CS 370: OPERATING SYSTEMS

[CPU SCHEDULING]

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Spring 2024

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Topics covered in this lecture

- Scheduling Algorithms
  - Priority Scheduling
  - Lottery scheduling
  - Round robin scheduling

- Scheduling Examples
  - Windows, Linux

Prediction of CPU bursts: Make estimates based on past behavior

- t_n : Length of the n^{th} CPU burst
- τ_n : Estimate for the n^{th} CPU burst
- α : Controls weight of recent and past history
- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$

- Burst is predicted as an exponential average of the measured lengths of previous CPU bursts

α controls the relative weight of recent and past history

- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- Value of t_n contains our most recent information, while τ_n stores the past history
- $\tau_{n+1}=\alpha t_n + (1-\alpha)\,\alpha t_{n-1} + \ldots + (1-\alpha)^j\,\alpha t_{n-j} + \ldots + (1-\alpha)^{n+1}\,\alpha\tau_0$
- α is less than 1, $(1-\alpha)$ is also less than one
  - **Each successive term has less weight than its predecessor**

The choice of α in our predictive equation

- $\tau_{n+1} = \alpha t_n + (1-\alpha)\,\tau_n$
- If $\alpha=0$, $\tau_{n+1} = \tau_n$
  - Current conditions are transient
- If $\alpha=1$, $\tau_{n+1} = t_n$
  - Only most recent bursts matter
  - History is assumed to be old and irrelevant

The choice of α in our predictive equation

- If $\alpha=1/2$
  - Recent history and past history are **equally weighted**

- With $\alpha = ½$; successive estimates of τ

$t_0/2 \quad t_0/4 + t_1/2 \quad t_0/8 + t_1/4 + t_2/2 \quad t_0/16 + t_1/8 + t_2/4 + t_3/2$

  - By the 3rd estimate, weight of t_0 has dropped to 1/8.

PRIORITY SCHEDULING

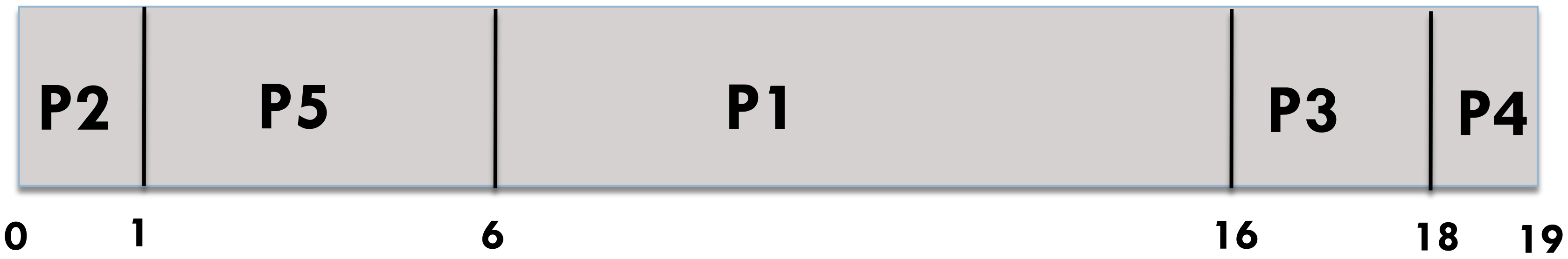
Priority Scheduling

- **Priority** associated with each process
- CPU allocated to process with **highest** priority
- Can be preemptive or nonpreemptive
  - If preemptive: Preempt CPU from a lower priority process when a higher one is ready

Depiction of priority scheduling in action

Process	Burst Time	Priority
P1	10	3
P2	1	1
P3	2	4
P4	1	5
P5	5	2

Here: Lower number means higher priority



`Wait time = (6 + 0 + 16 + 18 + 1)/5 = 8.2`

How priorities are set

- Internally defined priorities based on:
  - **Measured** quantities
  - Time limits, memory requirements, # of open files, ratio (averages) of I/O to CPU burst

- External priorities
  - Criteria outside the purview of the OS
  - Importance of process, $ paid for usage, politics, etc.

Issue with priority scheduling

- Can leave lower priority processes waiting indefinitely
- Perhaps apocryphal tale:
  - MIT's IBM 7094 shutdown (1973) found processes from 1967!

Coping with issues in priority scheduling: Aging

- **Gradually increase priority** of processes that wait for a long time
- Example:
  - Process with priority of 127 and increments every 15 minutes
  - Process priority becomes 0 in no more than 32 hours

Can SJF be thought as a priority algorithm?

- Priority is **inverse** of CPU burst
- The larger the burst, the lower the priority

Round Robin scheduling

Round-Robin Scheduling

- Similar to FCFS scheduling
  - **Preemption** to enable switch between processes
- Ready queue is implemented as **FIFO**
  - Process Entry: PCB at *tail* of queue
  - Process chosen: From *head* of the queue
- CPU scheduler goes around ready queue
  - Allocates CPU to each process *one after the other*
    - CPU-bound up to a maximum of 1 **quantum**

Round Robin: Choosing the quantum

- Context switch is **time consuming**
  - Saving and loading registers and memory maps
  - Updating tables
  - Flushing and reloading memory cache
- What if quantum is 4 ms and context switch overhead is 1 ms?
  - 20% of CPU time thrown away in administrative overhead

Round Robin: Improving efficiency by increasing quantum

- Let's say quantum is 100 ms and context-switch is 1ms
  - Now wasted time is only 1%
- But what if 50 concurrent requests come in?
  - Each with widely varying CPU requirements
  - 1st one starts immediately, 2nd one 100 ms later, …
  - The last one may have to wait for 5 seconds!
  - A shorter quantum would have given them better service

If quantum is set longer than mean CPU burst?

- **Preemption will not happen very often**
- Most processes will perform a blocking operation before quantum runs out
- Switches happens only when process blocks and cannot continue

Quantum: Summarizing the possibilities

- Too short?
  - Too *many* context switches
  - Lowers CPU efficiency
- Too long?
  - *Poor* responses to interactive requests

Lottery Scheduling

Lottery scheduling

- Give processes **lottery tickets** for various system resources
  - E.g. CPU time
- When a scheduling decision has to be made
  - Lottery ticket is *chosen at random*
  - Process holding **ticket gets** the resource

All processes are equal, but some processes are more equal than others

- More important processes are given **extra tickets**
  - Increase their odds of winning
- Let's say there are 100 outstanding tickets
  - 1 process holds 20 of these
  - Has 20% chance of winning each lottery
- A process holding a fraction f of tickets
  - Will get about a fraction f of the resource

Lottery Scheduling: Properties (1/2)

- Highly **responsive**
  - Chance of winning is proportional to tickets
- Cooperating processes may **exchange** tickets
  - Process **A** sends request to **B**, and then hands **B** all its tickets for a faster response
- Avoids starvation
  - Each process holds at least one ticket …. Is guaranteed to have a non-zero probability of being scheduled

Lottery Scheduling: Properties (2/2)

- Solves problems that are *difficult to handle* in other scheduling algorithms

- E.g. video server that is managing processes that feed video frames to clients
  - Clients need frames at 10, 20, and 25 frames/sec
  - Allocate processes 10, 20 and 25 tickets
    - CPU divided into approximately 10:20:25

MULTIPROCESSOR/CORE ENVIRONMENTS

Load balancing: Migration based approaches

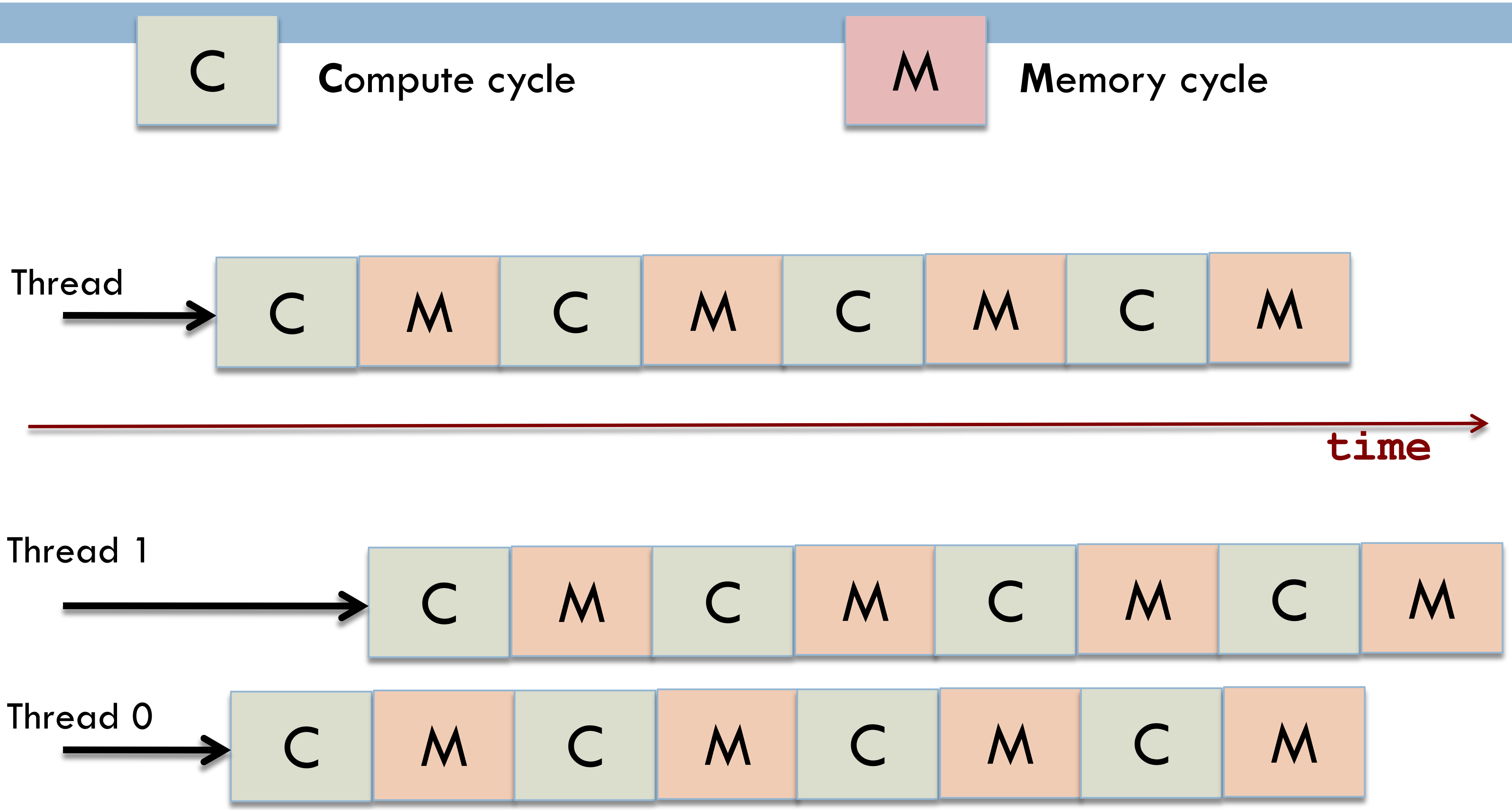
- Push migration
  - Specific task periodically checks for *imbalance*
  - Balances load by **pushing** processes from overloaded to less-busy processors.
- Pull migration
  - Idle processor pulls a waiting task from busy processor
- Schemes **not mutually exclusive**: used in parallel
  - Linux: Runs a load-balancing algorithm
    - Every 200 ms (**PUSH** migration)
    - When processor run-queue is empty (**PULL** migration)

Multicore processors place multiple processor cores on same physical chip

- Each core has its own register set
  - Appears to the OS as a separate physical processor

- Recent designs implement 2 or more hardware threads per core
  - If there is a memory stall (due to cache miss) on one thread, **switch** to another hardware thread

Coping with memory stalls



Multithreading a processor

- **Coarse** grained
  - Thread executes on processor till a memory stall
  - Switch to another thread

- Switching between threads
  - *Flush* the instruction pipeline
  - *Refill* pipeline as new thread executes

- **Finer** grained (or interleaved)
  - Switch between threads at the boundary of an instruction cycle
  - Design includes logic for thread switching: overheads are low

Tiered scheduling on multicore processors

- First-level: OS
  - OS chooses which software thread to run on each hardware thread
- Second-level: Core
  - Decides which hardware thread to run
- UltraSPARC T1
  - 8 cores, and 4 hardware threads/core
  - Round robin to schedule hardware threads on core

SCHEDULING EXAMPLES

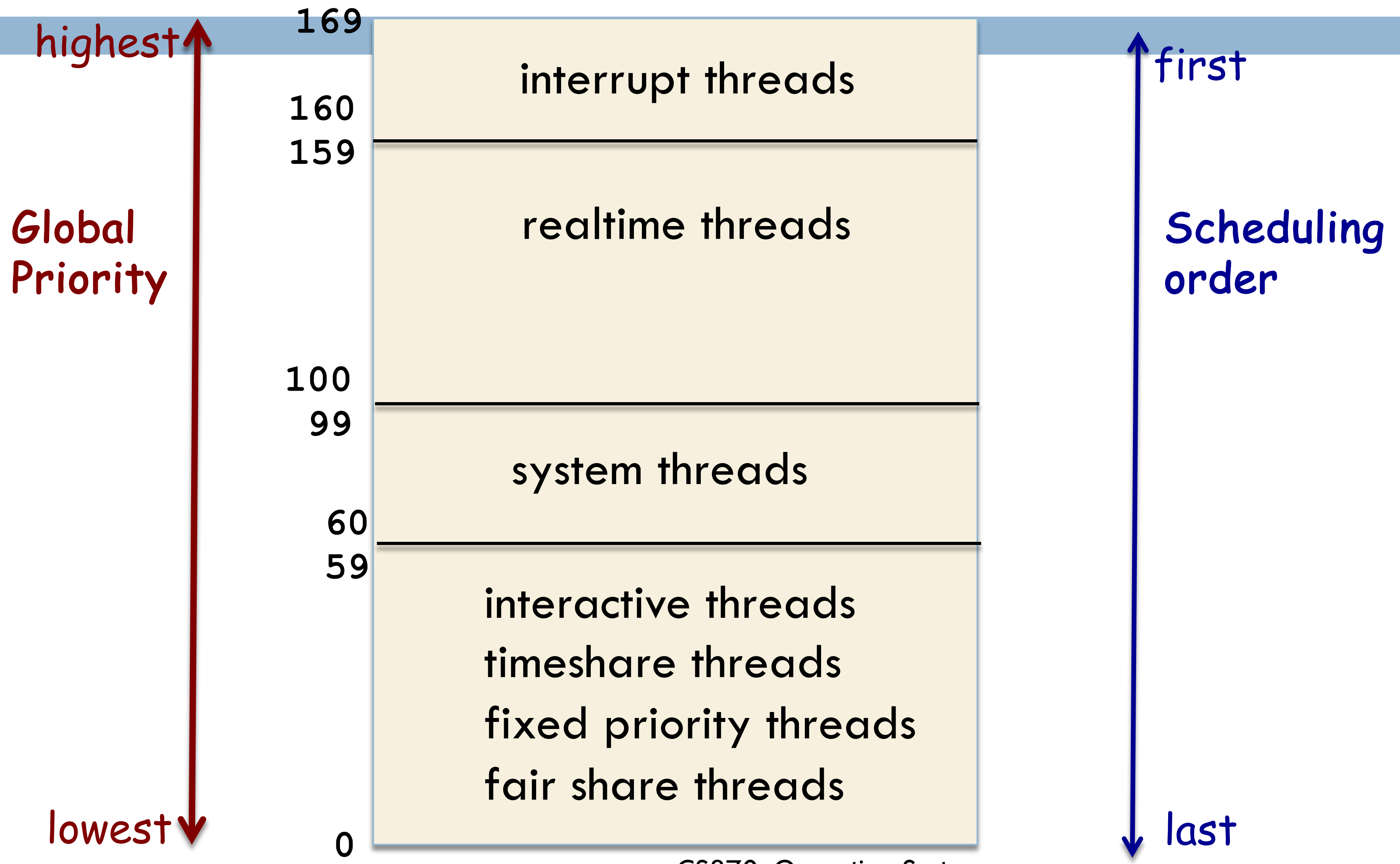
Scheduling examples

- Solaris
- Windows
- Linux

Scheduling Example: Solaris

- Thread belongs to 1 of six classes
- **Inverse relationship** between priorities and time slices
  - Higher priority = smaller time slice
    - Interactive processes
    - Priority 59: 20 millisecond quantum
  - Lower priority = bigger time slice
    - CPU bound processes
    - Priority 0 = 200 millisecond quantum

Solaris scheduling



WINDOWS XP SCHEDULING

Scheduling Example: Windows XP

- Priority-based, preemptive scheduling
  - Highest priority thread will always run
- 32-level priority scheme
  - Variable class: priorities 1-15
  - Realtime class: priorities 16-31
  - Memory management thread: priority 0

Dispatcher in Windows XP

- Use a **queue** for each scheduling priority
- **Traverse** the queues from highest to lowest
  - *Until* it finds a thread that is ready to run
- If no ready thread is found?
  - Dispatcher will execute a special thread: **idle thread**

Idle thread in Windows

- Primary purpose is to **eliminate a special case**
  - Cases when no threads are runnable or ready
  - Idle threads are always in a *ready* state
    - If not already running
- Scheduler can always find a thread to execute
- If there are other eligible threads?
  - Scheduler will never select the idle thread

Idle threads in Windows

- Windows thread priorities go from 0-31
  - Idle thread priority can be thought of as -1

- Threads in the system idle process can also implement CPU power saving
  - On x86 processors, run a loop of **halt** instructions
  - Causes CPU to **turn off internal components**
    - Until an interrupt request arrives
  - Recent versions also **reduce the CPU clock speed**

Time consumed by the idle process

- It may seem that the idle process is monopolizing the CPU
  - It is merely acting as a *placeholder during free time*
  - Proof that no other process wants that CPU time

Scheduling Example: Windows XP
Identifies 6 priority classes for threads

- Thread priorities for classes are **variable**
- Relative priority for thread within a class

Windows XP priorities: Threads within a priority class also have a relative priority

	REAL TIME	HIGH	ABOVE NORMAL	NORMAL	BELOW NORMAL	IDLE PRIORITY
Time-critical	31	15	15	15	15	15
highest	26	15	12	10	8	6
above normal	25	14	11	9	7	5
normal	24	13	10	8	6	4
below normal	23	12	9	7	5	3
lowest	22	11	8	6	4	2
idle	16	1	1	1	1	1

Base priority for each thread class

Windows XP: Managing the priority of variable priority threads

- **Lowering** the priority of a thread
  - When a thread's quantum runs out
    - Lower priority BUT not below base priority

Windows XP: Boosting the priority of threads

- Upon release from a **wait** operation
  - Thread waiting for keyboard IO gets big boost
  - Thread waiting for disk IO gets *moderate* boost
- Window with which user is **interacting**
  - Gives good response for interactive thread
- When process moves to **foreground**
  - Scheduling quantum boosted by 3

LINUX SCHEDULING

Highlights of Linux scheduling (1)

- Scheduling algorithm runs in constant time
- Implements real-time scheduling (POSIX 1.b)
  - Real-time tasks have static priorities
  - Other tasks have dynamic priorities
- We look at the algorithm in kernel version 2.5
  - Revised again in version 2.6.23 of the kernel [called: Completely Fair Scheduler]

Highlights of Linux scheduling (2)

- Preemptive, priority-based algorithm
- Two separate priority ranges
  - **Real-time** range: 0-99
  - **Nice** value: 100-140
- Numerically *lower* values indicate *higher* priority

Highlights of Linux scheduling (3)

- **UNLIKE** Solaris and Windows
  - Higher priority tasks = higher quanta
  - Lower priority tasks = lower quanta
- Task's **interactivity** determined by
  - *Sleeping times* waiting for I/O

Task execution in Linux

- Task eligible for execution as long as it has time remaining in its time slice
- When a task has exhausted its time slice?
  - Ineligible for execution again, until …
  - All other tasks have exhausted their time quanta

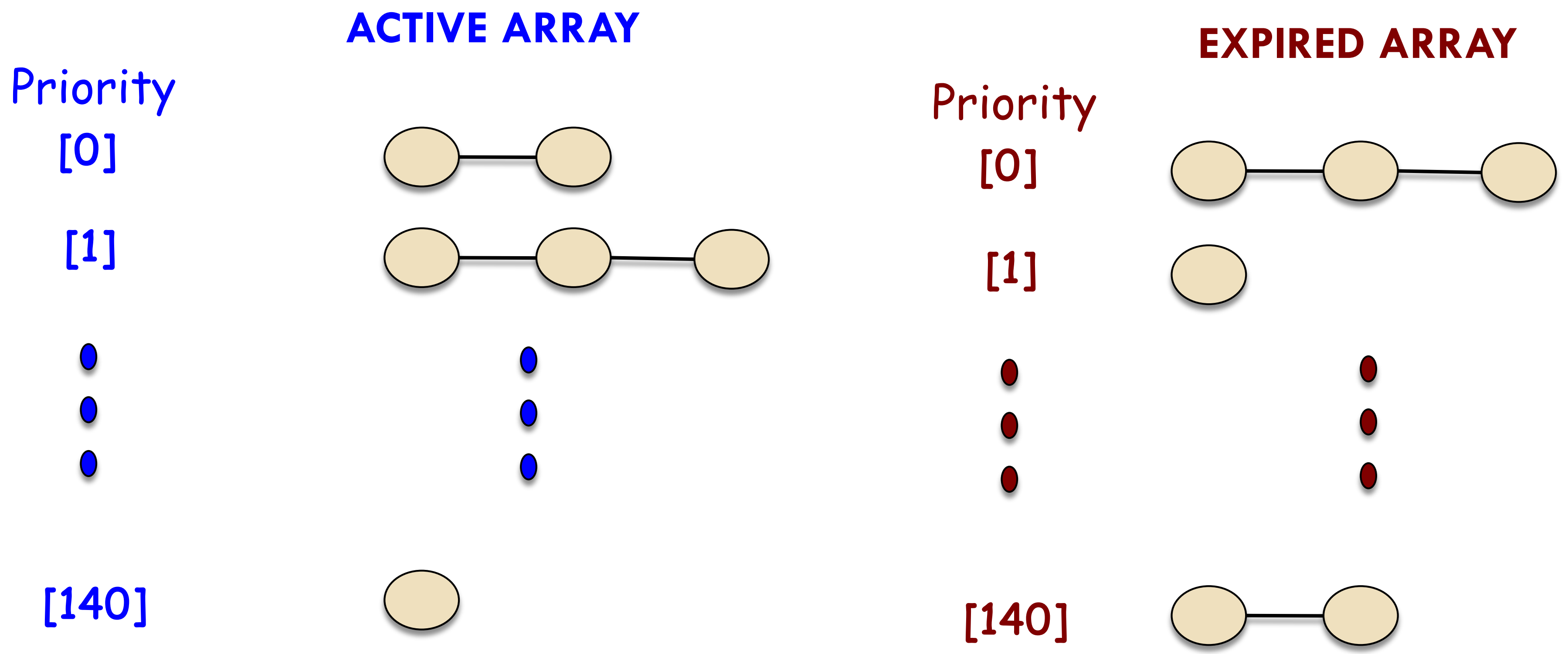
Each `runqueue` contains two priority arrays: Active and Expired

- Active array
  - All tasks with time remaining in their time slices
- Expired array
  - Contains all expired tasks
- Each priority array contains list of tasks **indexed** according to priority

Swapping the active and expired arrays

- When **all tasks have exhausted** their time slices?
  - Active array is empty
- The two priority arrays are **exchanged**
  - Expired array becomes the active array, and vice versa

Linux: Tasks indexed according to priority



Little's formula

- n be the average queue length
- W average wait time in the queue
- λ average arrival rate of processes

When a process waits for time W

λ x W processes arrives

Steady state: Processes leaving = Processes arriving

$$n = \lambda \times W$$

The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 6]

- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2]