05. Scheduling Algorithms

9th ed: Ch. 6

10th ed: Ch. 5

Objectives

- To understand how to apply several common scheduling algorithms
  - FCFS, SJF, SRTF
  - Round Robin
  - Priority
  - Multilevel Queues
- To understand use of measurement and prediction for unknown scheduling parameters

Outline

- First-Come First-Served (FCFS)
- Shortest Job First (SJF)
- Shortest Remaining Time First (SRTF)
- Round Robin (RR)
- Priority scheduling
- Multilevel queues

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  - Convoy effect
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First-Come First-Served (FCFS)

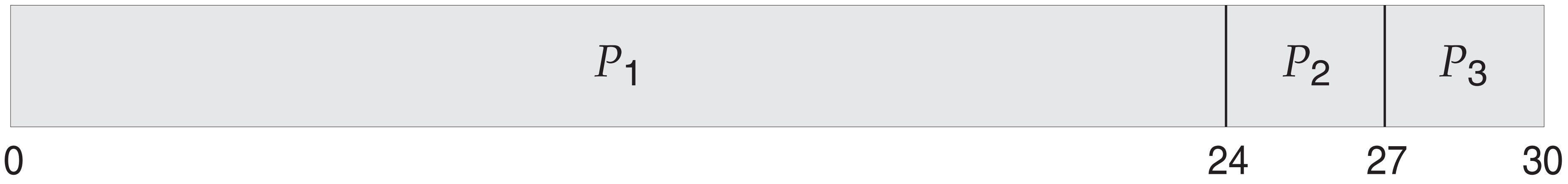
- Schedule depends purely on the order in which processes arrive
- Simplest possible scheduling algorithm
- Not terribly robust to different **arrival processes**

- E.g., suppose processes with the following burst times arrive in the order P_1, P_2, P_3

Process	Burst Time
P_1	24
P_2	3
P_3	3

First-Come First-Served (FCFS)

- Then the Gantt chart is



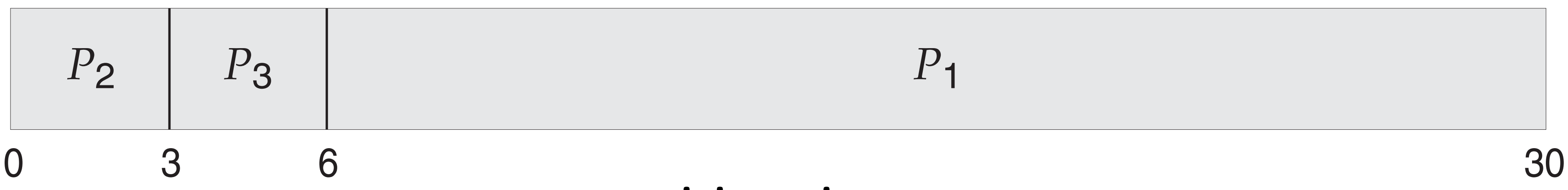
- The waiting times are

Process	Burst Time	Waiting Time
P_1	24	0
P_2	3	24
P_3	3	27

- This gives an average per-process waiting time of $\frac{0 + 24 + 27}{3} = 17$

The Convoy Effect

- Now suppose the same processes arrive in the order P_2, P_3, P_1
- Then the Gantt chart and waiting times are:



- Gives an average per-process waiting time of $\frac{6 + 0 + 3}{3} = 3$

Process	Burst Time	Waiting Time
P_1	24	6
P_2	3	0
P_3	3	3

- First case is an example of the **Convoy Effect**
  - Short-run processes getting stuck behind long-run processes
  - Consider one CPU-bound and many IO-bound processes

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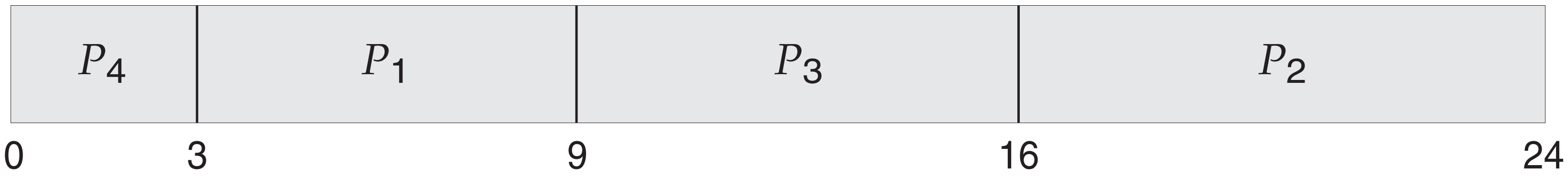
Shortest Job First (SJF)

- Associate length of next CPU burst with each process
- Schedule the process with the shortest next burst
- Optimality: SJF gives the least possible waiting time for a given set of processes

Shortest Job First (SJF)

- Consider the following arrivals process and resulting Gantt chart:

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3



- Gives an average per-process waiting time of $\frac{3 + 16 + 9 + 0}{4} = 7$

Outline

- First-Come First-Served (FCFS)
- Shortest Job First (SJF)
- Shortest Remaining Time First (SRTF)
  - Predicting the future
  - Exponential averaging
- Round Robin (RR)
- Priority scheduling
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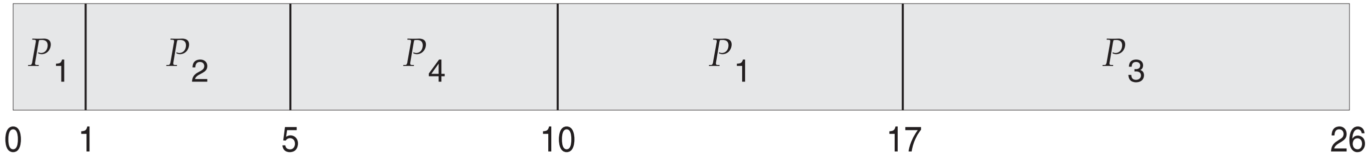
Shortest Remaining Time First (SRTF)

- Simply a pre-emptive version of SJF
  - Pre-empt current process if a new one arrives with a shorter burst length than the remaining time of the current process
- Distinguish **arrival time** and **burst length**, e.g.,

Process	Arrival Time	Burst Length
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

- Gives Gantt chart



- Average waiting time now $\frac{(10-1)+(1-1)+(17-2)+(5-3)}{4} = \frac{26}{4} = 6\frac{1}{2}$

Optimality in the future

- If SJF is optimal given a known set of processes (**demand**), then surely SRTF is optimal in the face of new runnable processes arriving?
- No! Why?
- Context switches are not free, so if short burst processes keep arriving the OS will start thrashing the CPU, so no useful work gets done

- More fundamentally,

*how can we know the length of a **future** burst?*

(Ask the user? Ask the developer? Measure and predict?)

Predicting burst lengths

- Assume the next burst will not be too different from the previous
- Then
  - measure burst lengths as processes are scheduled,
  - predict next burst length, and
  - choose the process with the shortest predicted burst length
- E.g., exponential averaging on length of previous bursts
  - Set t_n to be the measured length of the n^{th} CPU burst
  - Define τ_{n+1}, predicted length of $(n+1)^{th}$ burst as $\tau_{n+1} = \alpha t_n + (1 - \alpha)\tau_n$

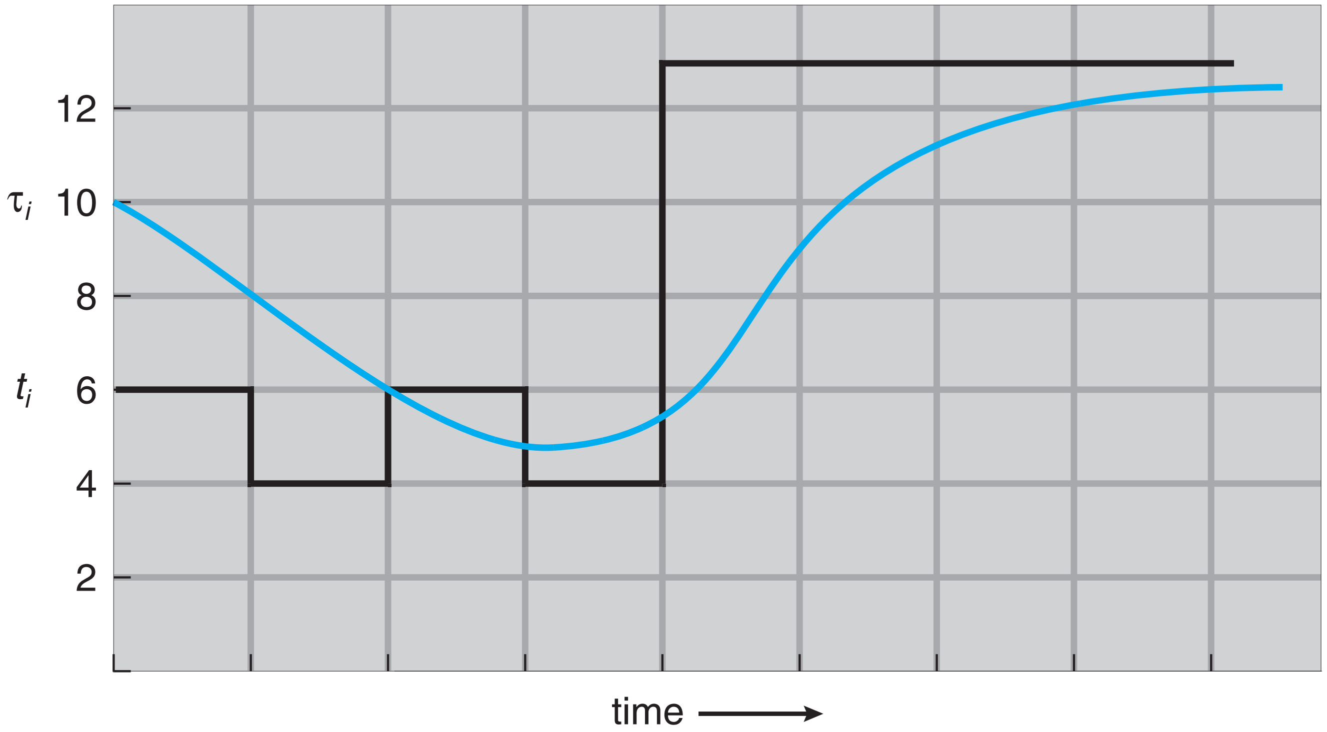
Examples of exponential averaging

- Expanding this formula gives, for τ_0 some constant

$$\tau_{n+1} = \alpha t_n + \ldots + (1-\alpha)^j \alpha t_{n-j} + \ldots + (1-\alpha)^{n+1} \tau_0$$

- As both α, 1–α ≤ 1, each term has less weight than its predecessor
- Choose value of α according to our belief about the system, e.g,
  - If we believe past history irrelevant, choose $\alpha \approx 1$ and then get $\tau_{n+1} \approx t_n$
  - If we believe recent history irrelevant, choose $\alpha \approx 0$ and then get $\tau_{n+1} \approx \tau_n$
- Exponential averaging is often a good predictor if the variance is small
  - ...if the variance is not changing "too fast" with respect to the size of time slot
  - Also consider system load, else (counter-intuitively) priorities increase with load

Examples of exponential averaging



CPU burst (t_i)		6	4	6	4	13	13	13	…
"guess" (τ_i)	10	8	6	6	5	9	11	12	…

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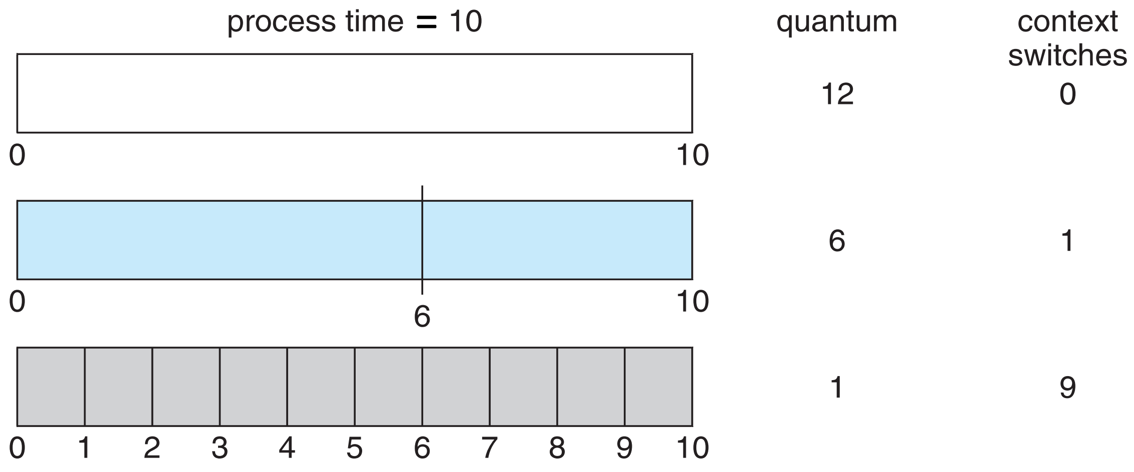
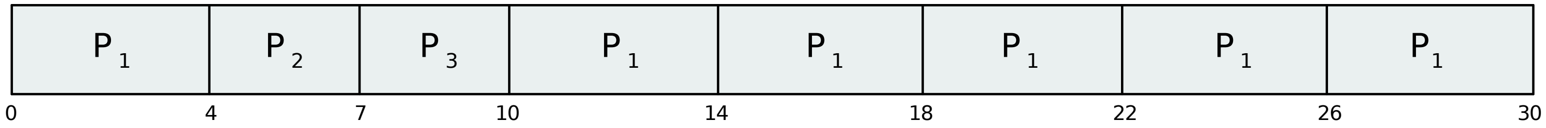
Round Robin

- A pre-emptive scheduling scheme for time-sharing systems
  - Give each process a **quantum** (or time-slice) of CPU time e.g., 10—100 milliseconds
  - Once quantum elapsed, process is pre-empted and appended to the ready queue
  - Timer interrupts every quantum to schedule next process
- Can be tricky to choose correctly
  - *q* too large degenerates into a FIFO queue (~ FCFS)
  - *q* too small makes the context switch overhead too great
- *q* usually 10ms to 100ms, while context switch < 10 µsec



Round Robin

- Consider the first example again



Process	Burst Time
P_1	24
P_2	3
P_3	3

- For quantum *q* and *n* processes ready,
  - **Fair**: each process gets 1/n CPU time in chunks of at most *q* time units, and
  - **Live**: no process ever waits more than (*n-1*)*q* time units
- Typically
  - higher average turnaround time than SRTF, but
  - better average response time

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  - Dynamic priorities
  - Computed priorities
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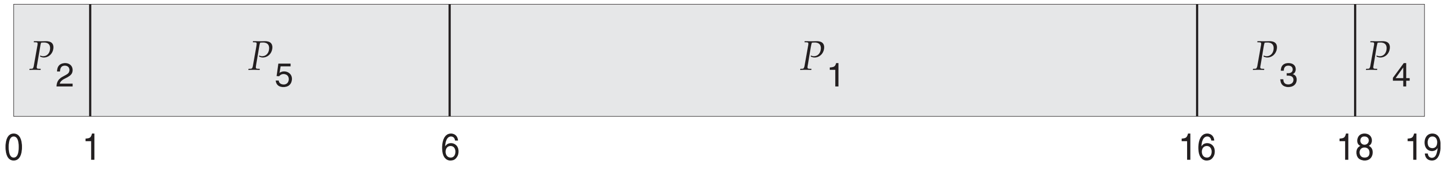
Priority scheduling

- Associate integer priority with process, and schedule the highest priority (~ lowest number) process, e.g.,



Process	Priority	Burst Length
P_1	3	10
P_2	1	1
P_3	4	2
P_4	5	1
P_5	2	5

- Average waiting time now

$$\frac{(1+5) + 0 + (1+5+10) + (1+5+10+2) + 1}{5} = \frac{41}{5} = 8\frac{1}{5}$$

- Consider: SJF as priority scheduling using inverse of predicted burst length

Dynamic priority scheduling

- **Starvation** can occur if low priority processes never execute
- Urban legend?
  - When the IBM 7074 at MIT was shut down in 1973, low-priority processes were found that had been submitted in 1967 and had not yet been run...
- This is the biggest problem with static priority systems!
  - A low priority process is not guaranteed to run — ever!
- Solve by making priorities **dynamic**
  - E.g., **aging** increases priority starting from a static base as time passes without process being scheduled

Computed Priority

- E.g., UNIX scheduler
  - Priorities 0–127; user processes ≥ *Base* = 50
  - Round robin within priority queue, quantum = 100ms
  - Priority recalculated every 4 ticks (typically, 40ms) it is found running
- Kernel mode process scheduling
  - Fixed priority, non-preemptive
  - Modified by reasons for process waiting
  - E.g., waiting for disk I/O < waiting for terminal input
- User mode process scheduling
  - Dynamically computed, pre-emptive
  - Per-tick (10ms), if there is a higher-priority process, switch to it
  - Per-quantum (10 ticks = 100ms), if there is a process in the same priority queue, switch to it

Computing the priority

- Priority of process *j* at start of interval *i* is based on
  - $base_j$, the base priority of a user mode process (50)
  - $nice_j$, a user controllable parameter between -20 and 20 (default = 0)
  - $load_j$, the sampled (1 minute) average length of the run queue
  - CPU_j, incrementing counter if process *j* was observed running this tick
- Every 100 ticks,
  - Age the CPU_j counter: $\mathrm{CPU}_j(i) = \frac{2 \times \mathrm{load}_j}{(2 \times \mathrm{load}_j) + 1} \mathrm{CPU}_j(i-1)$
  - Compute the new priority: $P_j(i) = \mathrm{Base}_j + \frac{\mathrm{CPU}_j(i)}{4} + 2 \times \mathrm{nice}_j$

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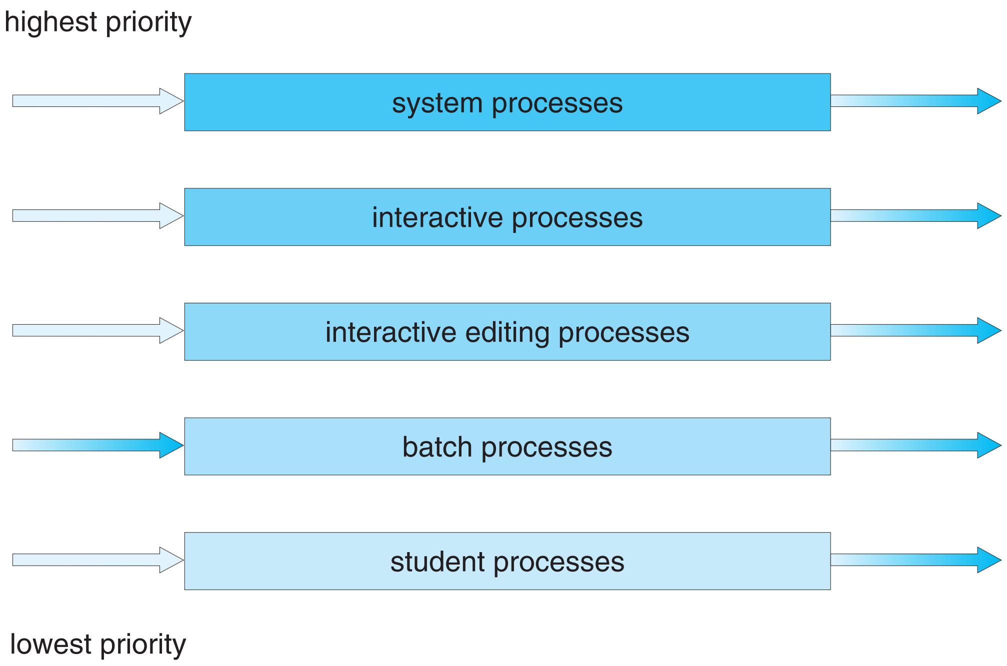
    - Multilevel queues
    - Multilevel feedback queues

Multilevel Queues

- Partition Ready queue into many queues for different types of process, e.g.,
  - Foreground/interactive processes
  - Background/batch processes
- Each process is permanently assigned a given queue
- Each queue runs its own scheduling algorithm, e.g.,
  - Foreground runs Round Robin
  - Background runs First-Come First-Served

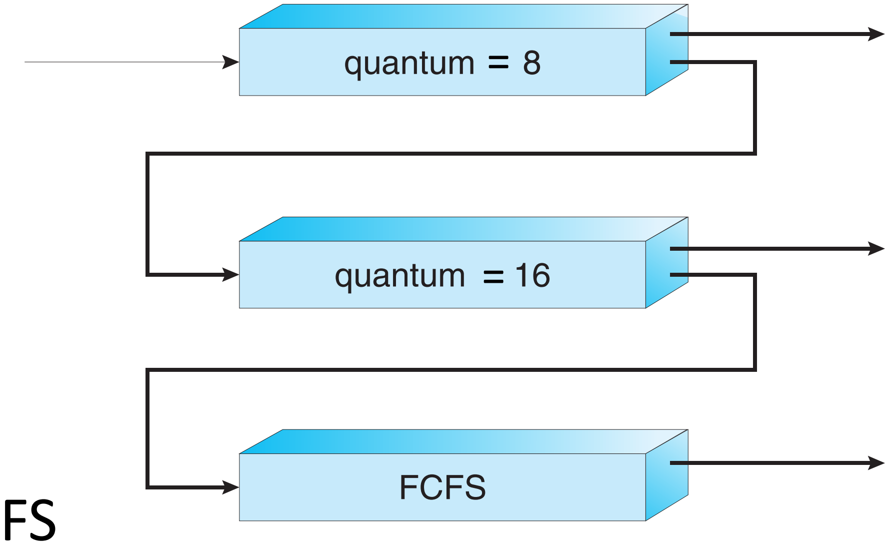


Multilevel Feedback Queues

- Now scheduling must be done between the queues:
  - **Fixed priority**, e.g., serve all from foreground then from background, permits starvation
  - **Time slice**, each queue gets a certain amount of CPU time which it can schedule amongst its processes, e.g., 80% to foreground in RR, 20% to background in FCFS
- A process can move between the various queues
  - Aging can be implemented this way
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when to demote a process
  - method used to determine which queue a process will enter when it needs service

Multilevel Feedback Queues

- Three queues:
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS



- Scheduling
  - A new job enters queue Q_0 which is served FCFS
  - When it gains CPU, job receives 8 milliseconds
  - If it does not finish in 8 milliseconds, job is moved to queue Q_1
  - At Q_1 job is again served FCFS and receives 16 additional milliseconds
  - If it still does not complete, it is pre-empted and moved to queue Q_2

Summary

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  - Convoy effect
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