# Power-aware Scheduling for Real-Time Systems

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power consumption: (80, 170, 400, 900, 1600) mWatt

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Main goal: Minimize power while maintaining the real-time properties (deadlines)

# Power-Aware EDF

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Static frequency scaling

- When CPU utilization is < 100% use idle time

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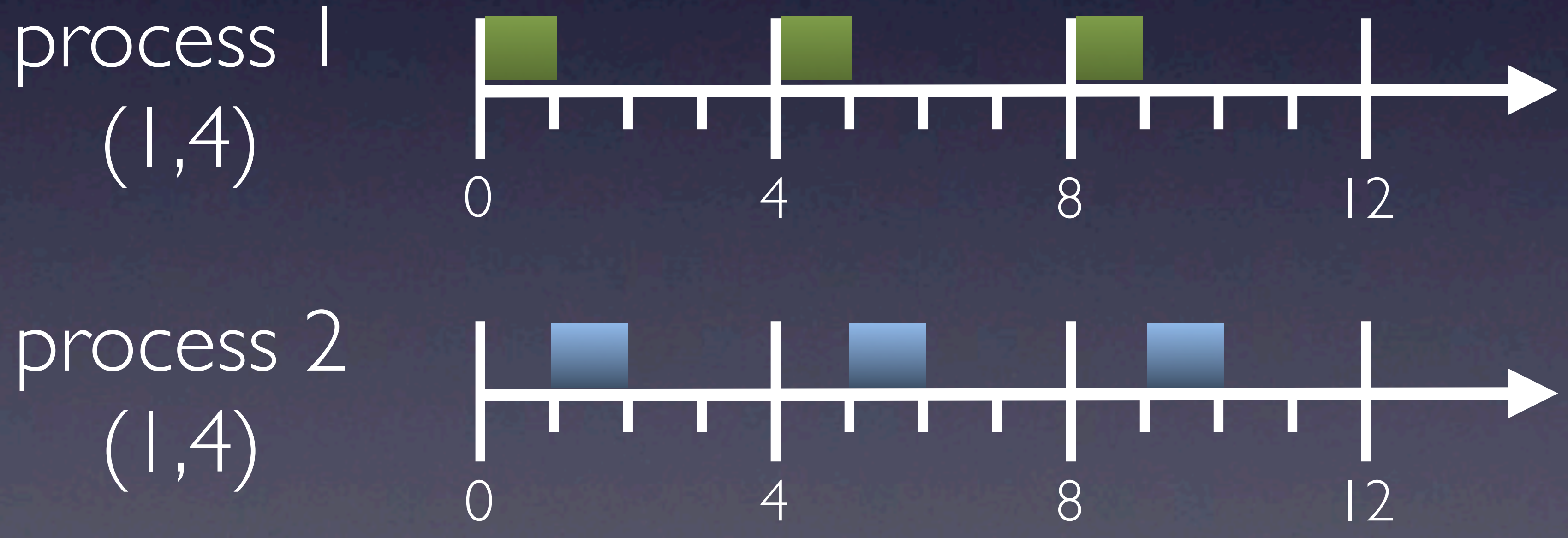

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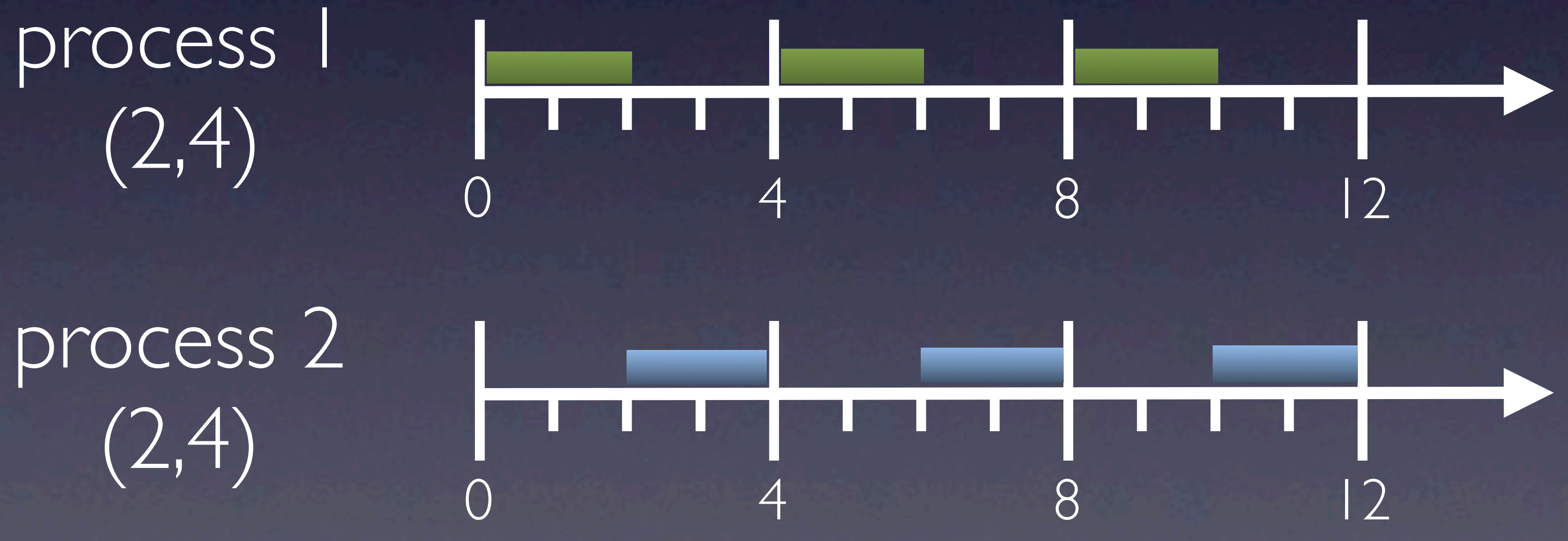

process 1
(2,4)

process 2
(2,4)

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- Processes use much less than their WCET in general

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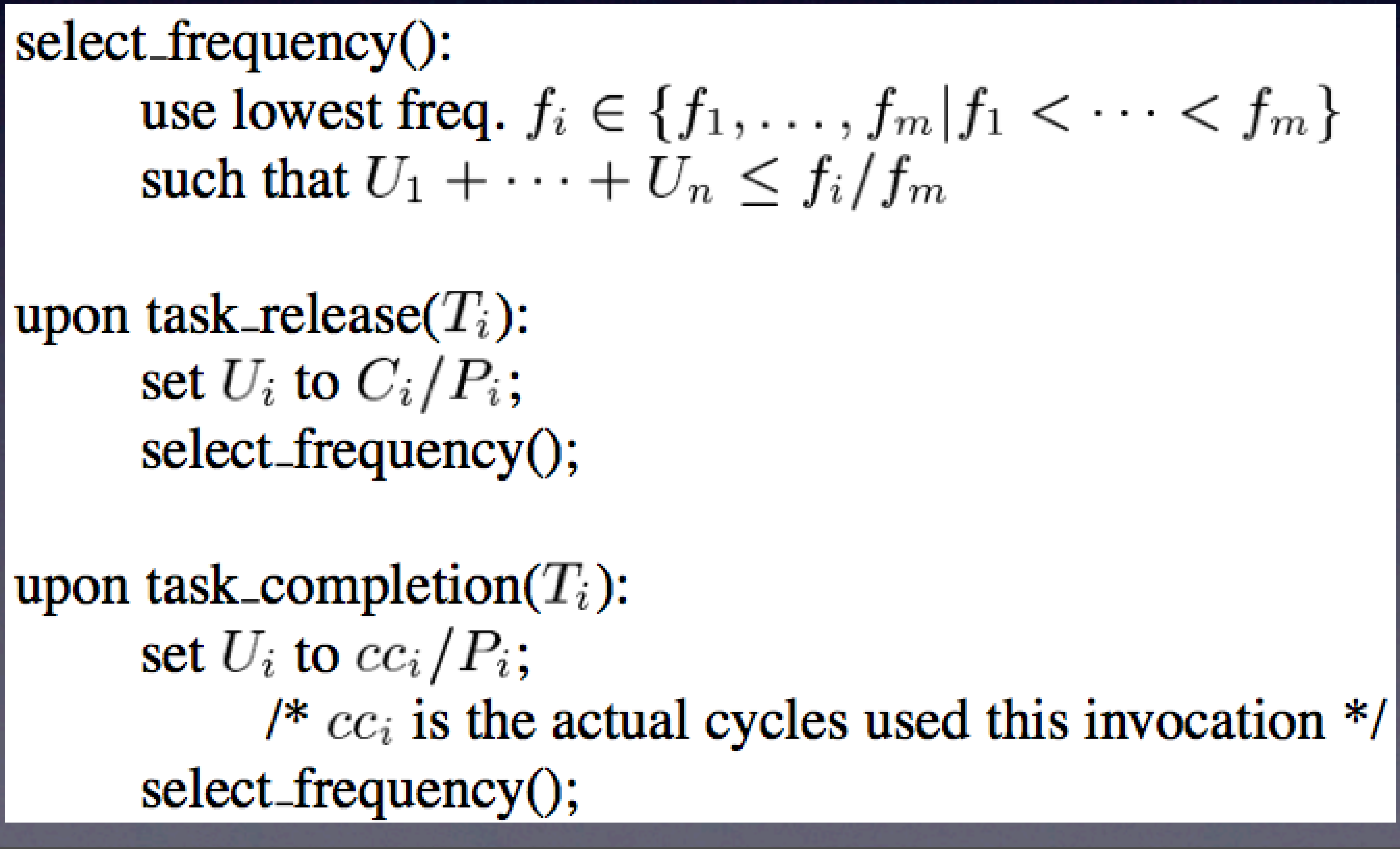
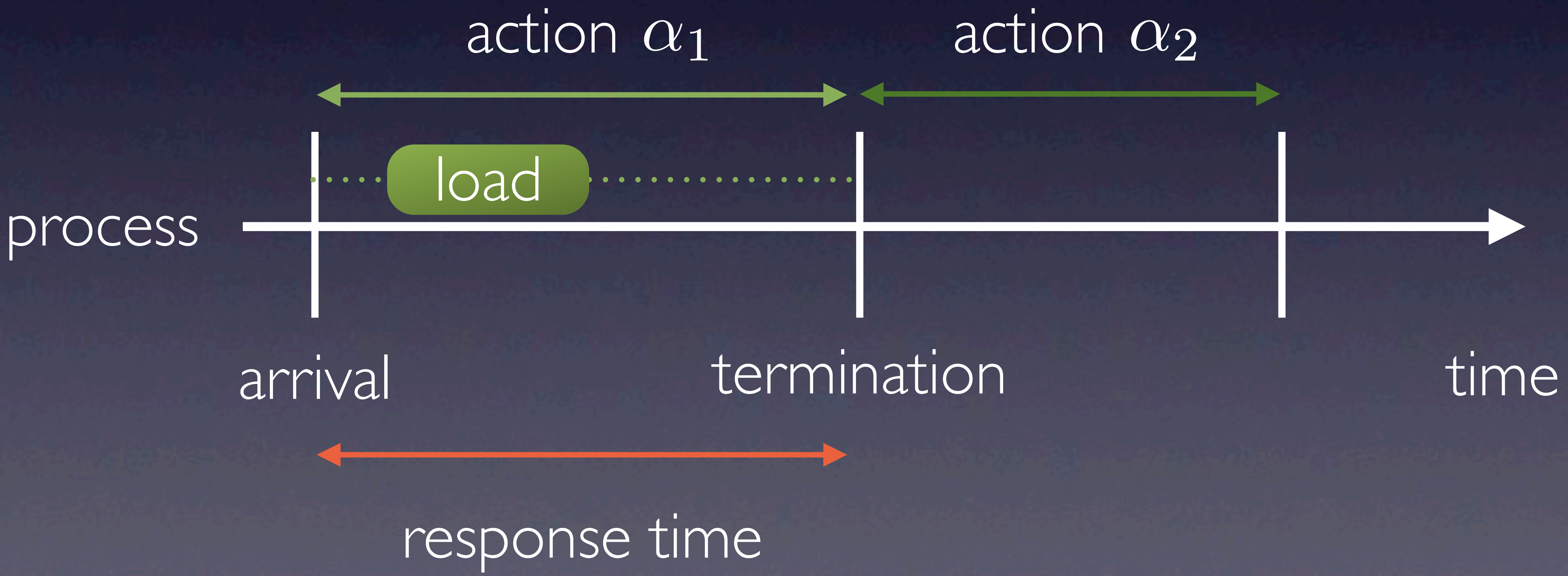


```
select_frequency():
    use lowest freq. $f_i \in \{f_1, \ldots, f_m | f_1 < \cdots < f_m\}$
    such that $U_1 + \cdots + U_n \leq f_i / f_m$

upon task_release($T_i$):
    set $U_i$ to $C_i / P_i$;
    select_frequency();

upon task_completion($T_i$):
    set $U_i$ to $cc_i / P_i$;
        /* $cc_i$ is the actual cycles used this invocation */
    select_frequency();
```

# Power-Aware VBS

Maintain VBS properties (temporal isolation, bounds)

We cannot use early completion (different process model)



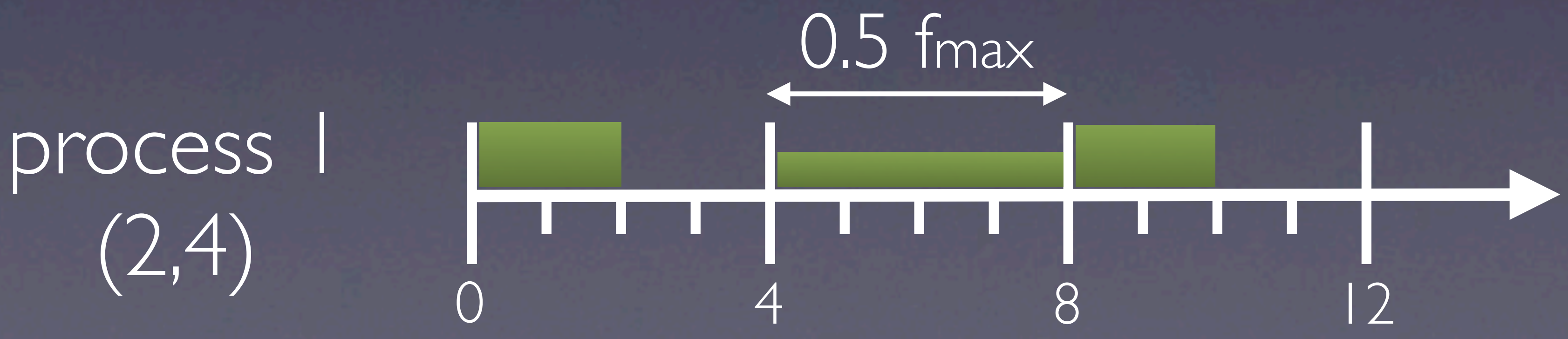
# Power-Aware VBS

EDF frequency scaling result:

An EDF-schedulable set of tasks is still schedulable if the processor frequency in between any two release times is set to at least

$$U_c \cdot f_{max}$$

current total utilization of all released tasks in the considered interval of time between two releases



# Frequency-scaling VBS

Slack

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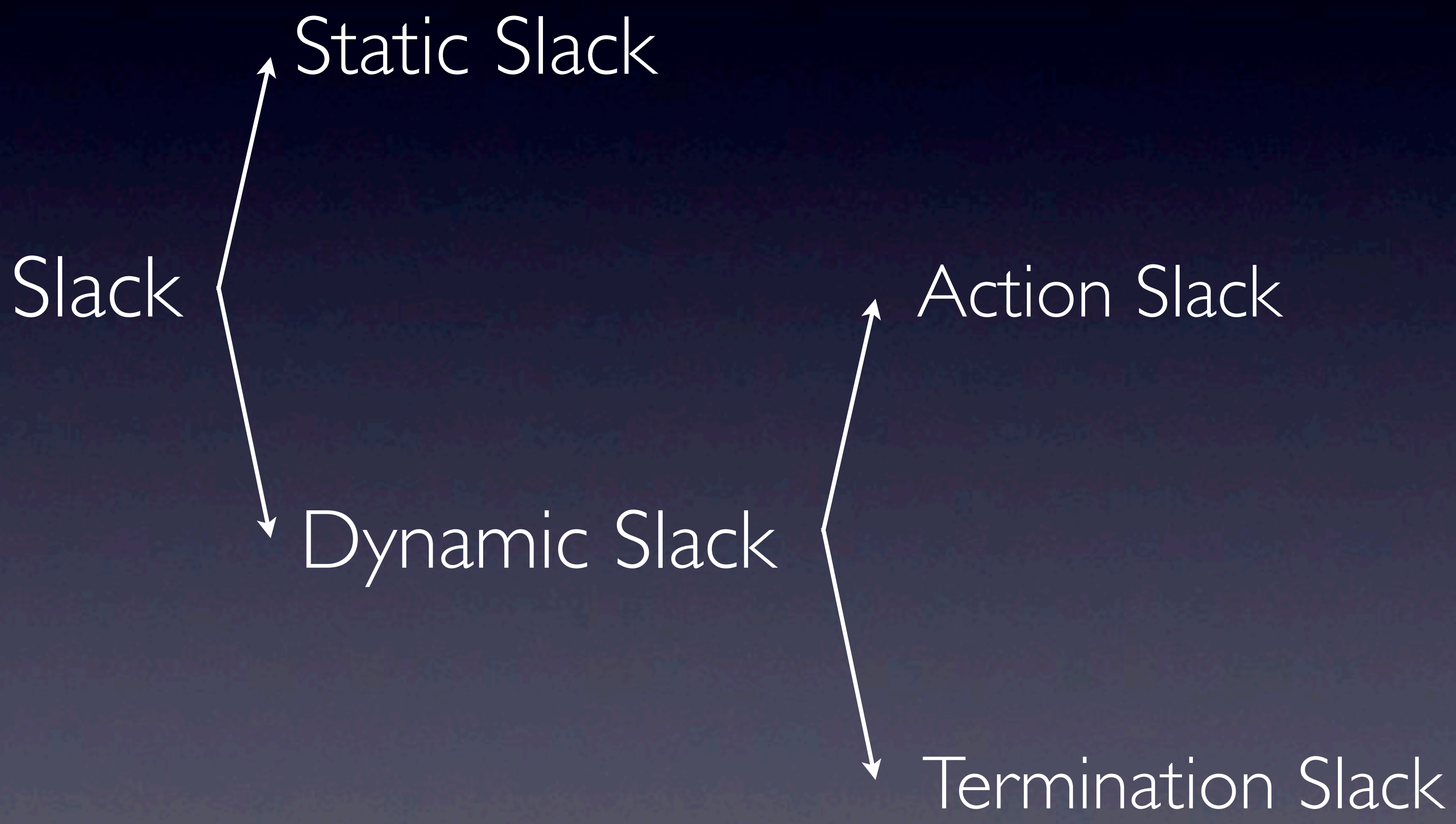

Slack

Static Slack

Dynamic Slack

Action Slack

Termination Slack

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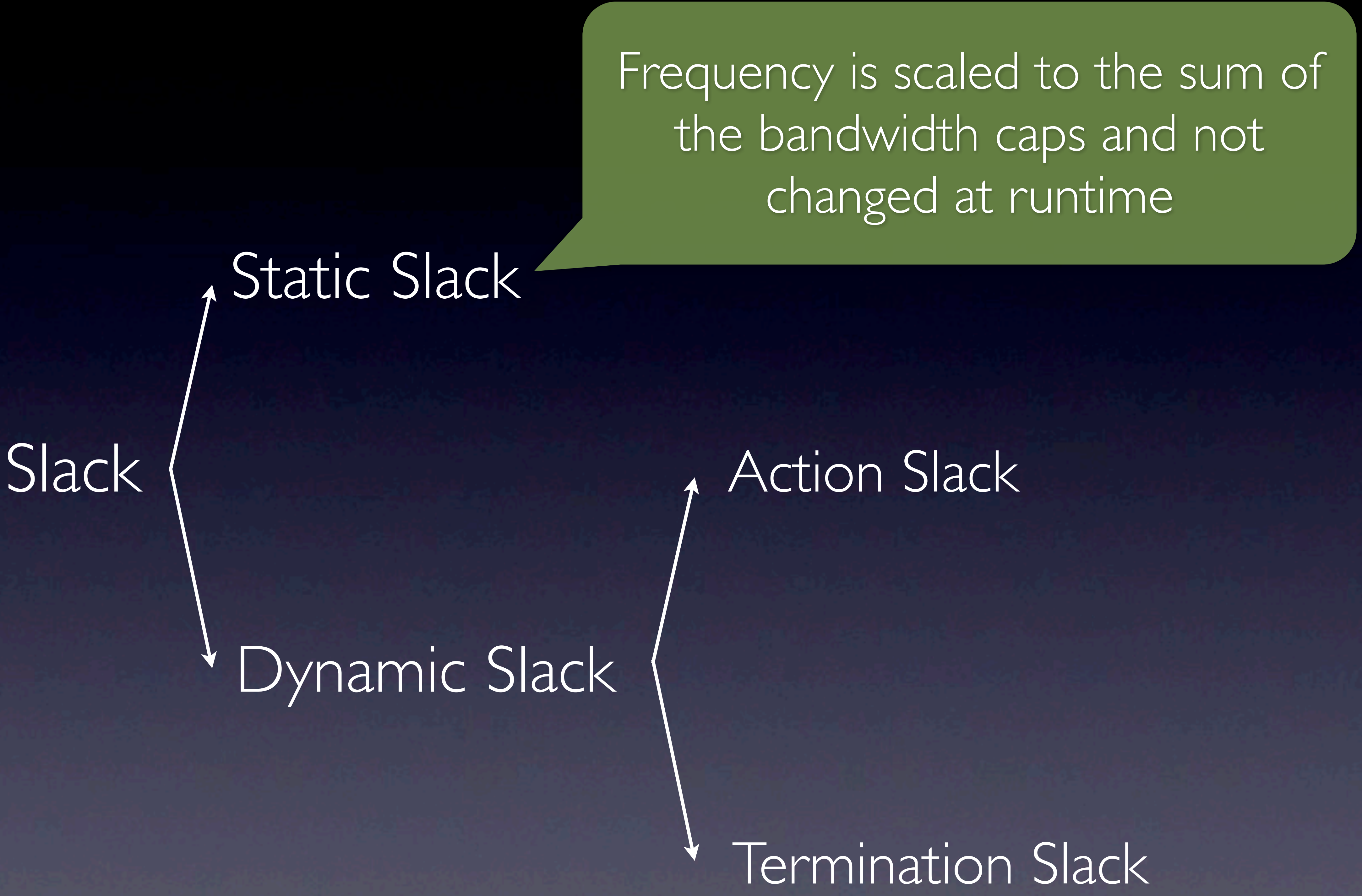

Frequency is scaled to the sum of the bandwidth caps and not changed at runtime

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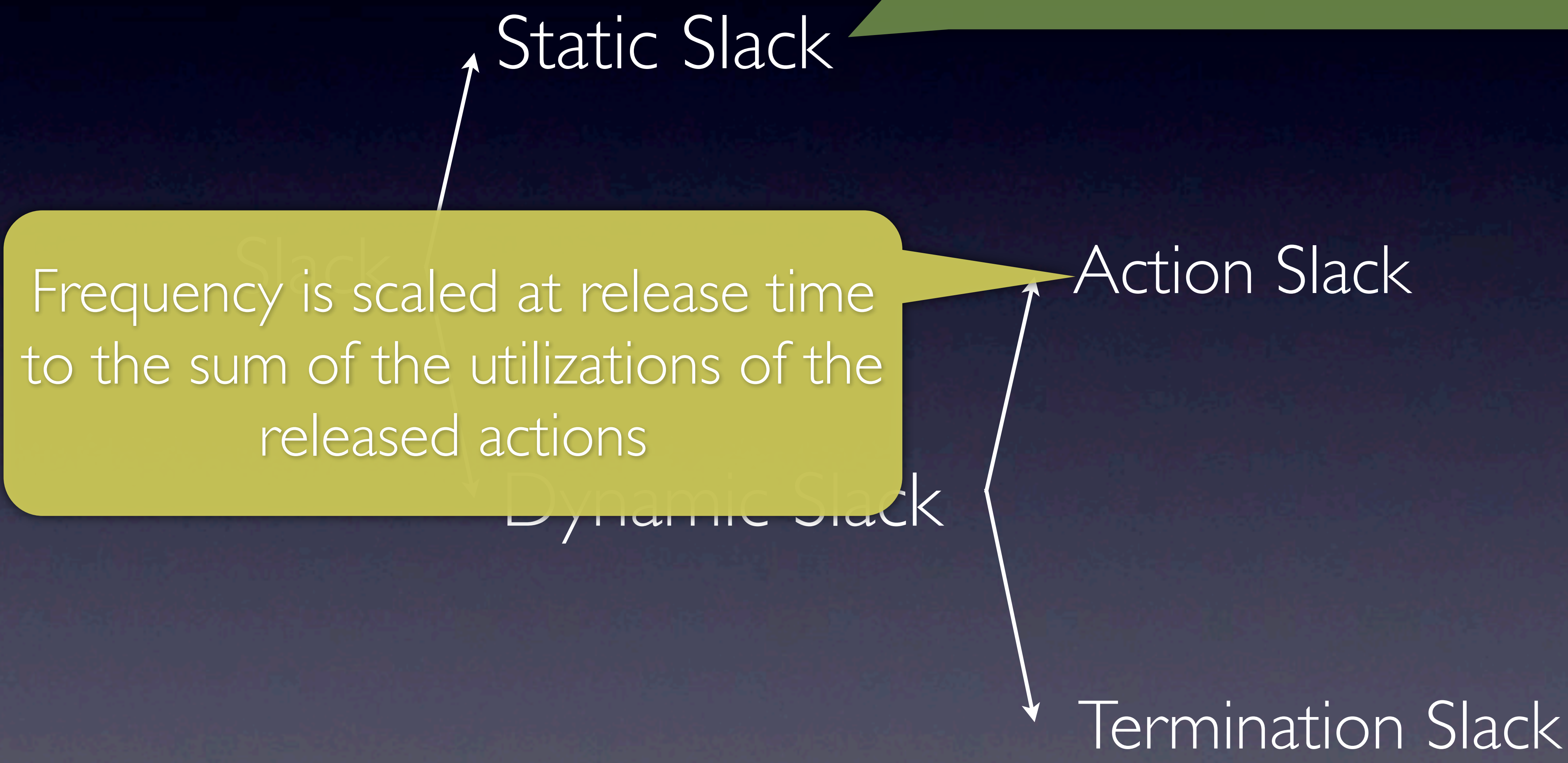

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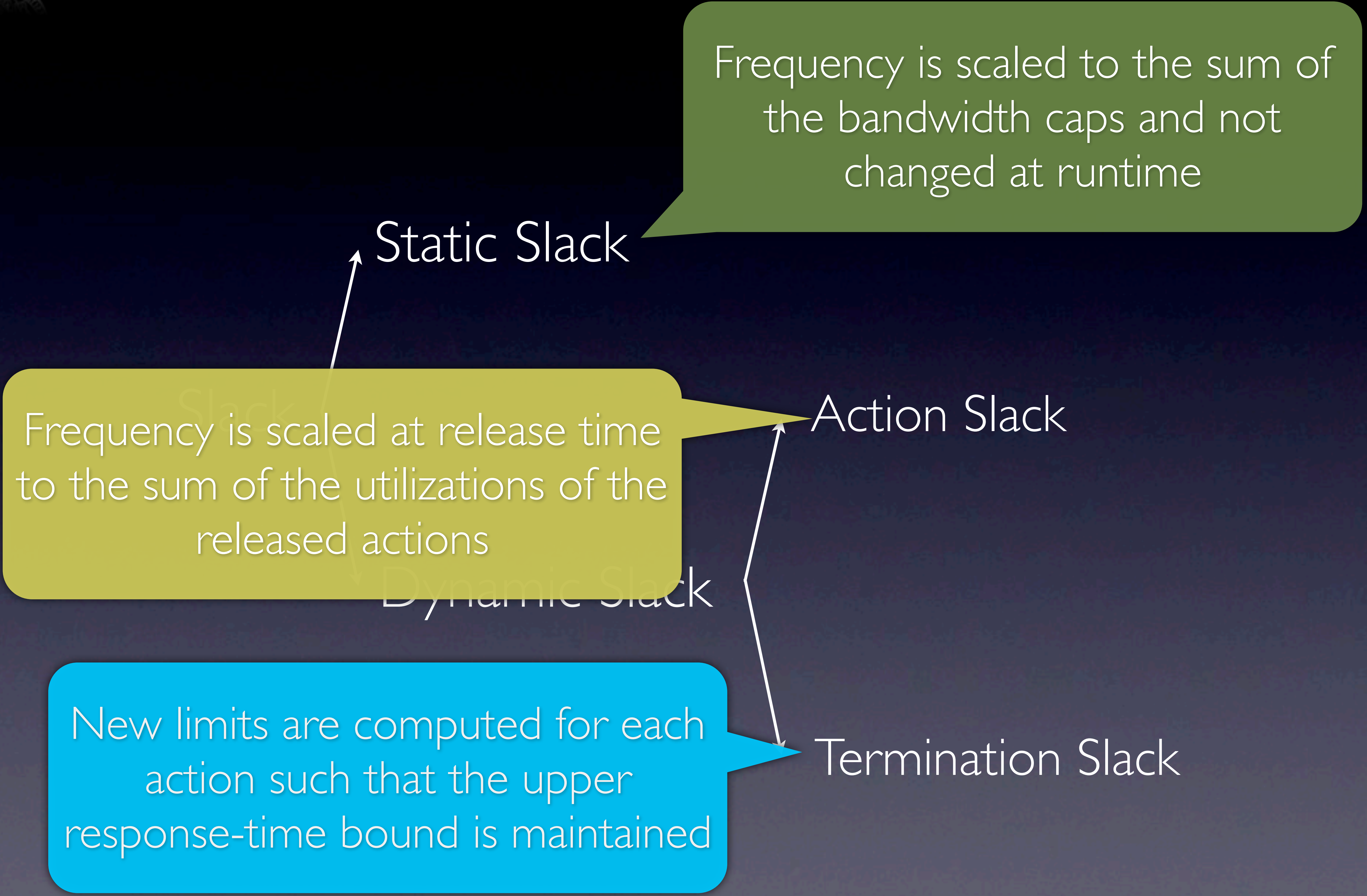

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Frequency is scaled to the sum of the bandwidth caps and not changed at runtime

Frequency is scaled at release time to the sum of the utilizations of the released actions

New limits are computed for each action such that the upper response-time bound is maintained

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Action slack

$$f = \sum_{i=1}^{n} \frac{\lambda_{i,j}}{\pi_{i,j}} \cdot f_{max}$$

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Termination slack

$$f = \sum_{i=1}^{n} \frac{\lambda^*_{i,j}}{\pi_{i,j}} \cdot f_{max} \qquad \lambda^*_{i,j} = \left\lceil \frac{l_{i,j}}{n_{i,j}} \right\rceil \qquad n_{i,j} = \left\lceil \frac{l_{i,j}}{\lambda_{i,j}} \right\rceil$$

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Termination and action slack can be used separately or together

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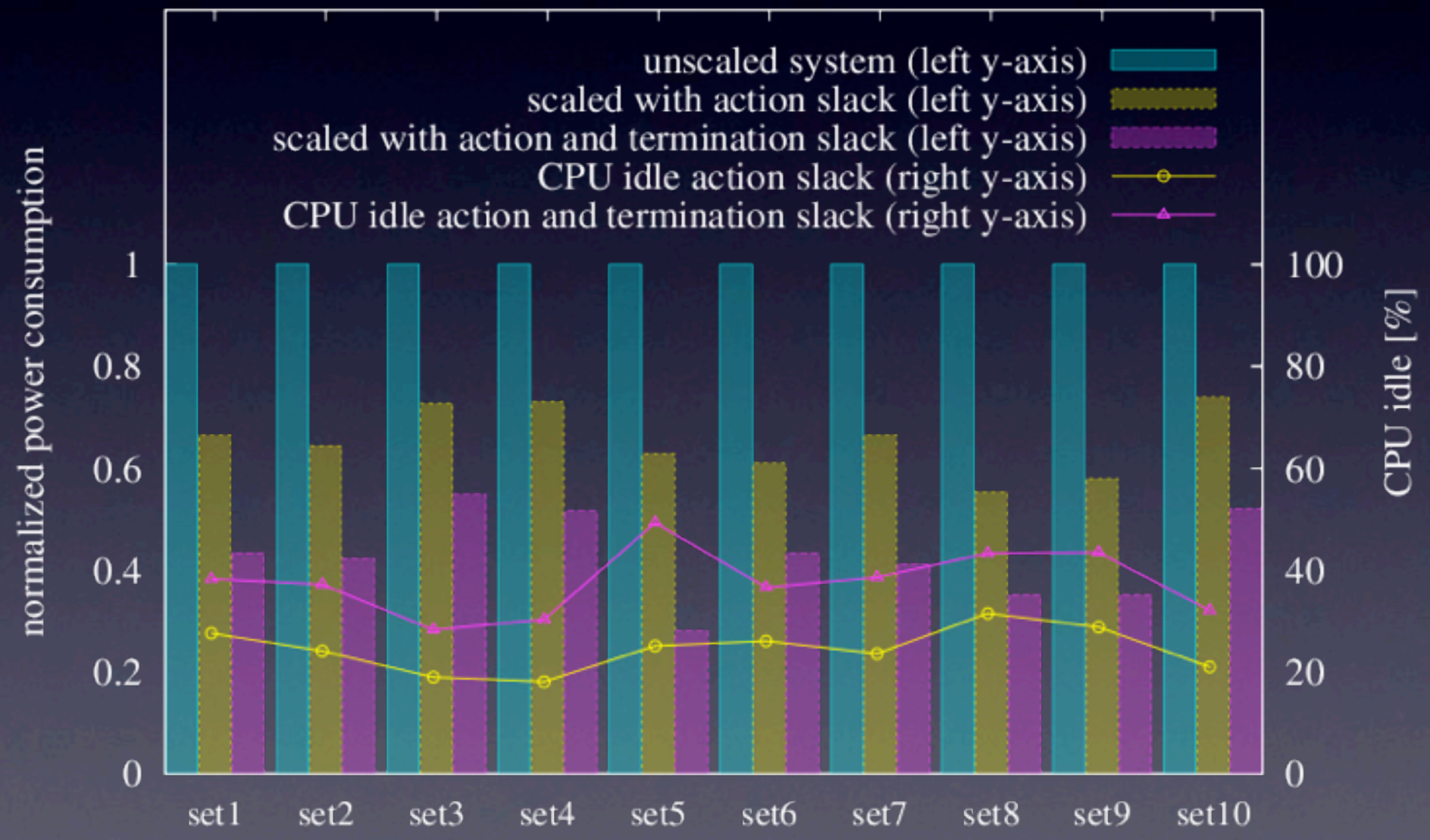
Assuming a simple power model (P ∝ $V^2$)



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- time overhead included using overhead accounting

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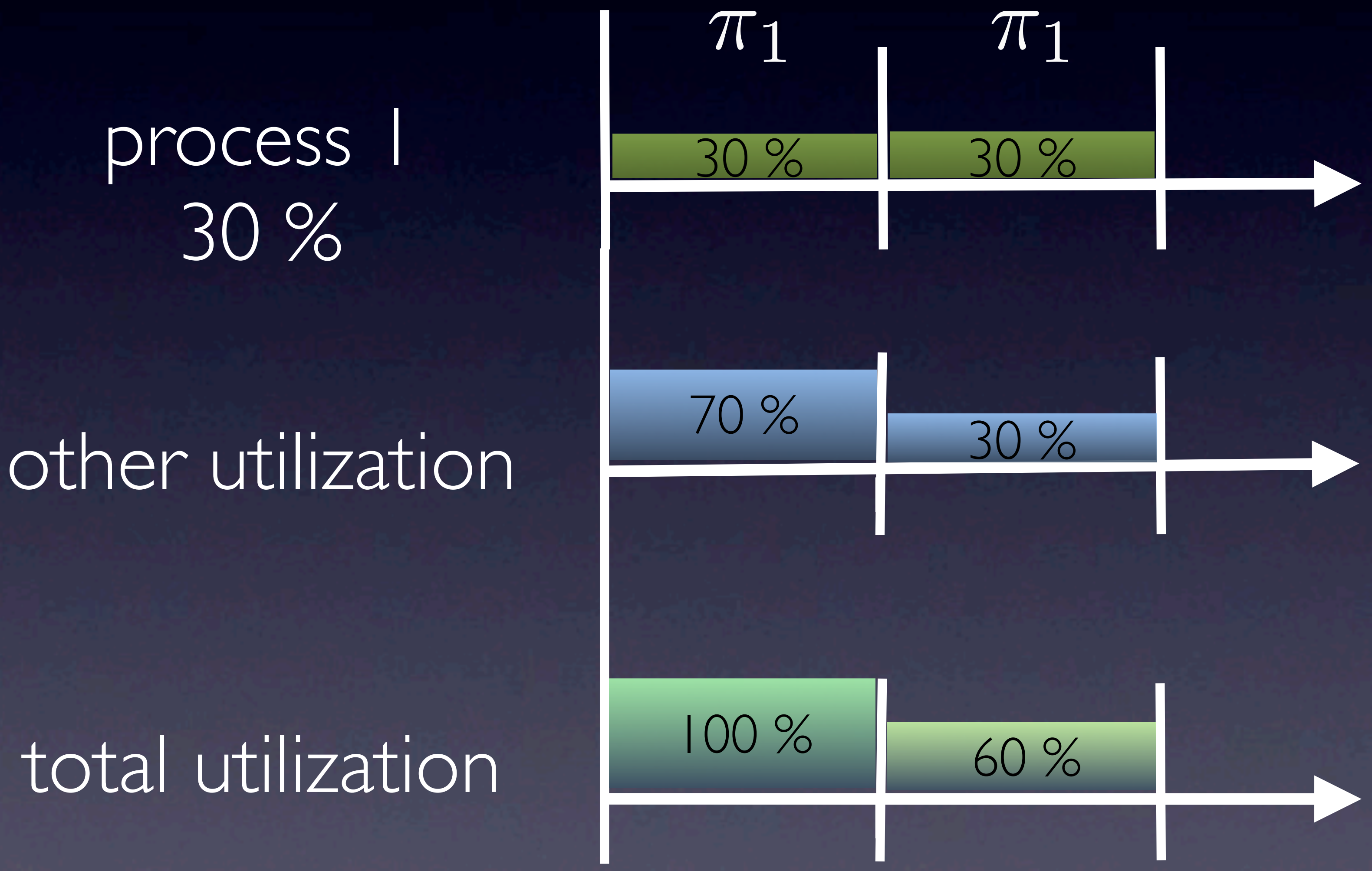

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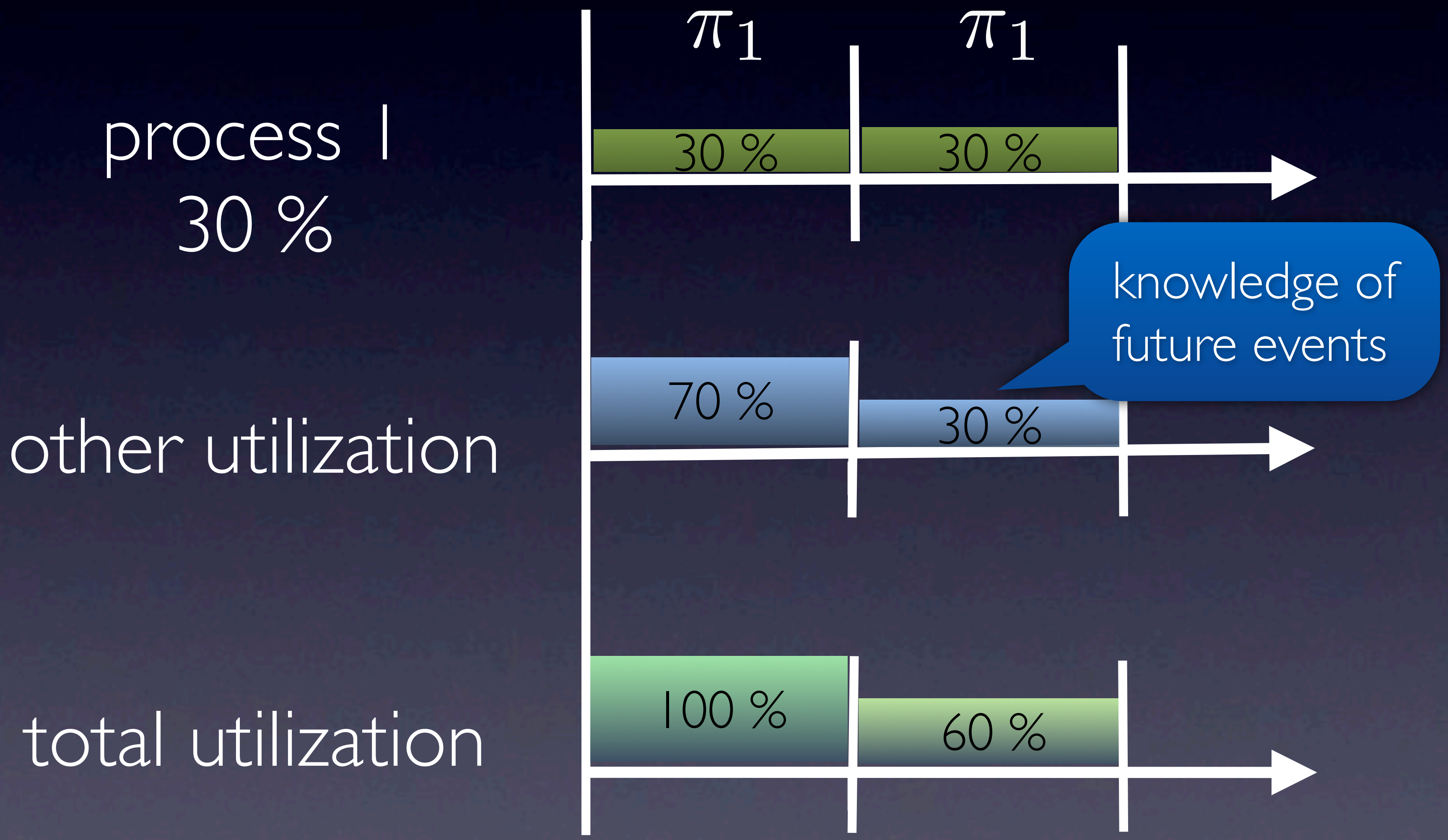

process 1
30 %

other utilization

total utilization

$\pi_1$ $\pi_1$

30 % 30 %

70 % 30 %

100 % 60 %

knowledge of future events

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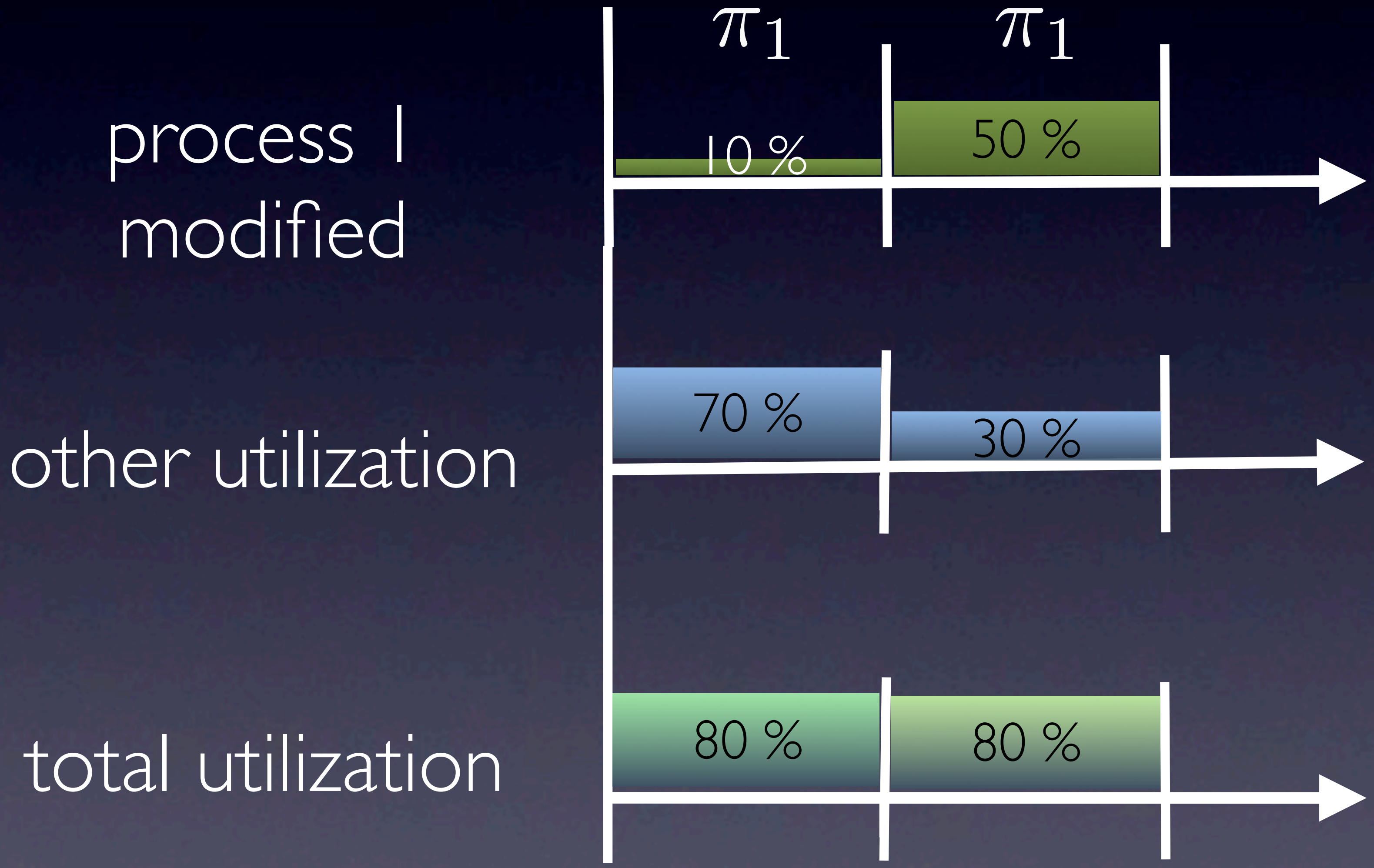

$\pi_1$ $\pi_1$

process 1 modified

10 % 50 %

other utilization

70 % 30 %

total utilization

80 % 80 %

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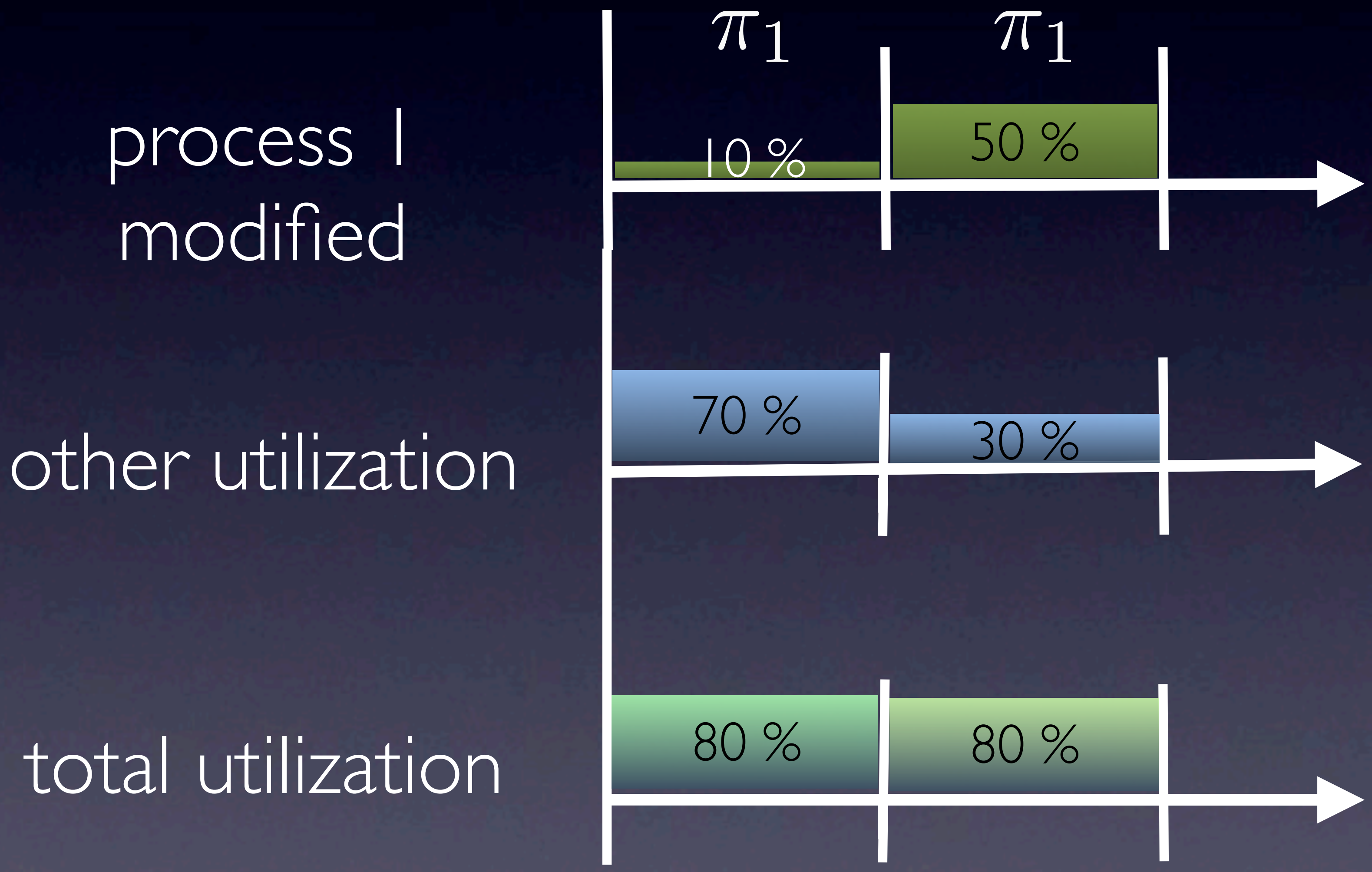

actual improvement depends
on the power model

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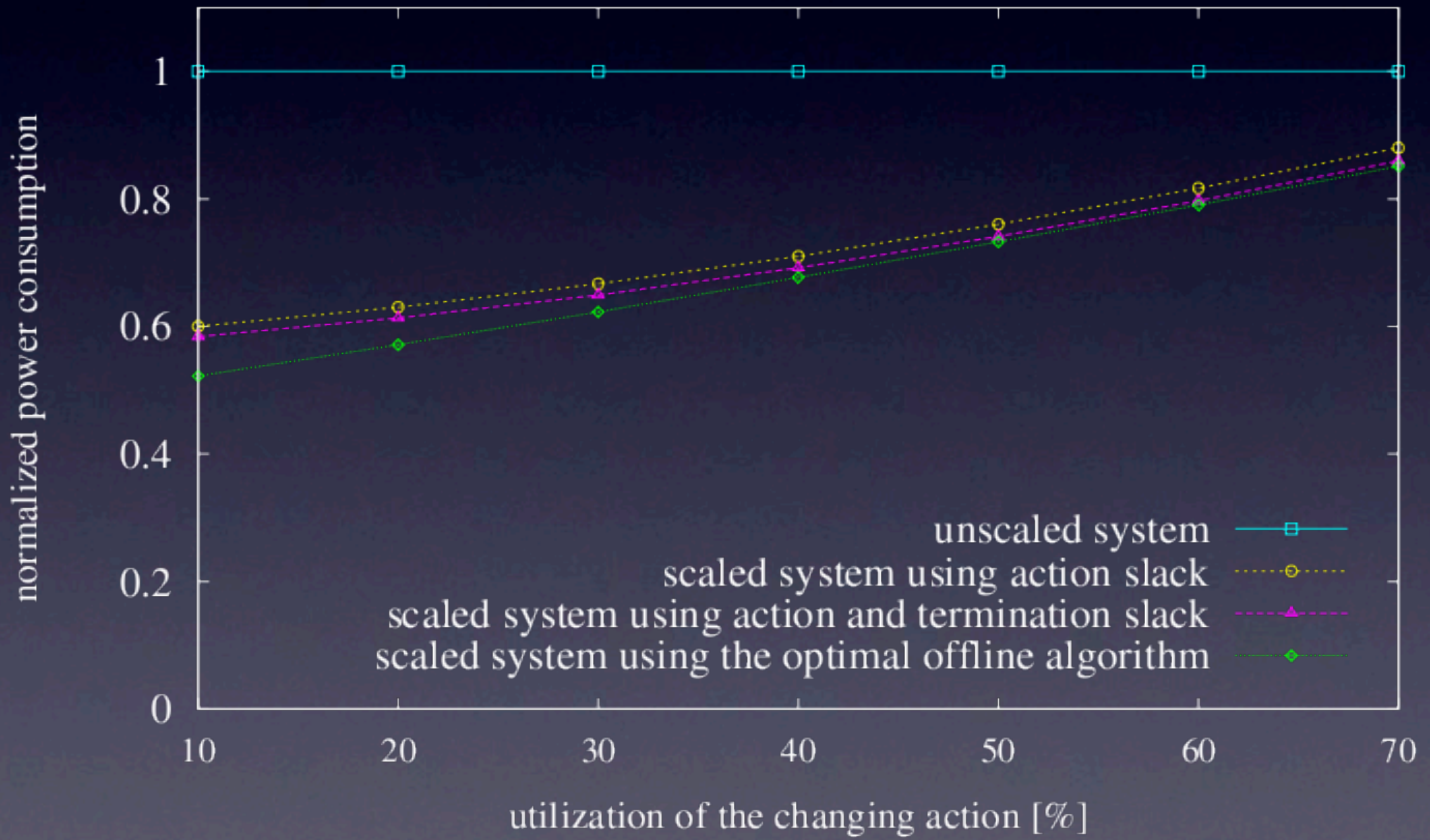

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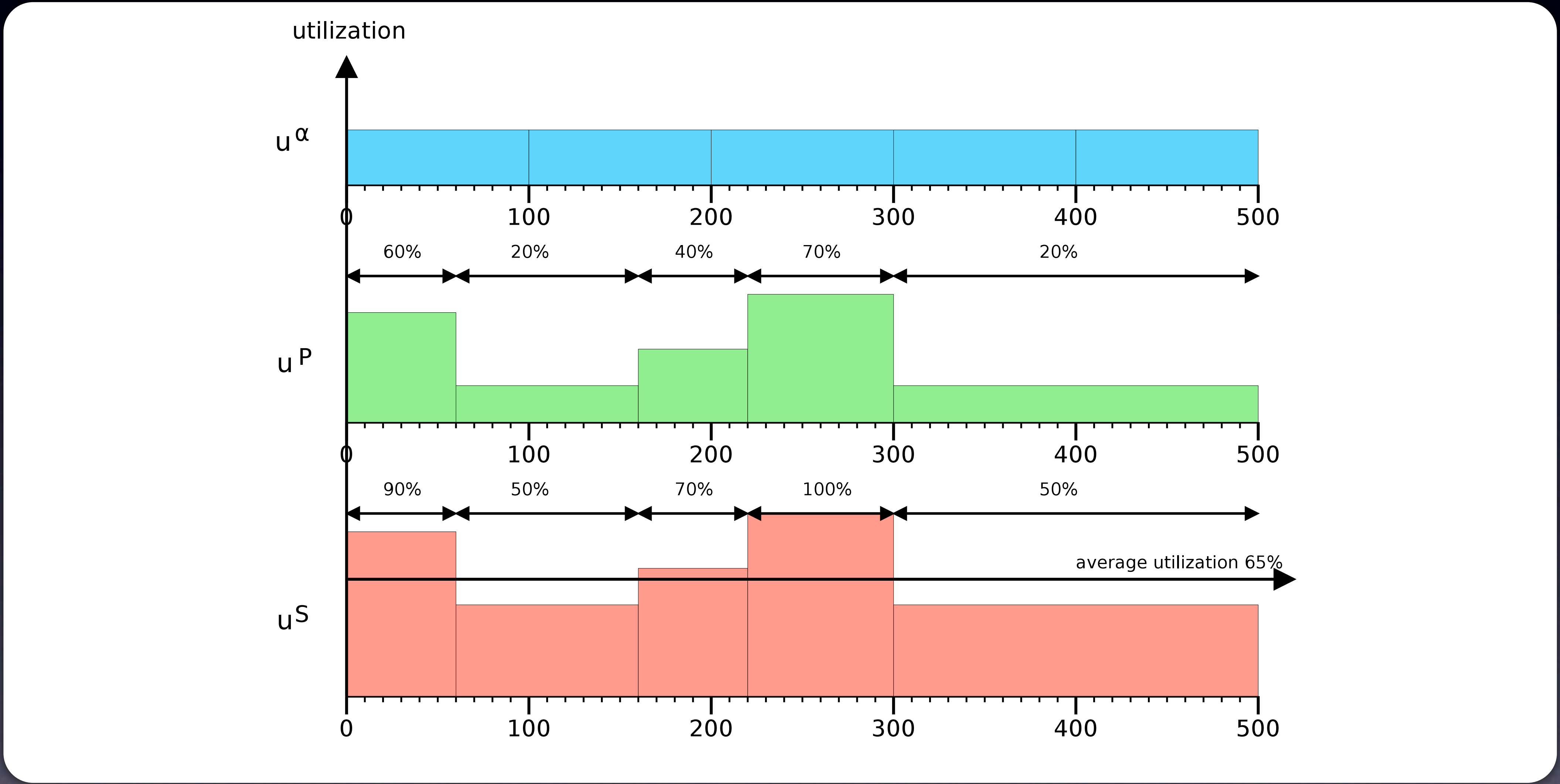

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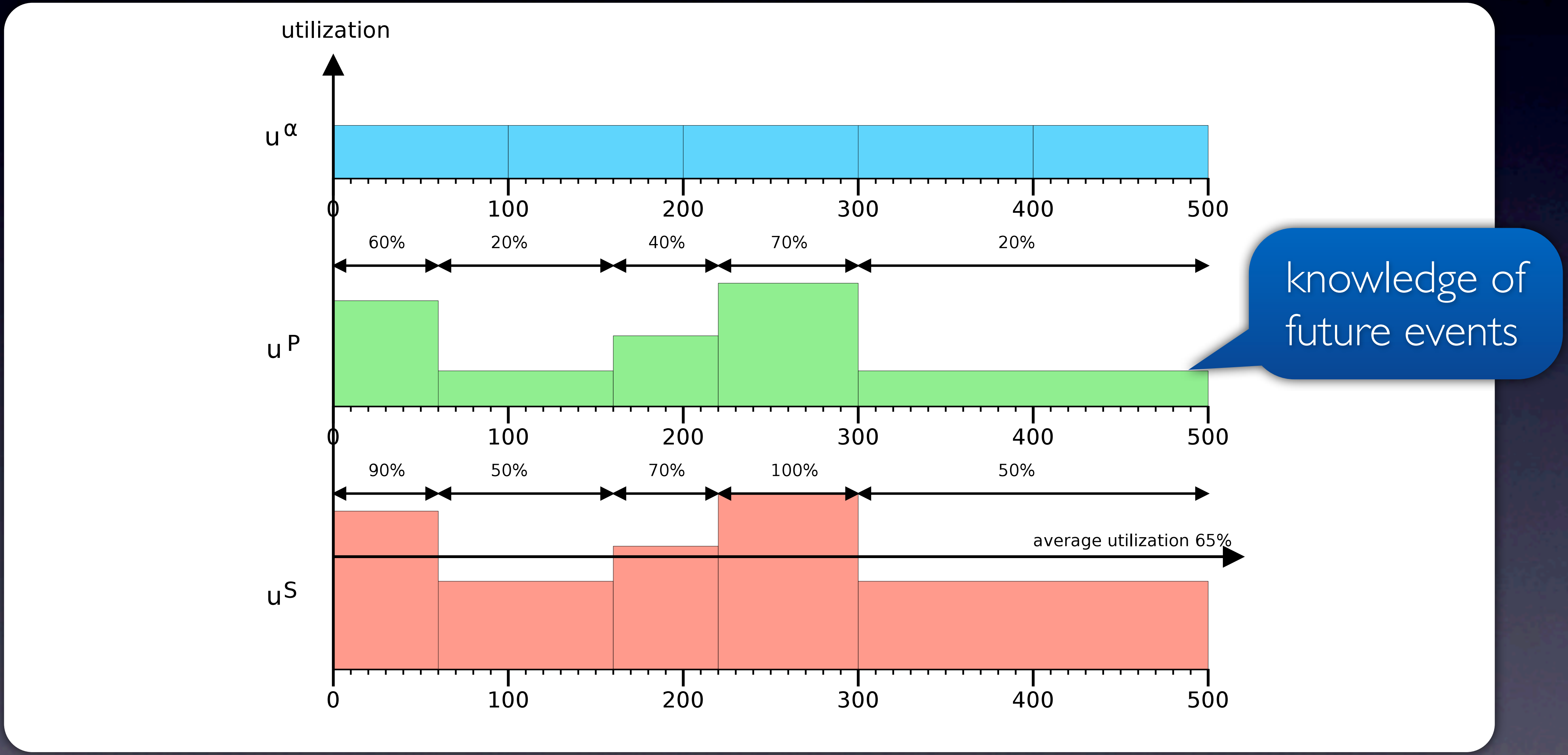

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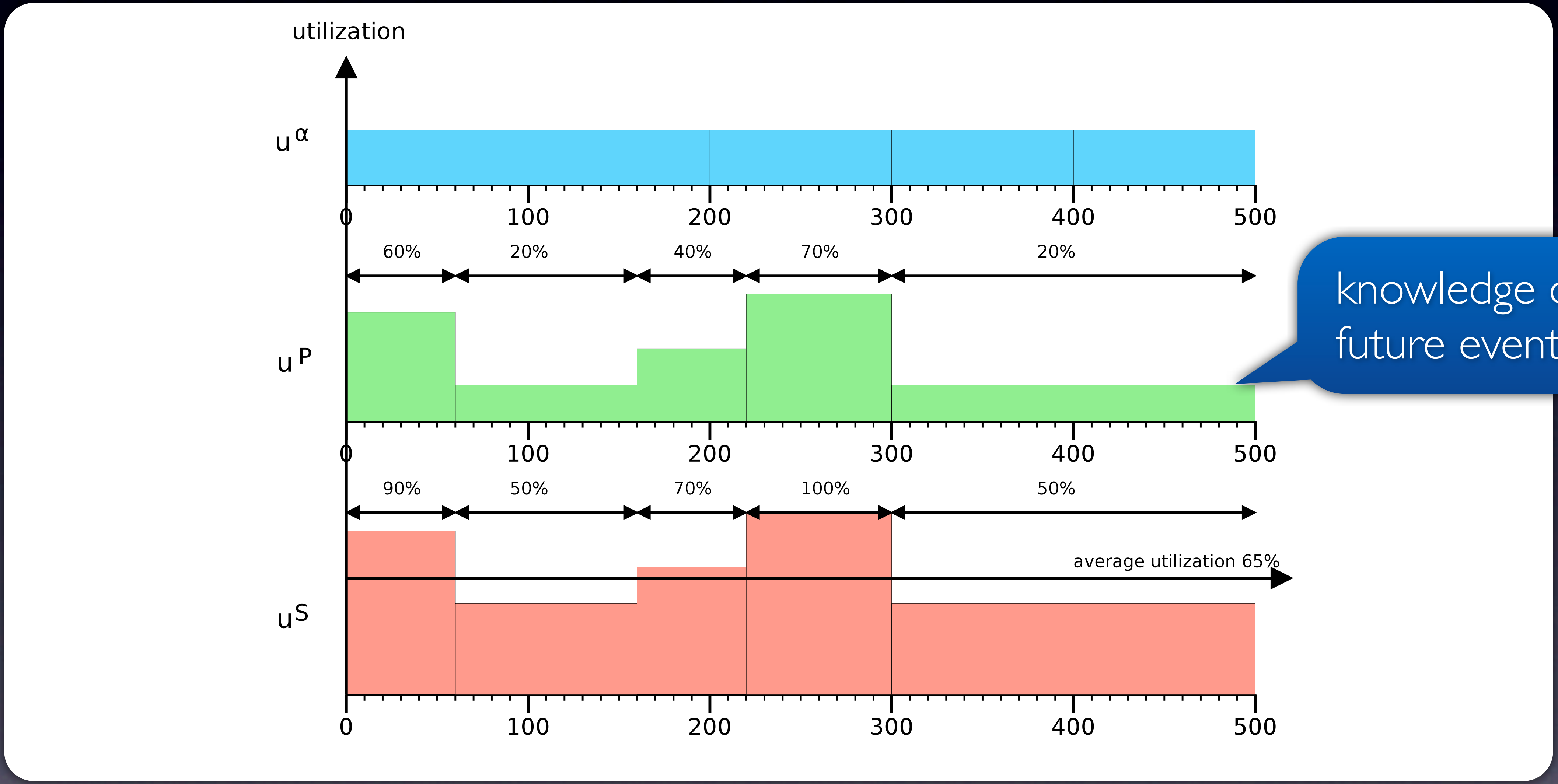

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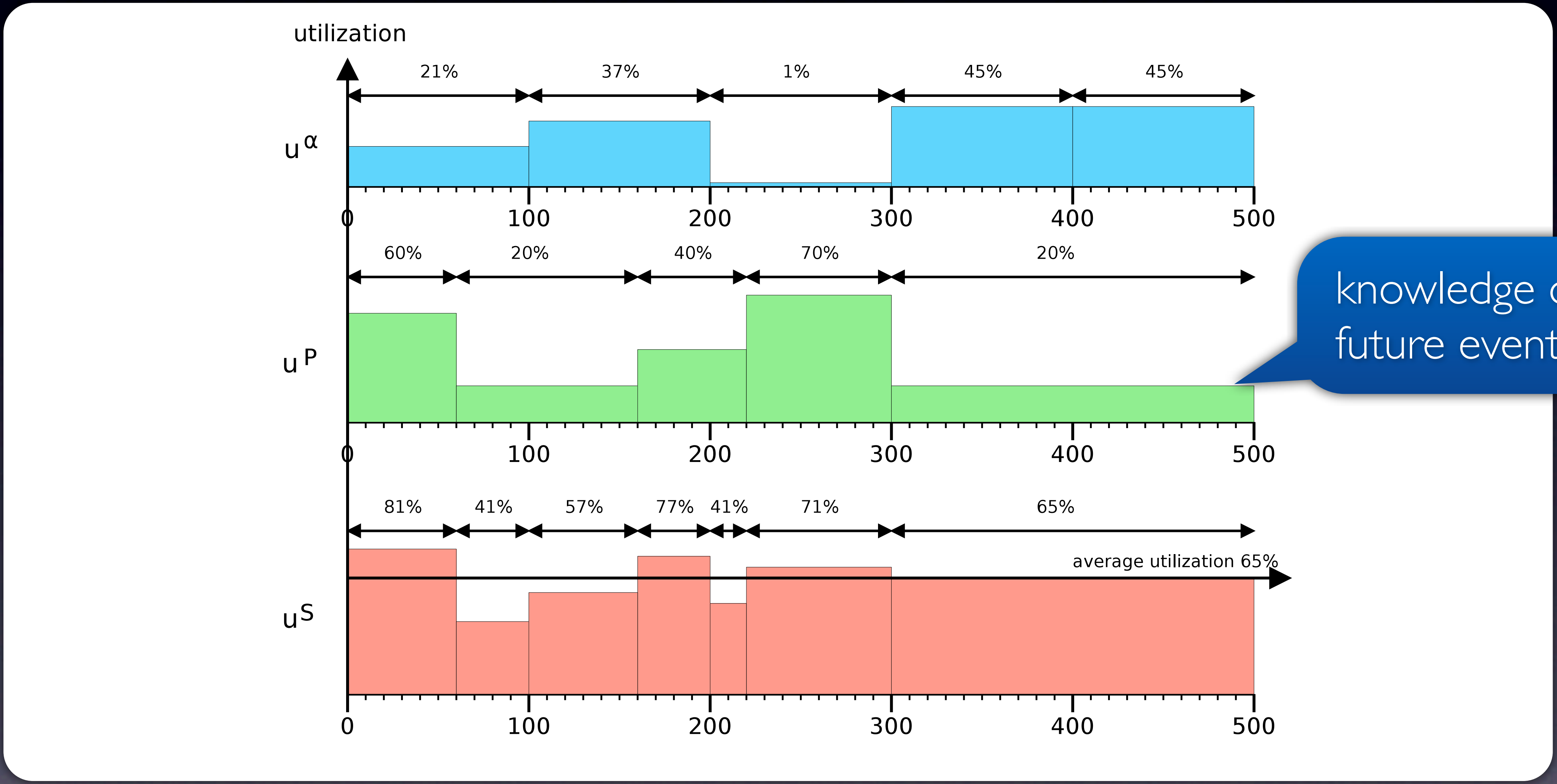

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Yes, if there is no frequency scaling, and if scheduling and context switching cost is accounted for

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Temporal isolation through VBS

Spatial isolation through memory management

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Yes, if there is no frequency scaling, and if scheduling and context switching cost is accounted for

Time and power isolation with frequency scaling?
Problem: non-linear relationship of power consumption and processor frequency