Process/Thread/Task scheduling

Hung-Wei Tseng

Outline

- Mechanisms of changing processes
- Basic scheduling policies
- An experimental time-sharing system — The Multi-Level Scheduling Algorithm
- Scheduler Activations

The mechanisms of changing processes

The mechanisms of changing the running processes

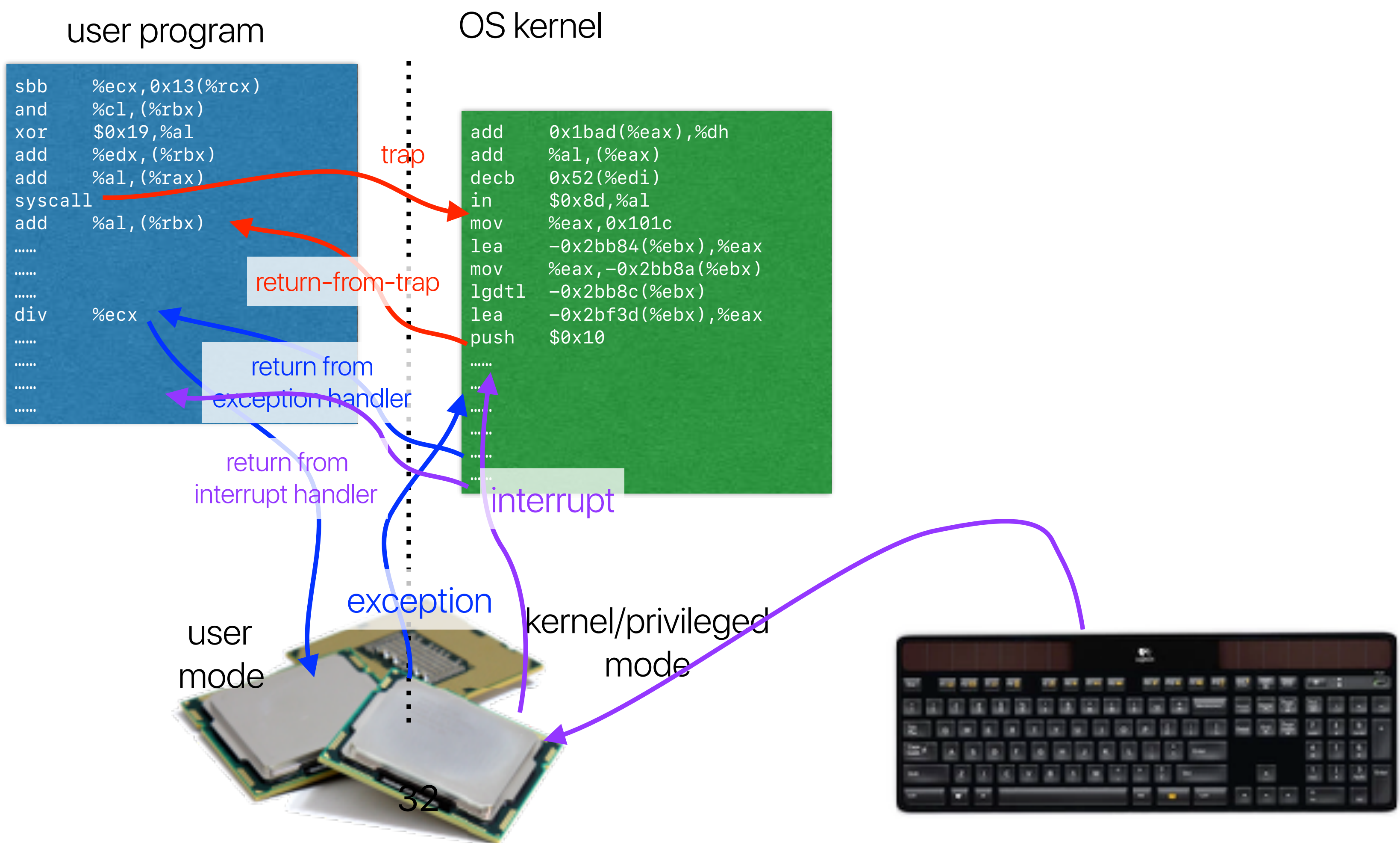
- Cooperative Multitasking (non-preemptive multitasking)
- Preemptive Multitasking

Preemptive Multitasking

- The OS controls the scheduling — can change the running process even though the process does not give up the resource
- But how?

Three ways to invoke OS handlers

- System calls / trap instructions — raised by applications
  - Display images, play sounds
- Exceptions — raised by processor itself
  - Divided by zero, unknown memory addresses
- Interrupts — raised by hardware
  - Keystroke, network packets



How preemptive multitasking works

- Setup a timer event before the process start running
- After a certain period of time, the timer generates interrupt to force the running process transfer the control to OS kernel
- The OS kernel code decides if the system wants to continue the current process
  - If not — context switch
  - If yes, return to the process

Basic scheduling policies

CPU Scheduling

- Virtualizing the processor
  - Multiple processes need to share a single processor
  - Create an illusion that the processor is serving my task by rapidly switching the running process
- Determine which process gets the processor for how long

What you learned before

- Non-preemptive/cooperative: the task runs until it finished
  - FIFO/FCFS: First In First Out / First Come First Serve
  - SJF: Shortest Job First
- Preemptive: the OS periodically checks the status of processes and can potentially change the running process
  - STCF: Shortest Time-to-Completion First
  - RR: Round robin

An experimental time-sharing system

Fernando J. Corbató, Marjorie Merwin-Daggett and Robert C. Daley

Massachusetts Institute of Technology, Cambridge, Massachusetts

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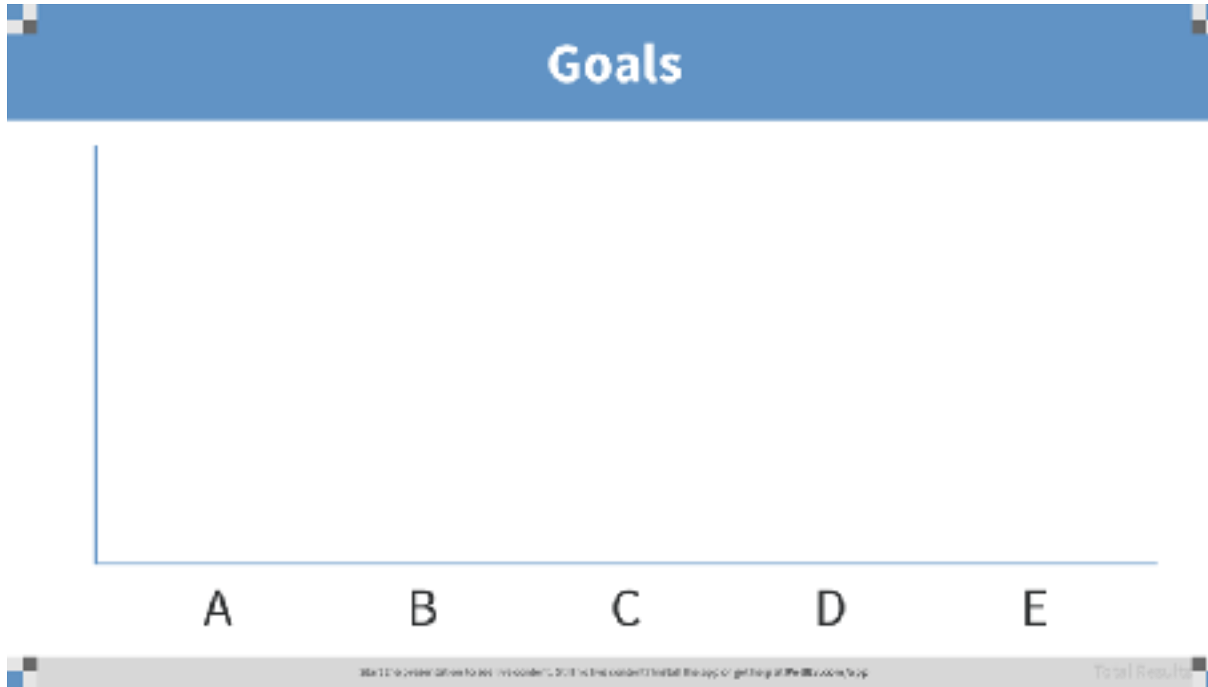
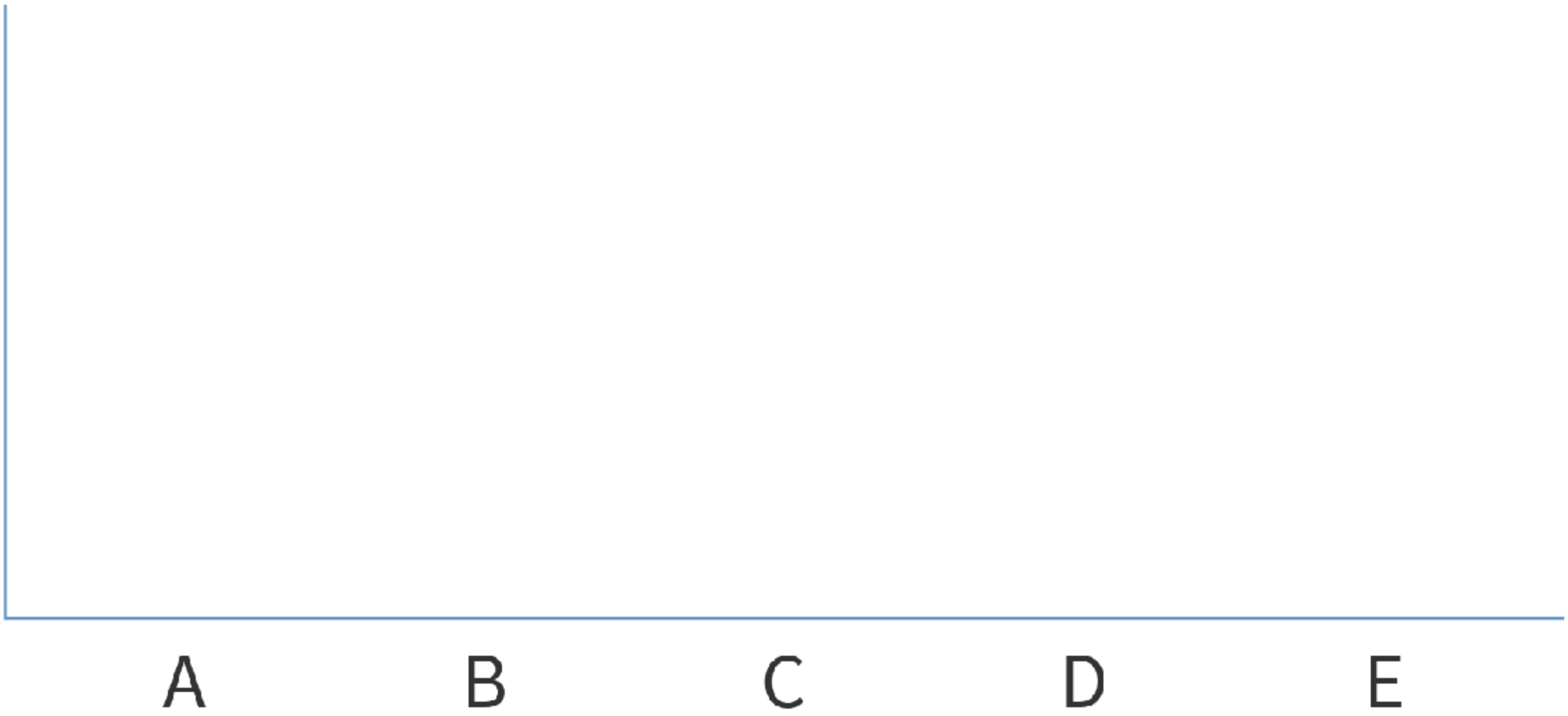
Why Multi-level scheduling algorithm

- Why MIT's experimental time-sharing system proposes Multi-level schedule algorithm? How many of the following
  ① Optimize for the average response time of tasks
  ② Optimize for the average turn-around time of tasks
  ③ Optimize for the performance of long running tasks
  ④ Guarantee the fairness among tasks

  A. 0
  B. 1
  C. 2
  D. 3
  E. 4



Goals



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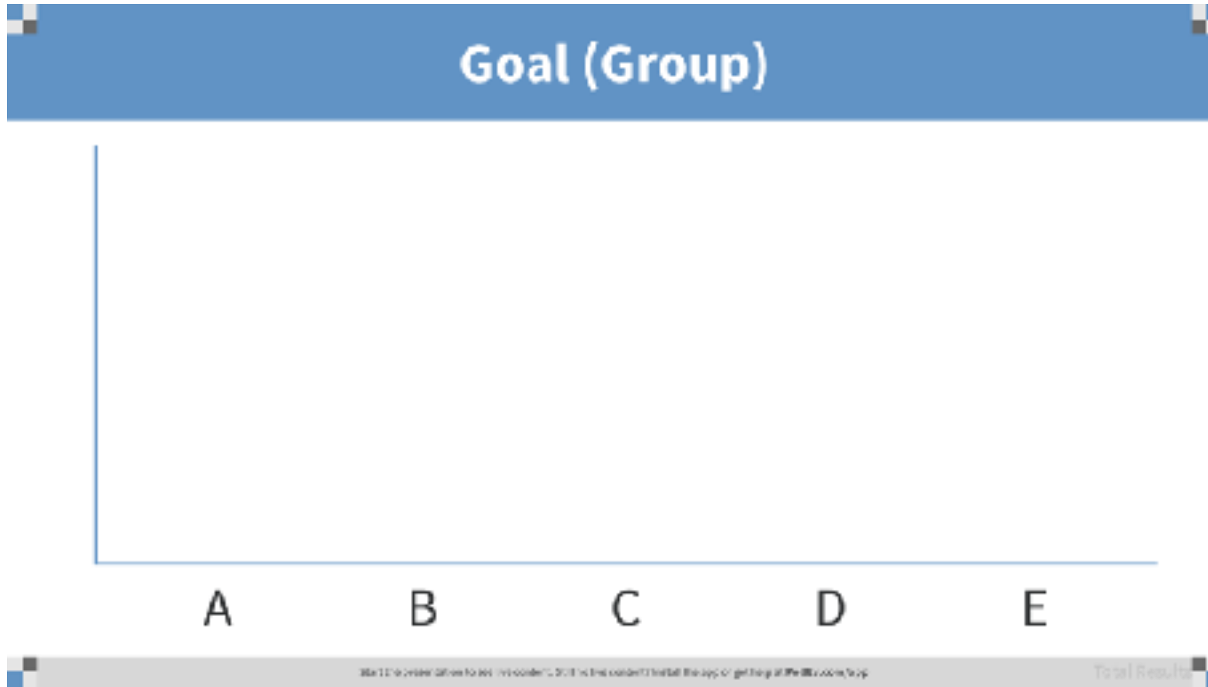
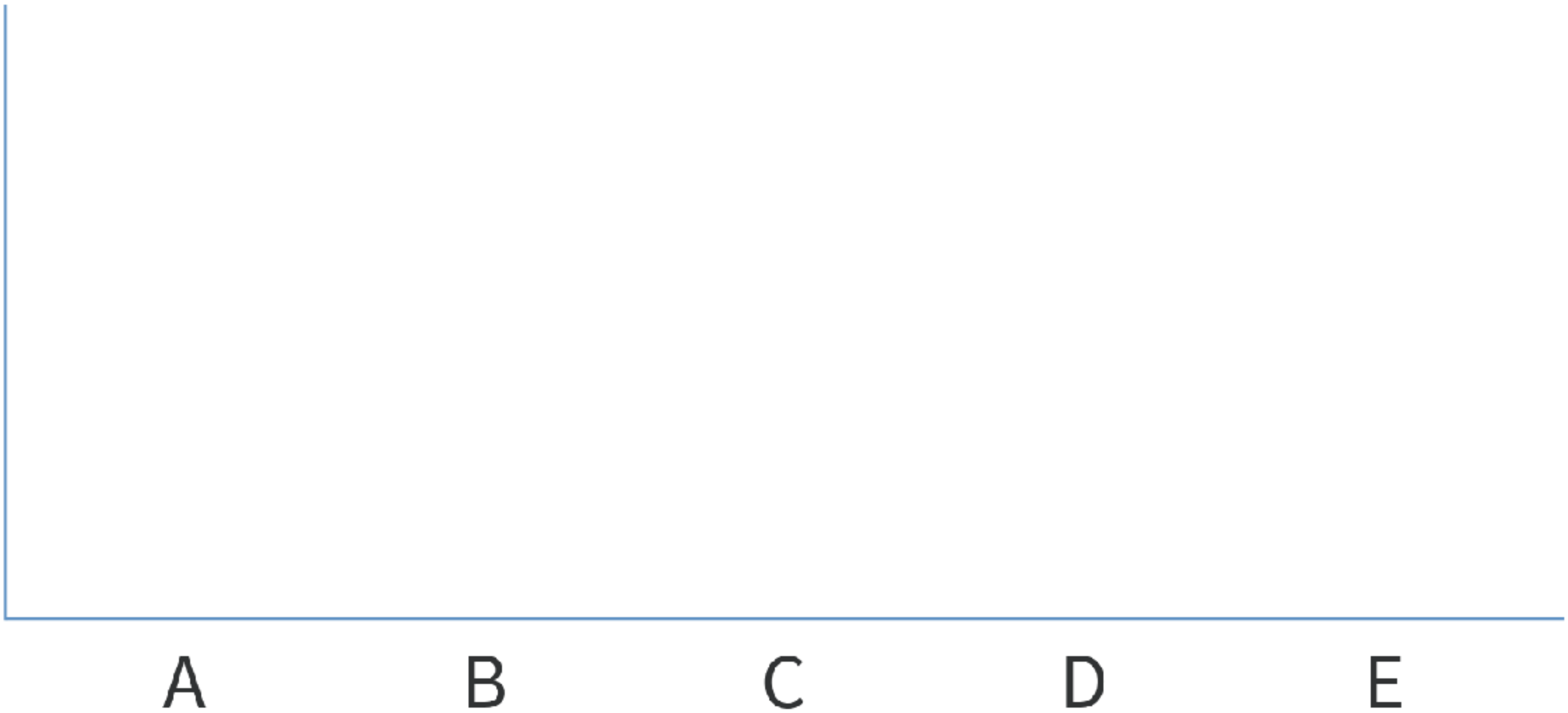


Goal (Group)



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> 4. The response time for programs of equal size, entering the system at the same time, and being run for multiple quanta, is no worse than approximately twice the response-time occurring in a single quanta round-robin procedure. If

> To illustrate the strategy that can be e ployed to improve the saturation performance of a time-sharing system, a multi-level scheduling algorithm is presented. This algorithm also

> Several important conclusions can be drawn from the above algorithm which allow the performance of the system to be bounded.

Why Multi-level scheduling algorithm?

- System saturation — the demand of computing is larger than the physical resource available
- Service level degrades
  - Lots of program swap ins-and-outs (known as context switches in our current terminology)
  - User interface response time is bad — you have to wait until your turn
  - Long running tasks cannot make good progress — frequent swap in-and-out

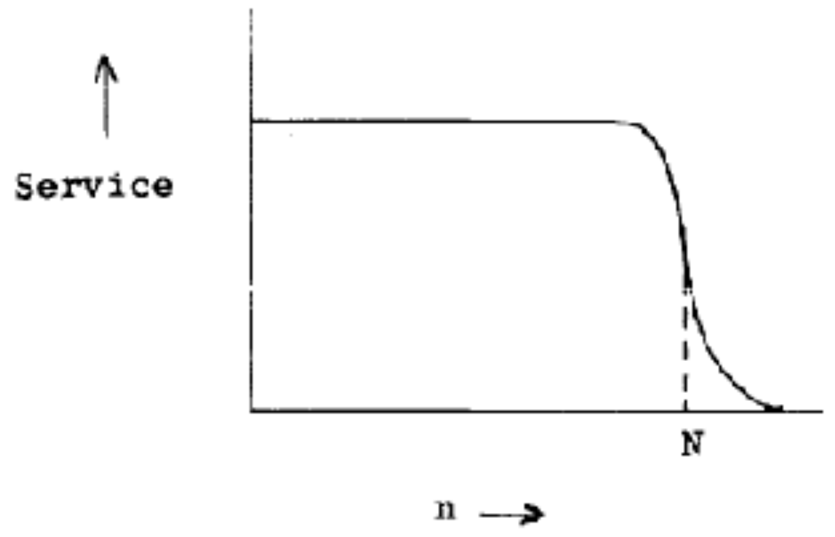
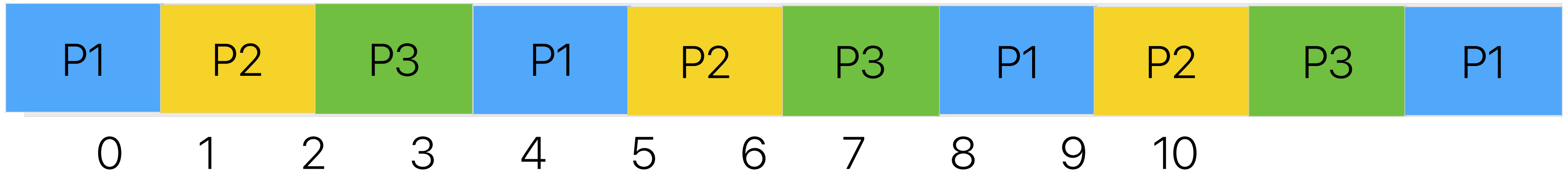


Figure 1. Service vs. Number of Active Users

Context Switch Overhead

You think round robin should act like this —



But the fact is —

- **Your processor utilization can be very low if you switch frequently**
- **No process can make sufficient amount of progress within a given period of time**
- **It also takes a while to reach your turn**

The Multilevel Scheduling Algorithm

- Place new process in the one of the queue
  - Depending on the program size

$$\ell_o = \left[\log_2\left(\left[\frac{w_p}{w_q}\right] + 1\right)\right]$$

w_p is the program memory size — smaller ones are assigned to lower numbered queues

Why?

  - **Smaller tasks are given higher priority in the beginning**

- Schedule processes in one of N queues
  - Start in initially assigned queue n
  - Run for 2^n quanta (where n is current depth)
  - If not complete, move to a higher queue (e.g. n +1)
  - **Larger process will execute longer before switch**
- Level m is run only when levels 0 to m-1 are empty
- **Smaller process, newer process are given higher priority**

The Multilevel Scheduling Algorithm

- Not optimized for anything — it's never possible to have an optimized scheduling algorithm without prior knowledge regarding all running processes
- It's practical — many scheduling algorithms used in modern OSes still follow the same idea

Lottery Scheduling: Flexible Proportional-Share Resource Management

Carl A. Waldspurger and William E. Weihl

Why lottery?

- Quality of Service — we need to give important applications higher priorities
- Flexible, responsive control — easy to adjust the priority of processes
- However —
  - Existing policies are difficult to understand
  - Precise control requires high overheads

What lottery proposed?

- Each process hold a certain number of lottery tickets
- Randomize to generate a lottery
- If a process wants to have higher priority
  - Obtain more tickets!

Ticket economics

- Ticket transfers
- Ticket inflation
- Ticket currencies
- Compensation tickets

How good is lottery?

- The overhead is not too bad
  - 1000 instructions ~ less than 500 ns on a 2 GHz processor
- Fairness
  - Figure 5: average ratio in proportion to the ticket allocation
- Flexibility
  - Allows Monte-Carlo algorithm to dynamically inflate its tickets
- Ticket transfer
  - Client-server setup

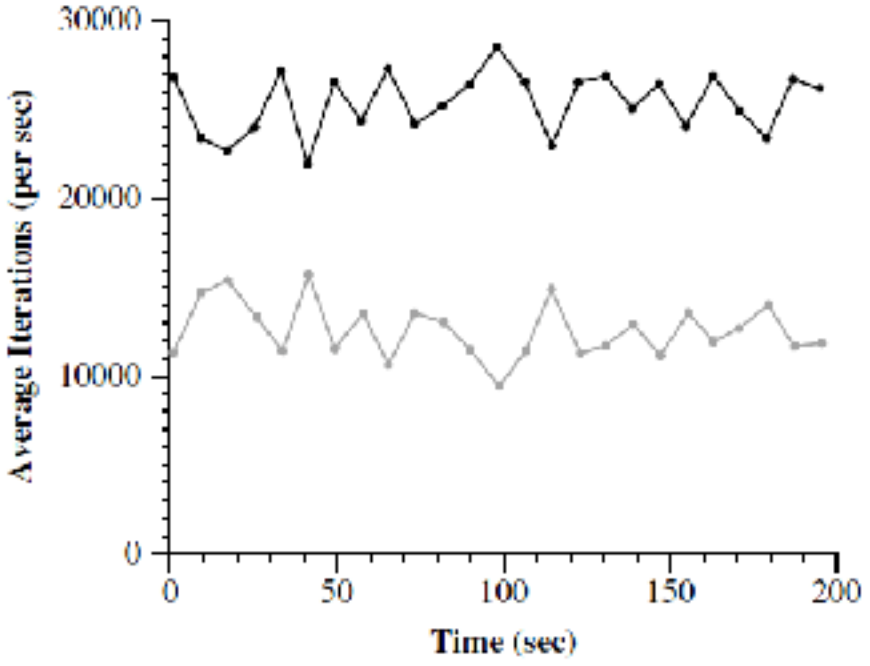


Figure 5: **Fairness Over Time.** Two tasks executing the Dhrystone benchmark with a 2 : 1 ticket allocation. Averaged over the entire run, the two tasks executed 25378 and 12619 iterations/sec., for an actual ratio of 2.01 : 1.

Will you use lottery for your system?

- Will it be good for
  - Event-driven application
  - Real-time application
  - GUI-based system
- Is randomization a good idea?
  - The authors later developed a deterministic stride-scheduling

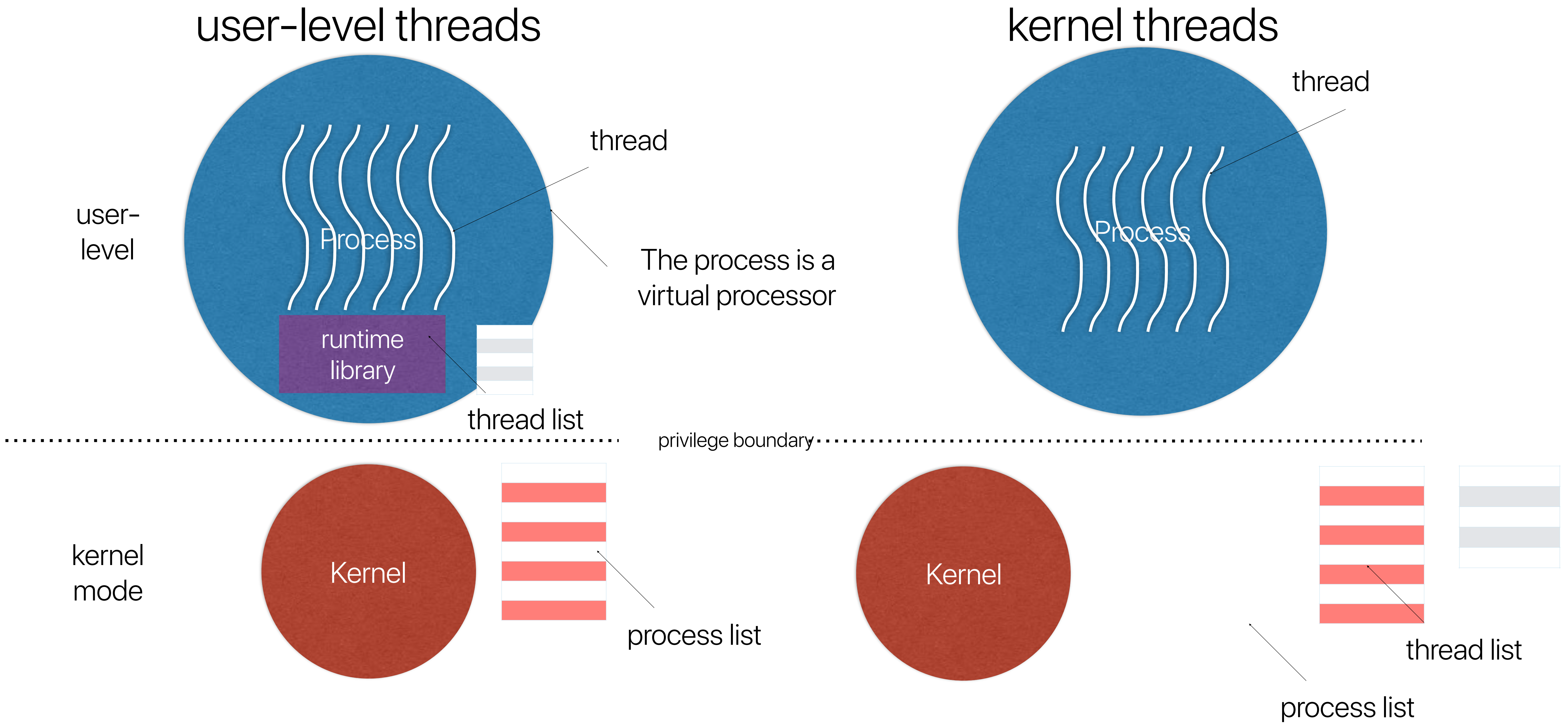
The impact of “lottery”

- Data center scheduling
  - You buy “times”
  - Lottery scheduling of your virtual machine

Scheduler Activations: Effective Kernel Support for the User-level Management of Parallelism

Thomas E. Anderson, Brian N. Bershad, Edward D. Lazowska and Henry M. Levy
University of Washington

User-level v.s kernel threads



- **The OS kernel is unaware of user-level threads**
- **Switching threads does not require kernel mode operations**
- **A thread can block other threads within the same process**

- **The kernel can control threads directly**
- **Thread switch requires kernel/user mode switch and system calls**
- **Thread works individually**

Why — the “dilemma” of thread implementations

- User-level threads
  - Efficient, flexible, safer, customizable
- Kernel threads
  - Slower, more powerful
  - Better matches the multiprocessor hardware
- Problems
  - OS is aware of kernel threads
  - OS is unaware of user-level threads as they are hidden behind each process

What does “Scheduler Activations” propose?

- The OS kernel provides each user-level thread system with its own virtual multiprocessor
- Communication mechanism between kernel and user-level

The virtual multiprocessor abstraction

- The kernel allocates processors to address space
  - An address space is shared by all threads within the same process
  - The kernel controls the number of processors to an address space
- Each address space has complete control over the processor-thread allocation
- The kernel notifies the address space when the allocated number of processors changes
- The address notifies the kernel when it needs more or fewer processors
- Transparent to users/programmers

Linux's thread implementation

- Linux treat all schedule identities as "tasks" — context of executions
- COEs can share parts of their contexts with each
  - Processes share nothing
  - Threads share everything but the CPU states
- http://www.evanjones.ca/software/threading-linus-msg.html

How scheduler activation works?

- Create a scheduler activation when the system create a process on a processor
- Create a scheduler activation when the kernel needs to perform an “upcall” user-level
  - Add a processor
  - Processor has been preempted
  - Scheduler activation has blocked
  - Scheduler activation has unblocked
- Downcalls — hints for kernel to perform resource management
  - Add more processors
  - This processor is idle
- Key difference from a kernel thread
  - Kernel never restarts user thread after it is blocked

Will you use Scheduler activation?

- Once been implemented in NetBSD, FreeBSD, Linux
- A user-level thread gets preempted whenever there is scheduling-related event
    - Overhead
    - You may preempt a performance critical thread
- Blocking system call