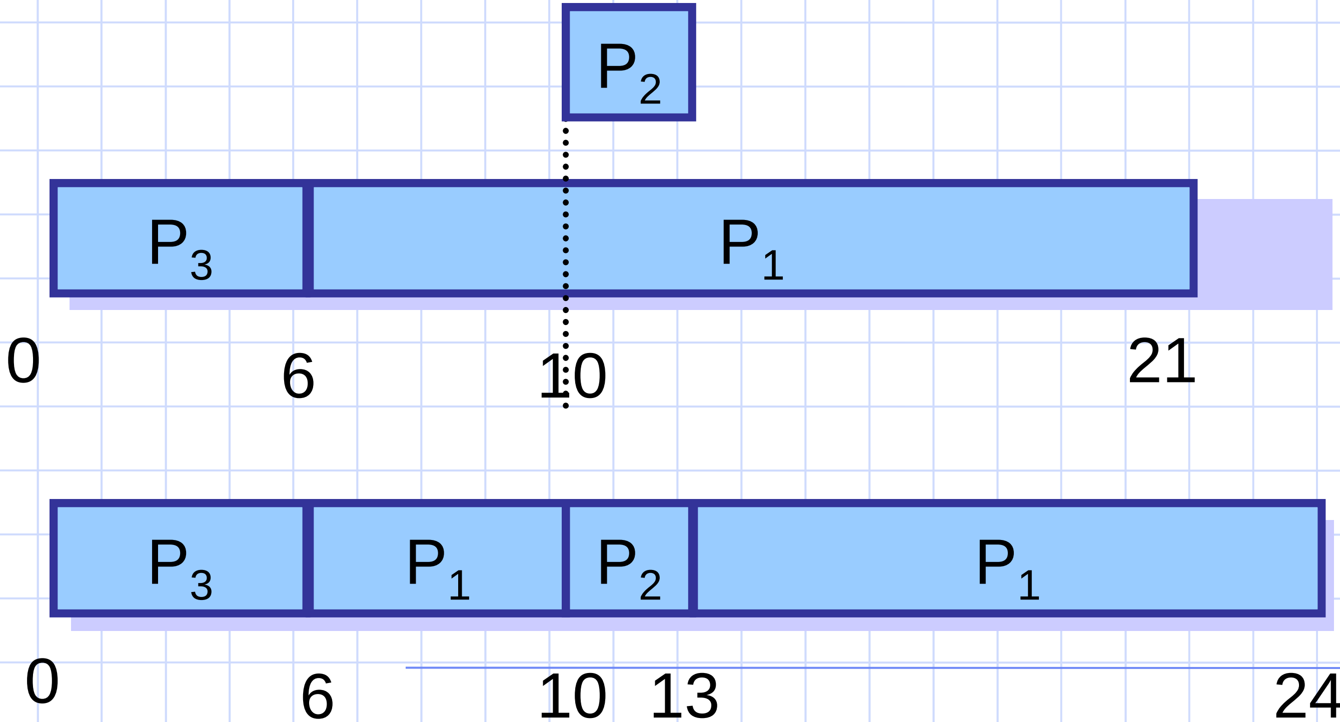
$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\, \tau_n$$

where $0 \leq \alpha \leq 1$

α determines the weight placed on past behavior

Scheduling Algorithms SRTF

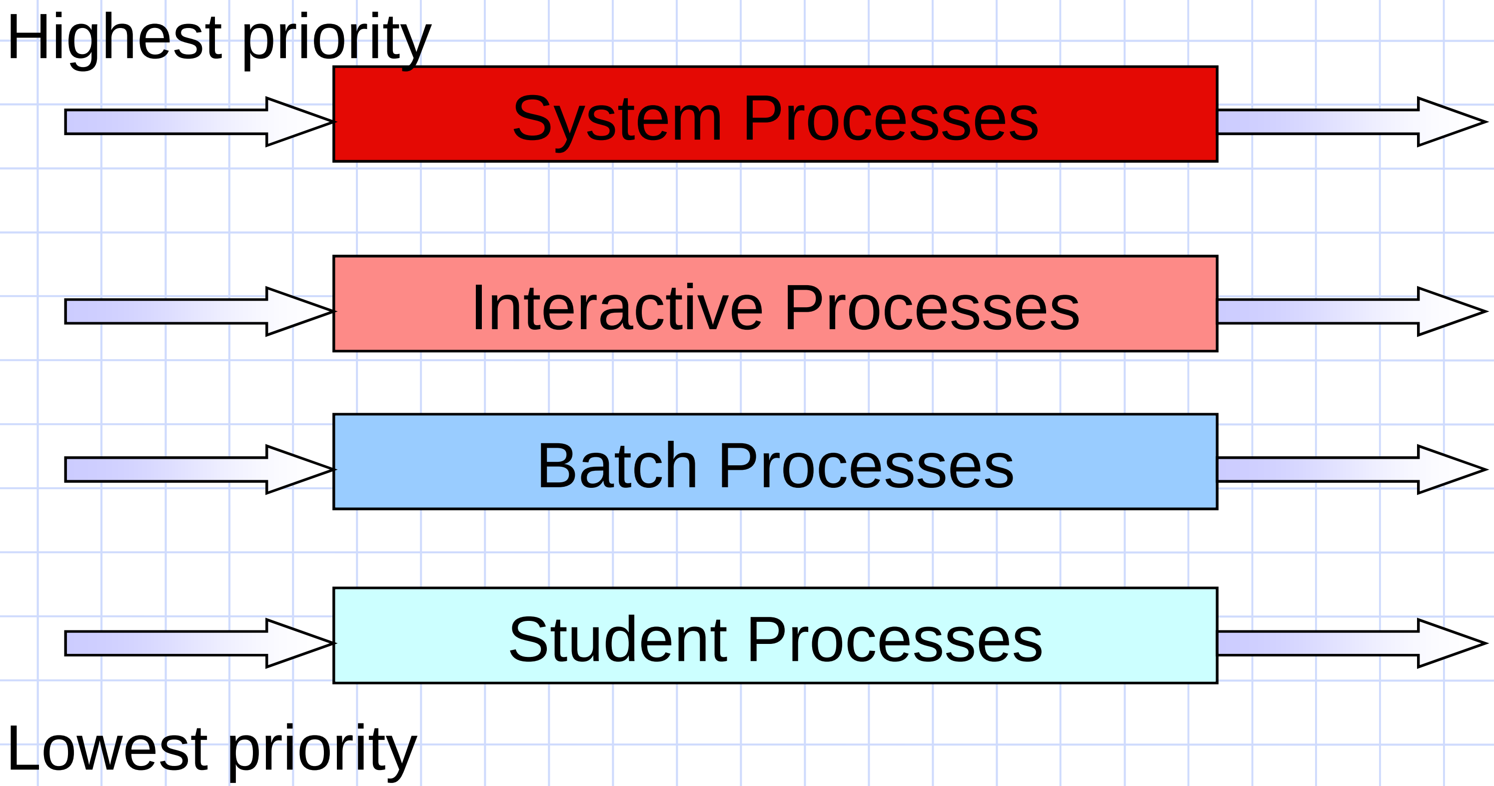
- SJF can be either preemptive or non-preemptive
  - New, short job arrives; current process has long time to execute
- Preemptive SJF is called *shortest remaining time first*



Priority Scheduling

- **Priority Scheduling**
  - Choose next job based on priority
  - For SJF, priority = expected CPU burst
  - Can be either preemptive or non-preemptive
- **Priority schedulers can approximate other scheduling algorithms**
  - **P = arrival time => FIFO**
  - **P = now - arrival time =>LIFO**
  - **P = job length => SJF**
- **Problem:**
  - Starvation: jobs can wait indefinitely
- **Solution to starvation**
  - Age processes: increase priority as a function of waiting time

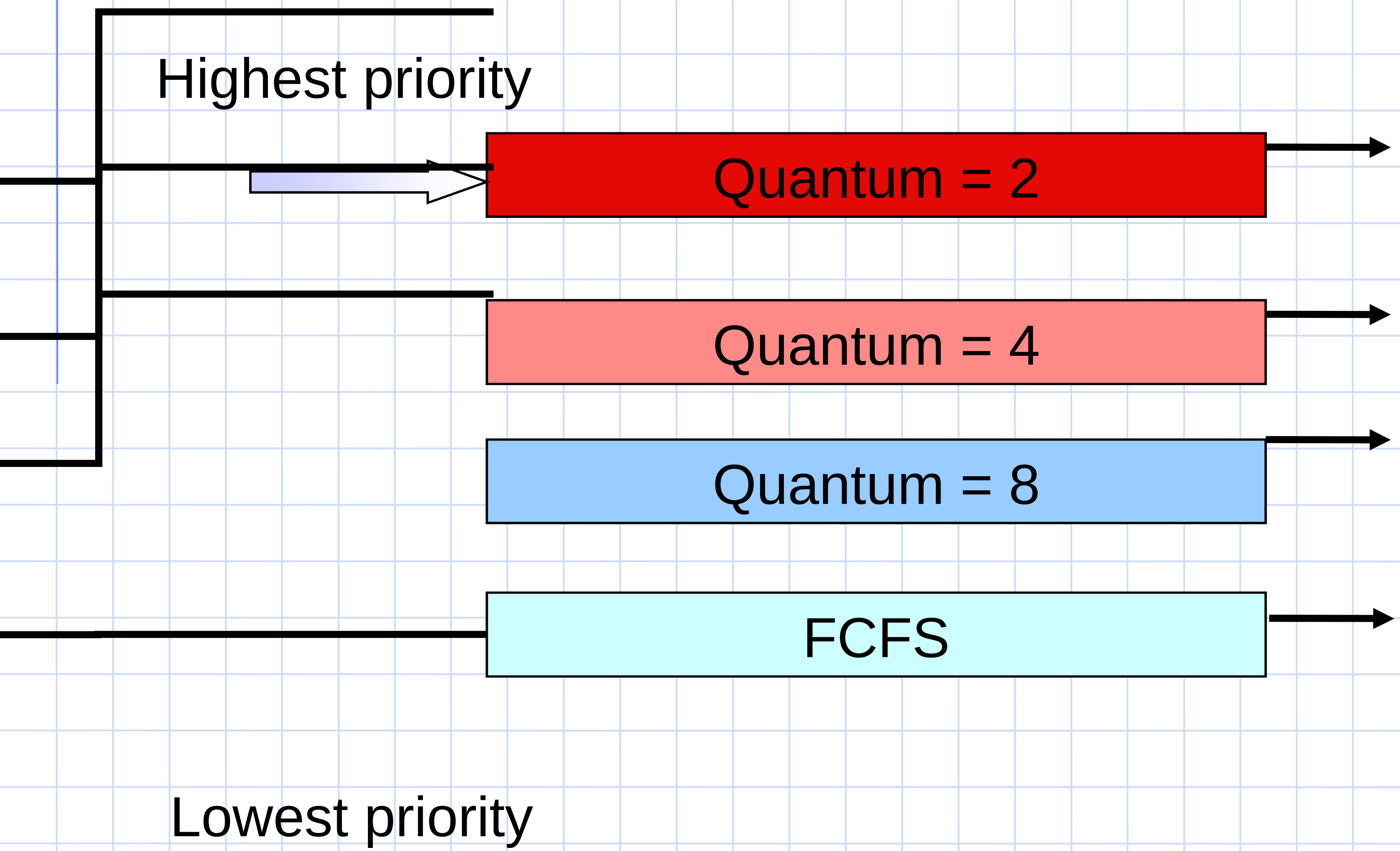
Multilevel Queue Scheduling



Multilevel Queue Scheduling

- Implement multiple ready queues based on job “type”
  - interactive processes
  - CPU-bound processes
  - batch jobs
  - system processes
  - student programs
- Different queues may be scheduled using different algorithms
- Intra-queue CPU allocation is either strict or proportional
- Problem: Classifying jobs into queues is difficult
  - A process may have CPU-bound phases as well as interactive ones

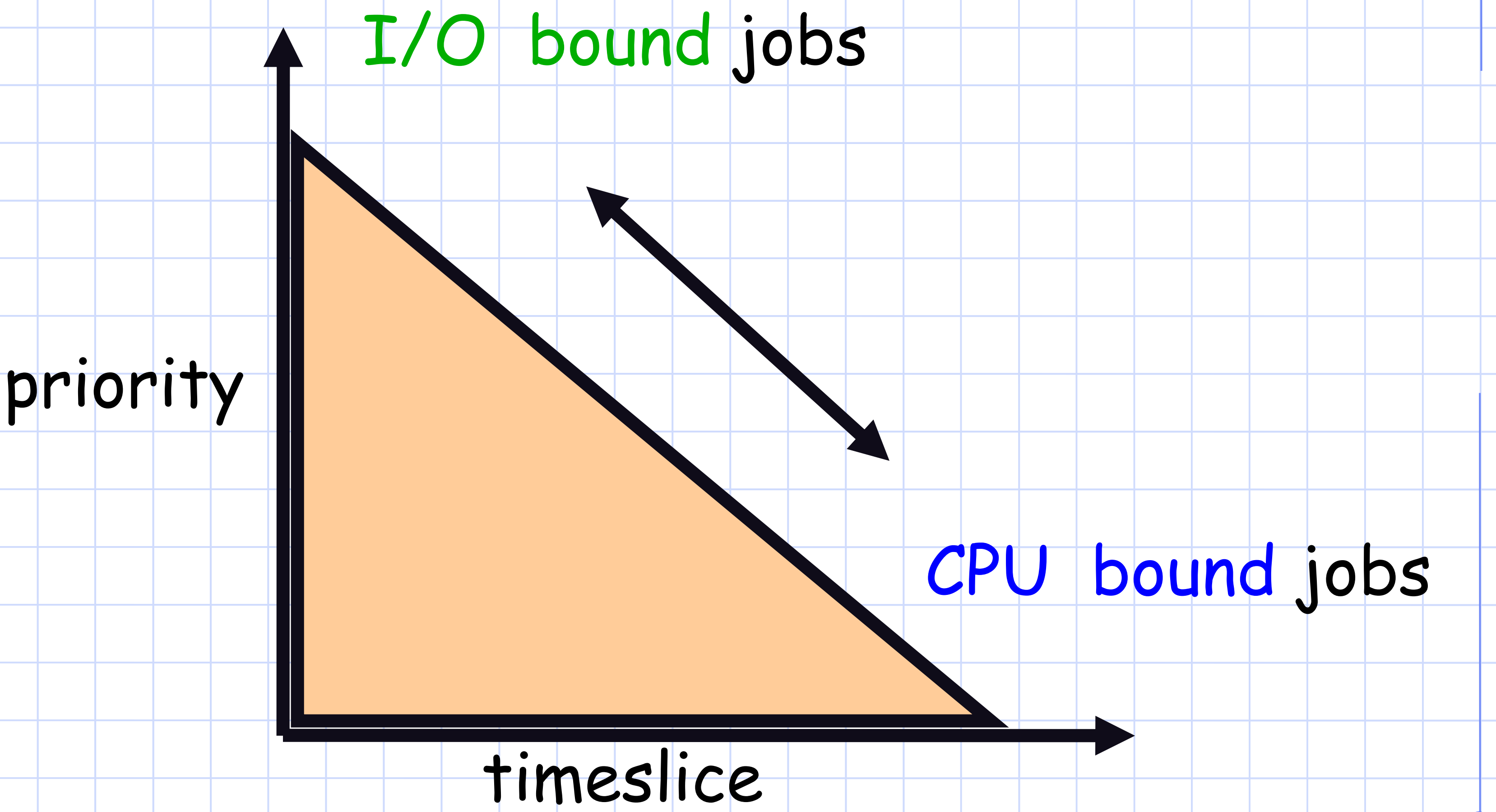
Multilevel Feedback Queues



Multilevel Feedback Queues

- Implement multiple ready queues
  - Different queues may be scheduled using different algorithms
  - Just like multilevel queue scheduling, but assignments are not static
- Jobs move from queue to queue based on feedback
  - Feedback = The behavior of the job,
    - e.g. does it require the full quantum for computation, or
    - does it perform frequent I/O ?
- Very general algorithm
- Need to select parameters for:
  - Number of queues
  - Scheduling algorithm within each queue
  - When to upgrade and downgrade a job

A Multi-level System



Algorithm Summary

- FIFO
- LIFO
- RR
- SJF
- SRTF
- Priority-based
- Multilevel queue
- Multilevel *feedback* queue

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advanced topics

real-time, threads, multiprocessor

Real-time Scheduling

- Real-time processes have timing constraints
  - Expressed as deadlines or rate requirements
- Common RT scheduling policies
  - Rate monotonic
    - Just one scalar priority related to the periodicity of the job
    - Priority = 1/rate
    - Static
  - Earliest deadline first (EDF)
    - Dynamic but more complex
    - Priority = deadline
- Both require admission control to provide guarantees

Common misconception: real time does not mean fast!

Thread Scheduling

all threads share code & data segments

Option 1: Ignore this fact

Option 2: Two-level scheduling:

- user-level scheduler
- schedule processes, and within each process, schedule threads
- reduce context switching overhead and improve cache hit ratio

Multiprocessor Scheduling

Option 1. Ignore this fact

- random in time and space

Option 2. Space-based affinity:

- assign threads to processors

+ control resource sharing: sharing/interference

- possibly poor load balancing

Option 3. Gang scheduling

- run all threads belonging to a process <u>at the same time</u>

+ low-latency communication

- greater distance (cache)

Postscript

- To do absolutely best we'd have to predict the future.
  - Most current algorithms give highest priority to those that need the least!
- Scheduling has become increasingly ad hoc over the years.
  - 1960s papers very math heavy, now mostly "tweak and see"

Convoy Effect

- A CPU bound job will hold CPU until done,
  - or it causes an I/O burst
    - rare occurrence, since the thread is CPU-bound

  $\Rightarrow$ long periods where no I/O requests issued, and CPU held
  - Result: poor I/O device utilization
- Example: one CPU bound job, many I/O bound
    - CPU bound runs (I/O devices idle)
    - CPU bound blocks
    - I/O bound job(s) run, quickly block on I/O
    - CPU bound runs again
    - I/O completes
    - CPU bound still runs while I/O devices idle (continues…)
  - Simple hack: run process whose I/O completed?
    - What is a potential problem?

Problem Cases

- Blindness about job types
  - I/O goes idle
- Optimization involves favoring jobs of type “A” over “B”.
  - Lots of A’s? B’s starve
- Interactive process trapped behind others.
  - Response time suffers for no reason
- Priorities: A depends on B. A’s priority > B’s.
  - B never runs