Power-Aware Temporal Isolation with Variable-Bandwidth Servers

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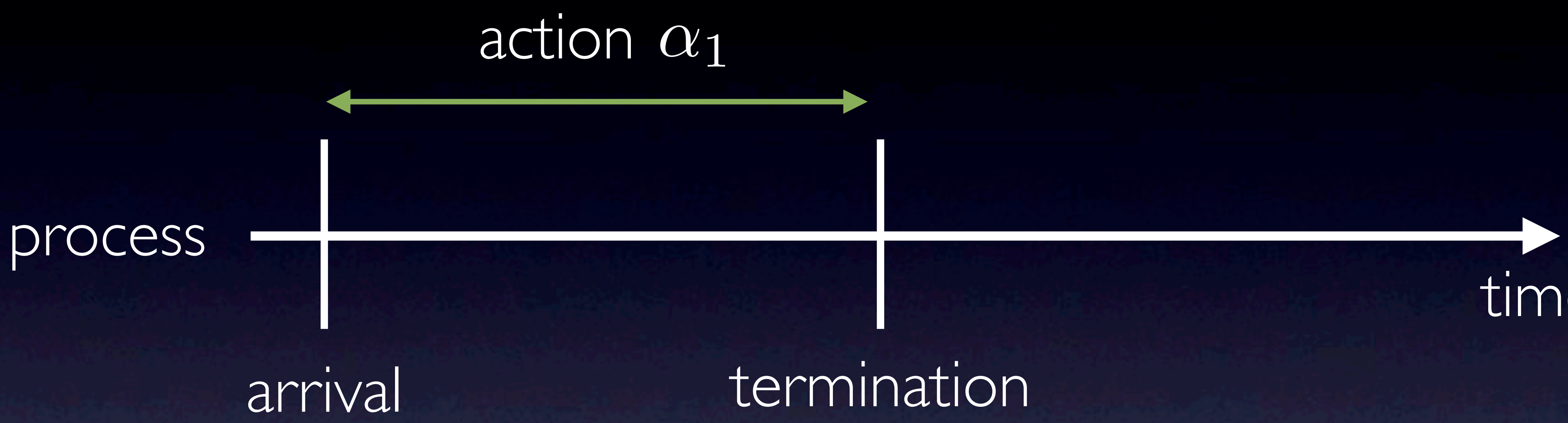
Process Model

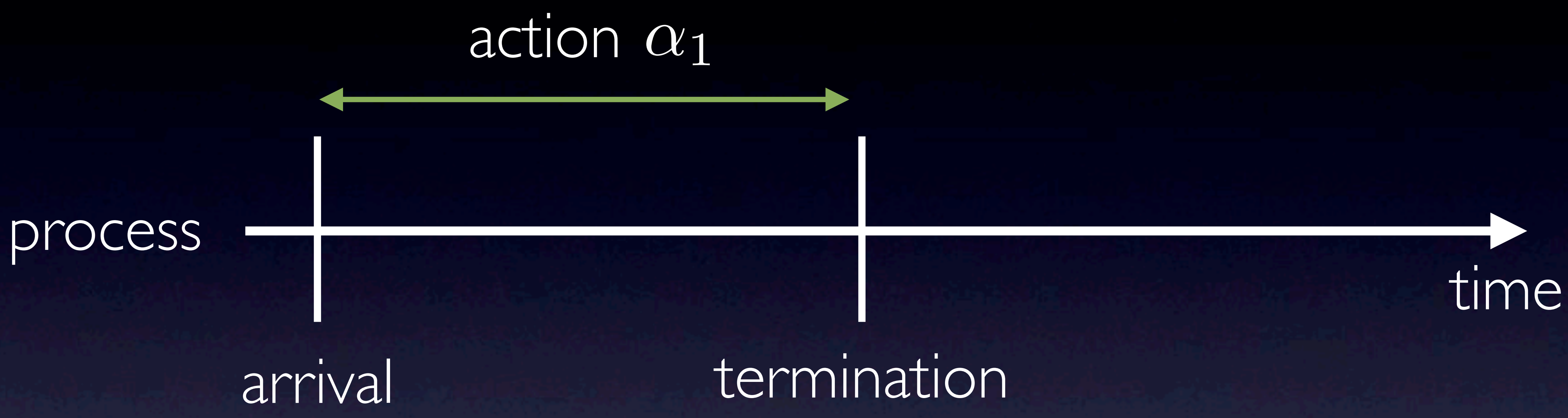
process

time

Process Model

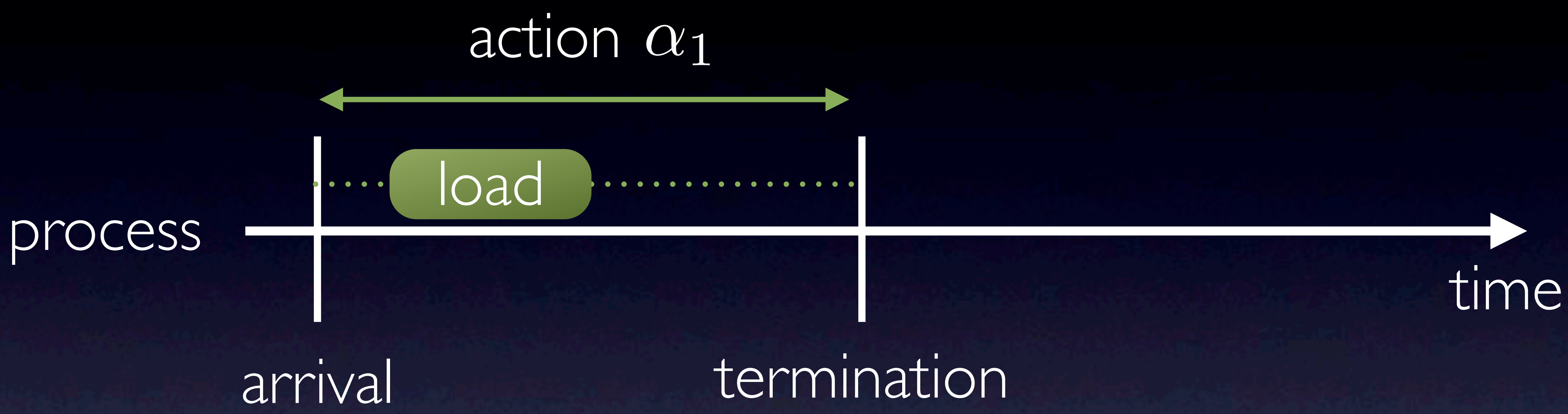


Process Model



- action is a piece of code

Process Model



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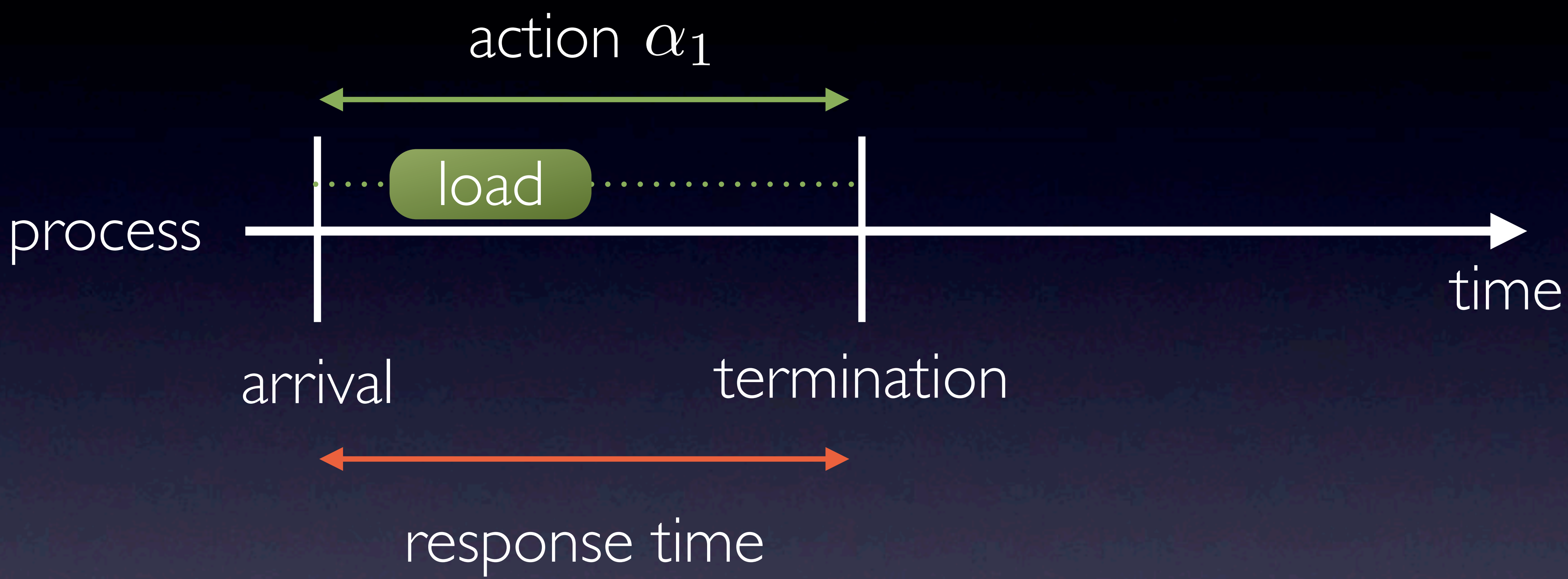

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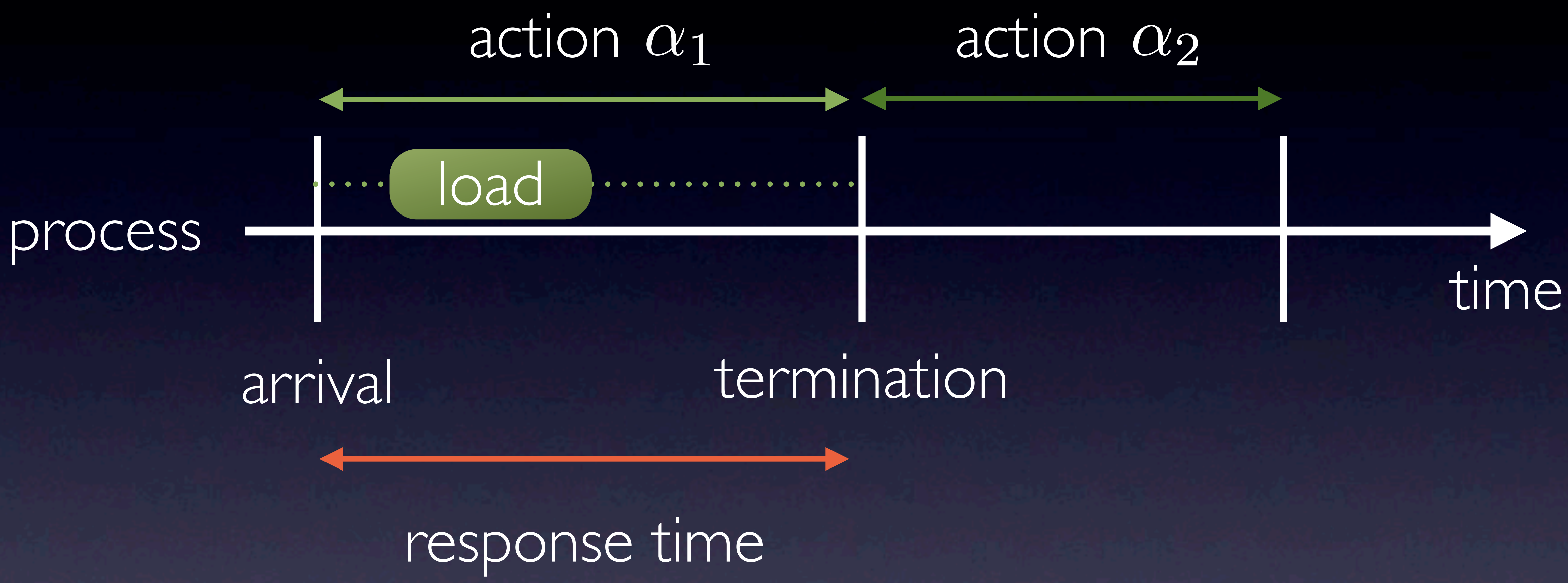

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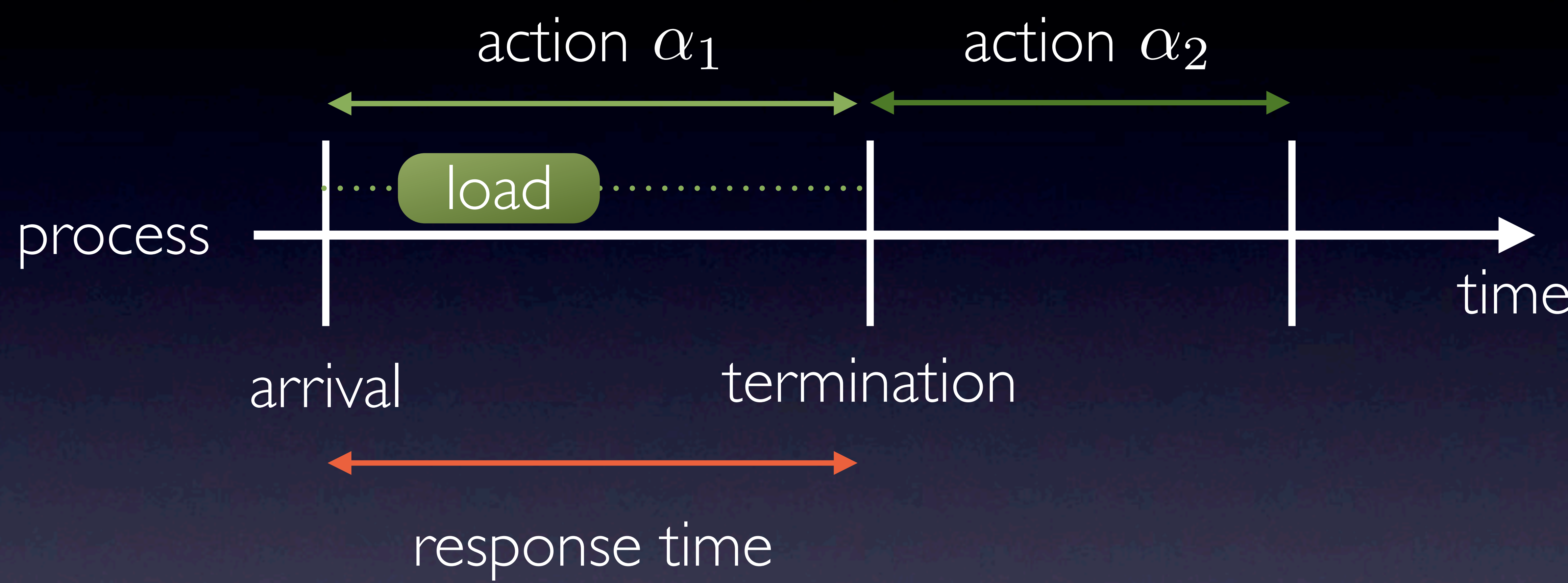
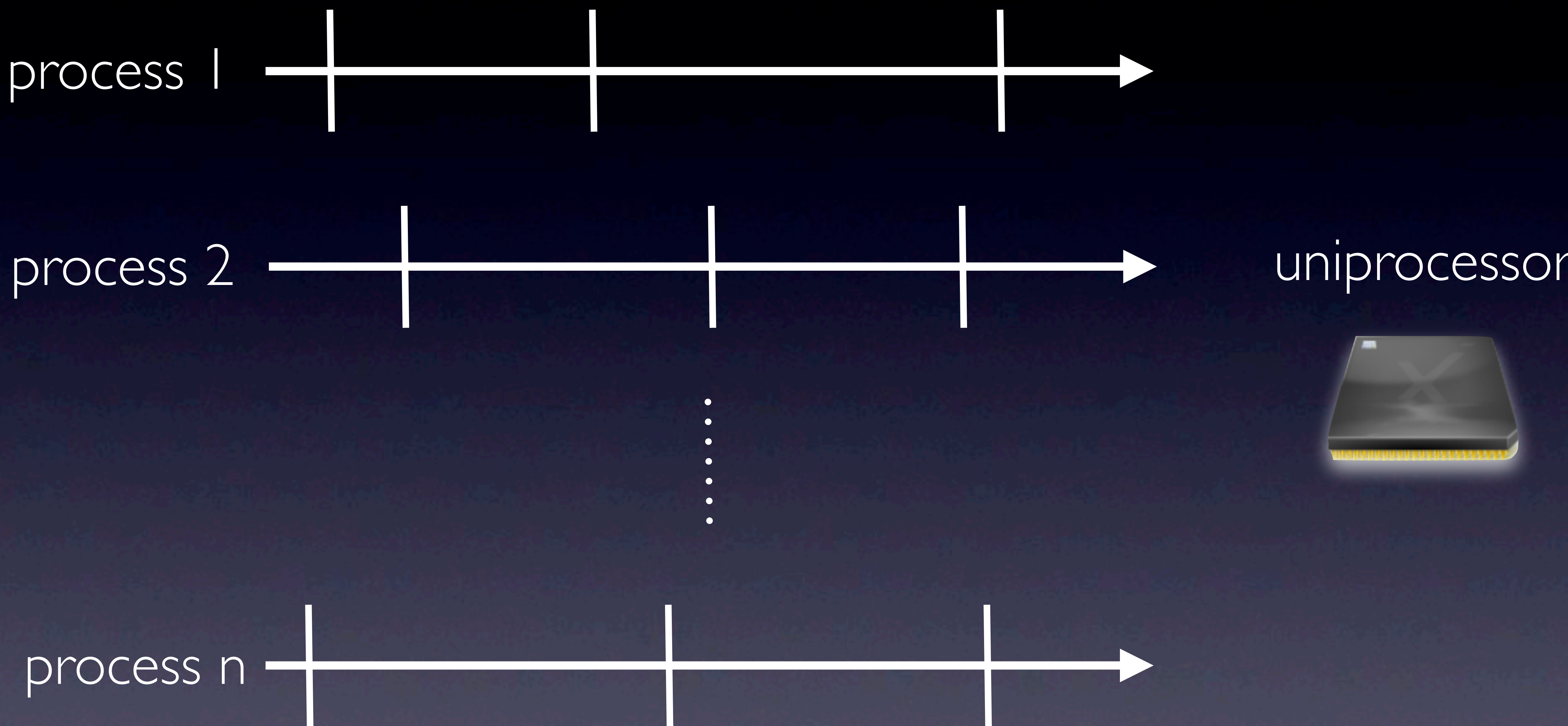
- process is a sequence of actions

Process Model



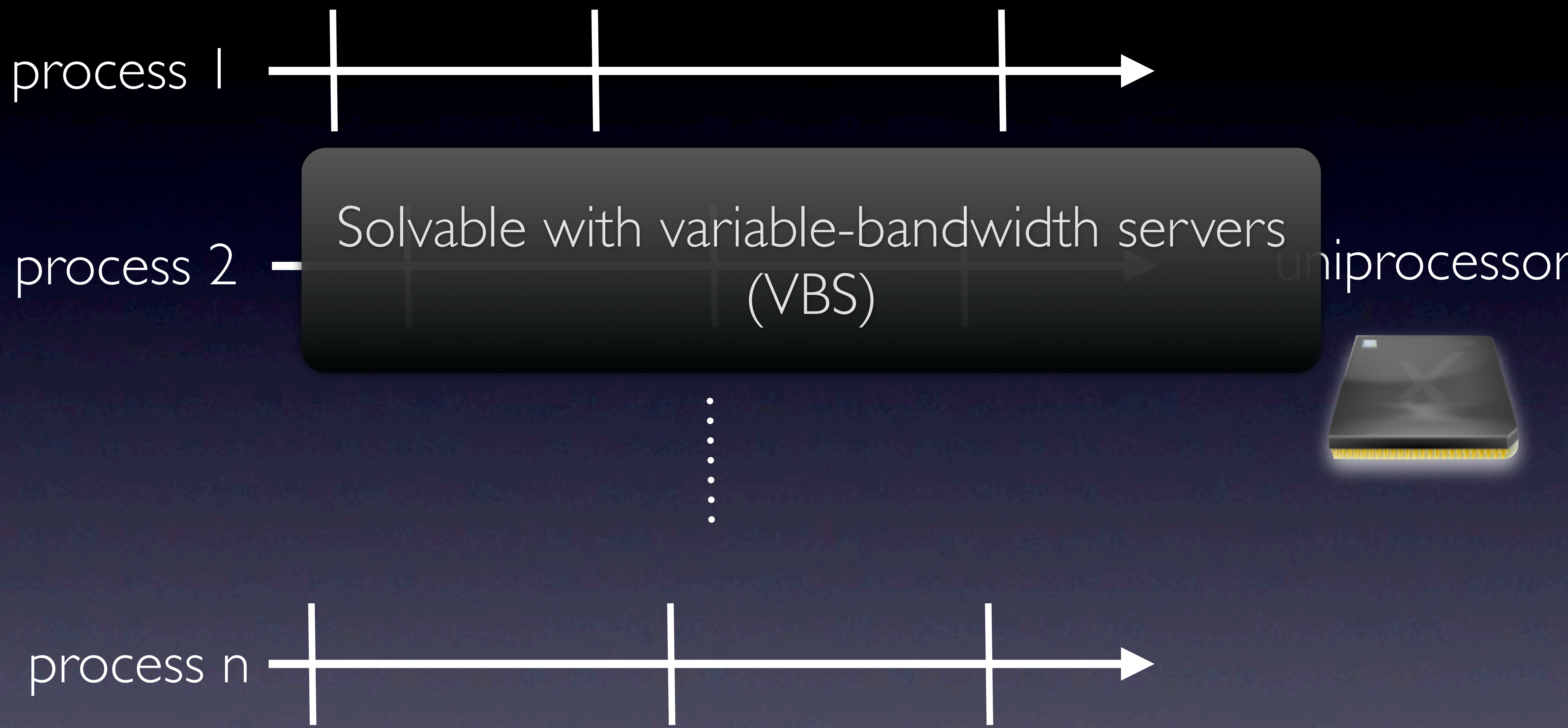
- action is a piece of code
- process is a sequence of actions
- throughput vs latency of process execution

Scheduling Problem



schedule the processes so that each of their actions maintains its response time

Scheduling Problem



Solvable with variable-bandwidth servers (VBS)

schedule the processes so that each of their actions maintains its response time

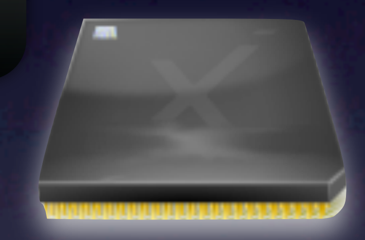
Scheduling Problem

process 1

Solvable with variable-bandwidth servers (VBS)

process 2

uniprocessor



Results [SIES09]:
- constant-time scheduling algorithm
- constant time admission test

process n

schedule the processes so that each of their actions maintains its response time

Resources and VBS

virtual periodic resources

period π limit λ utilization $\dfrac{\lambda}{\pi}$

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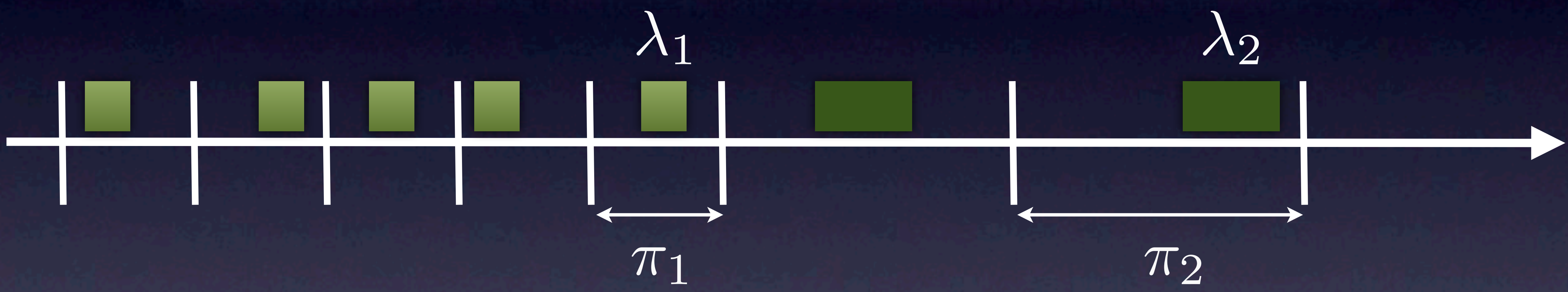

Resources and VBS

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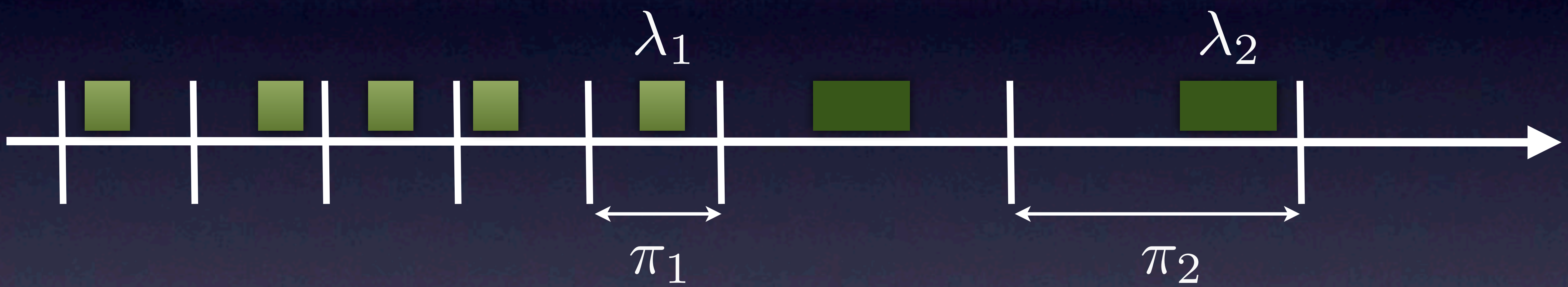


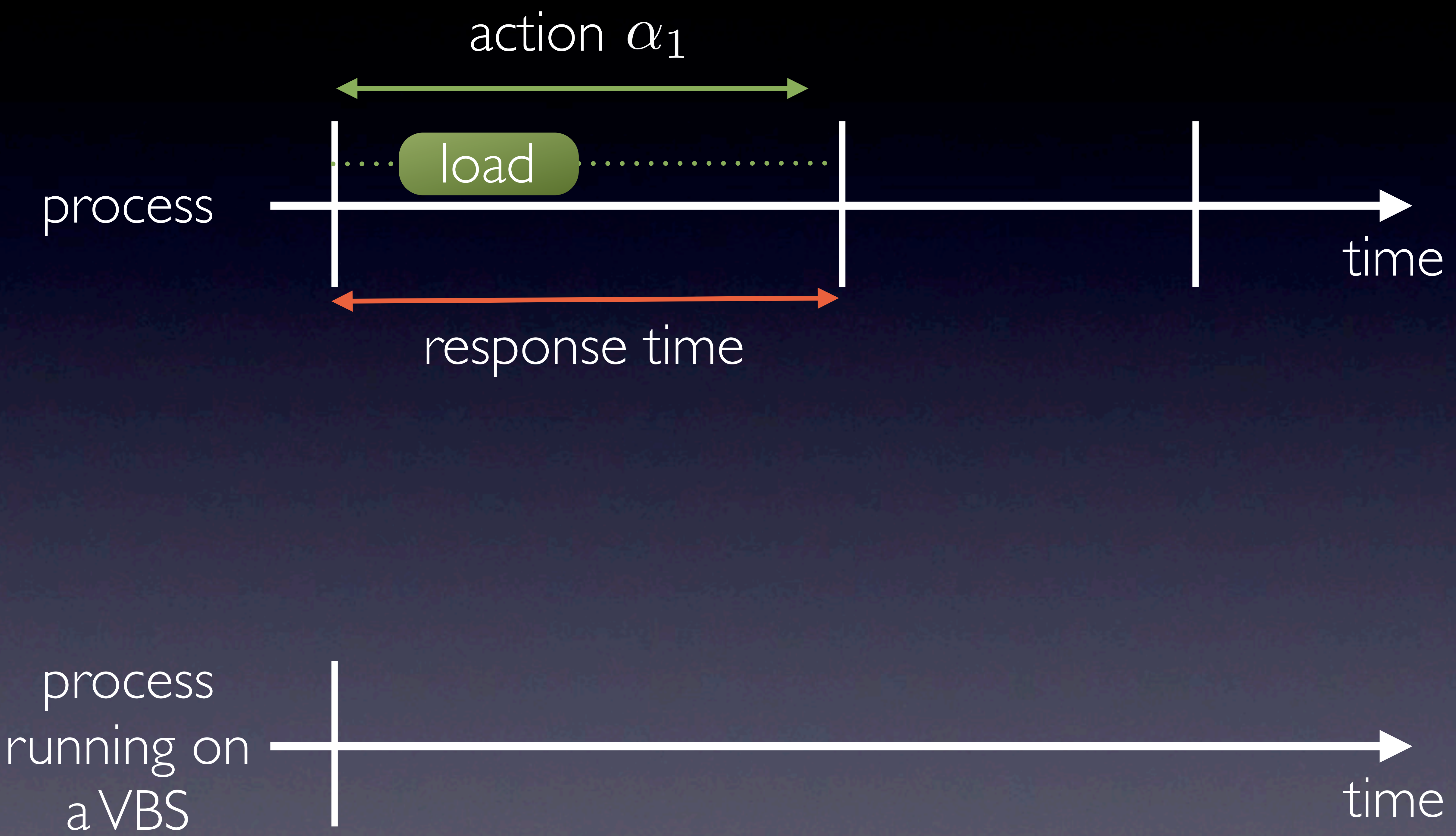
- VBS is determined by a bandwidth cap (u)
- VBS processes dynamically adjust speed (change resources)

$$\frac{\lambda_1}{\pi_1} \leq u \qquad \frac{\lambda_2}{\pi_2} \leq u$$

- generalization of constant bandwidth servers (CBS)

[Abeni and Buttazzo 2004]

One Process on a VBS



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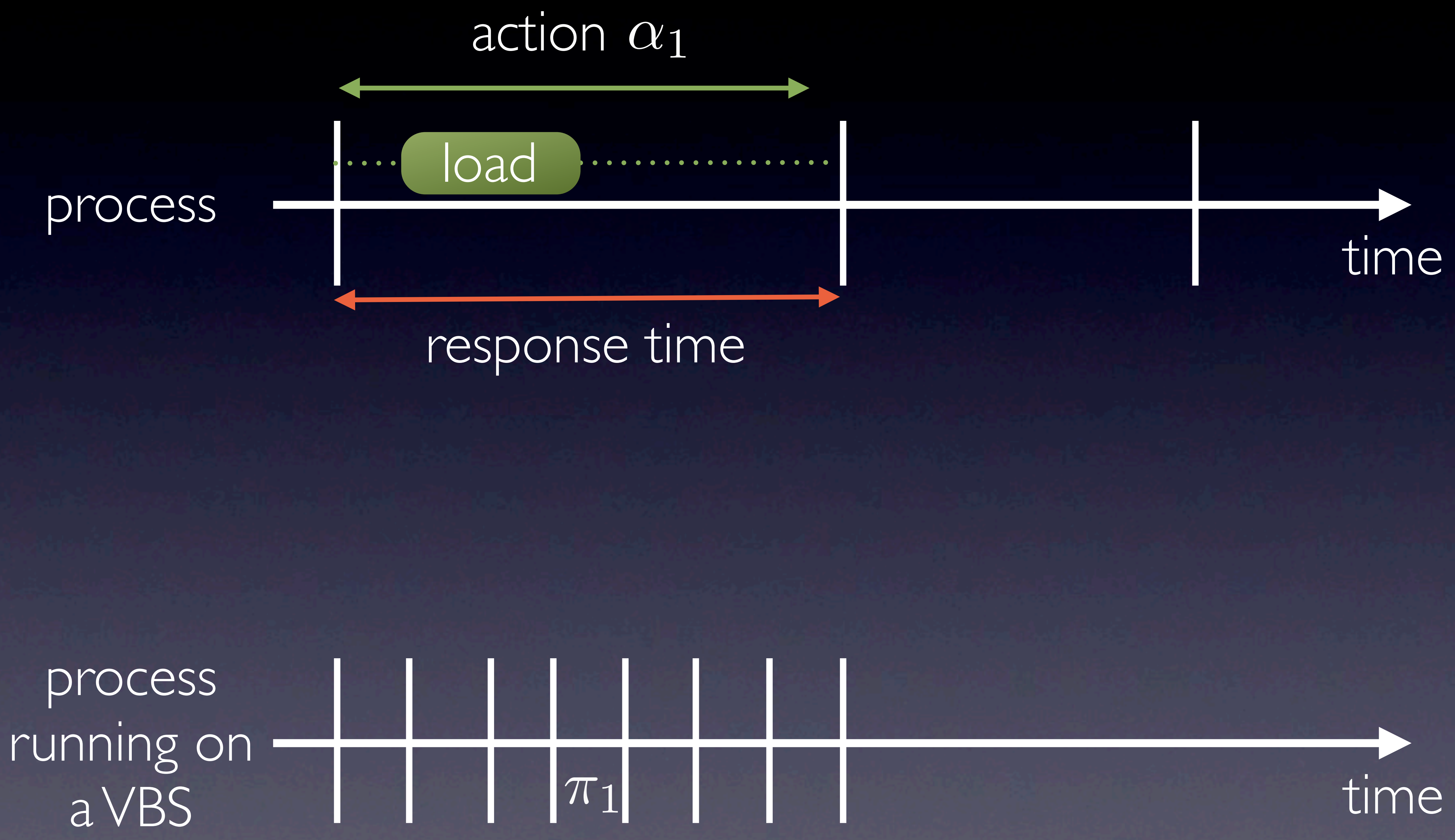

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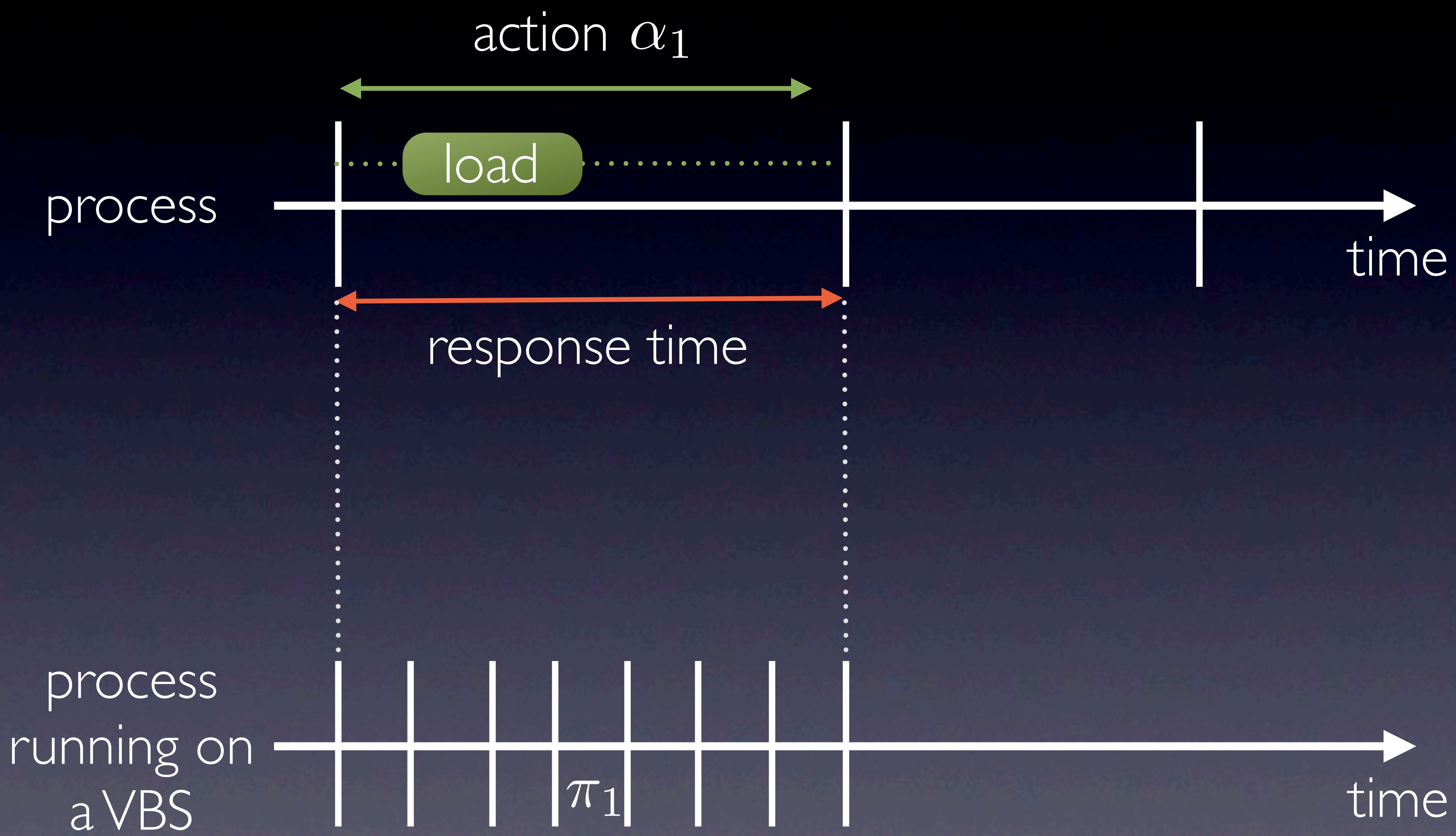

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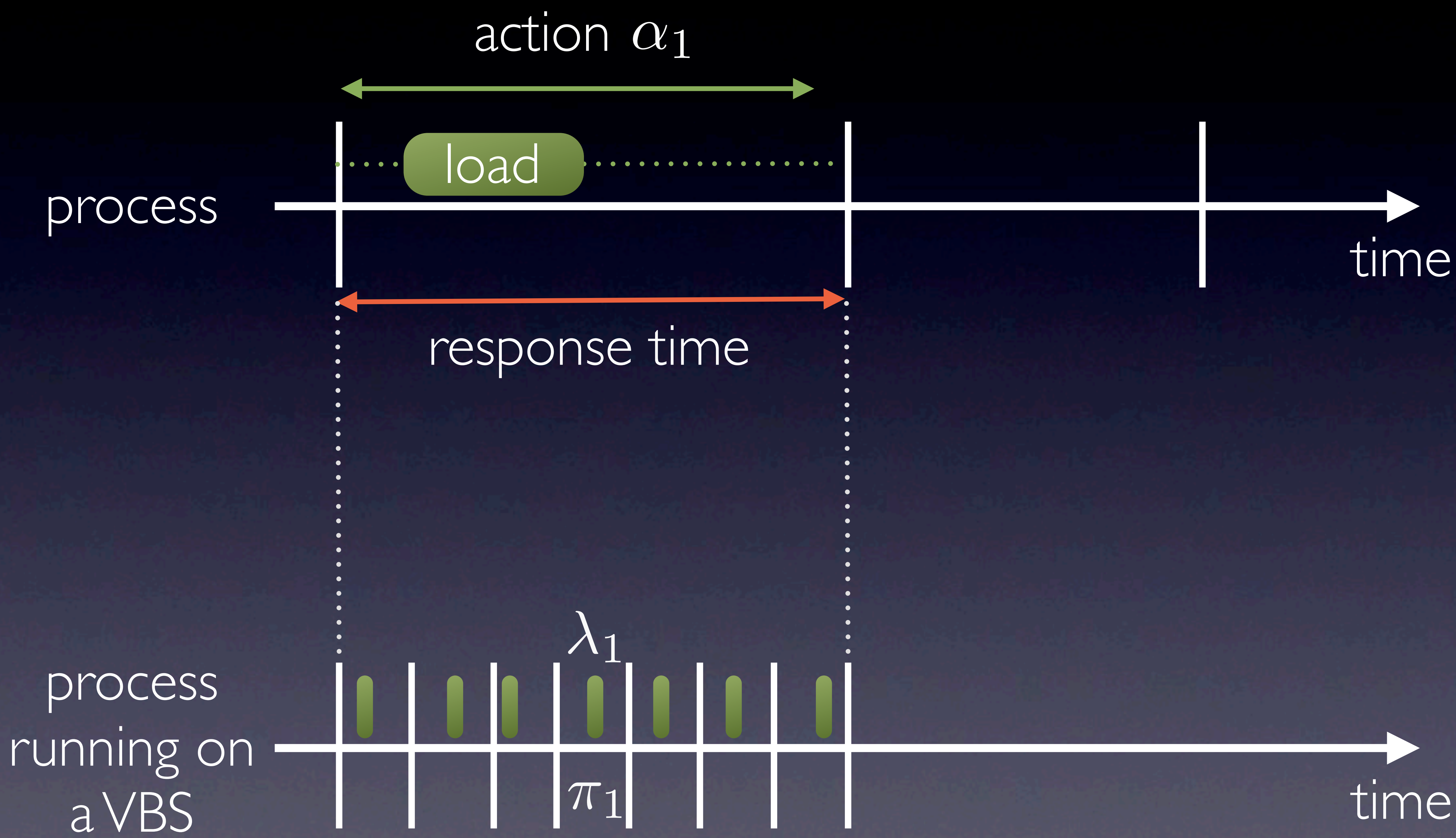

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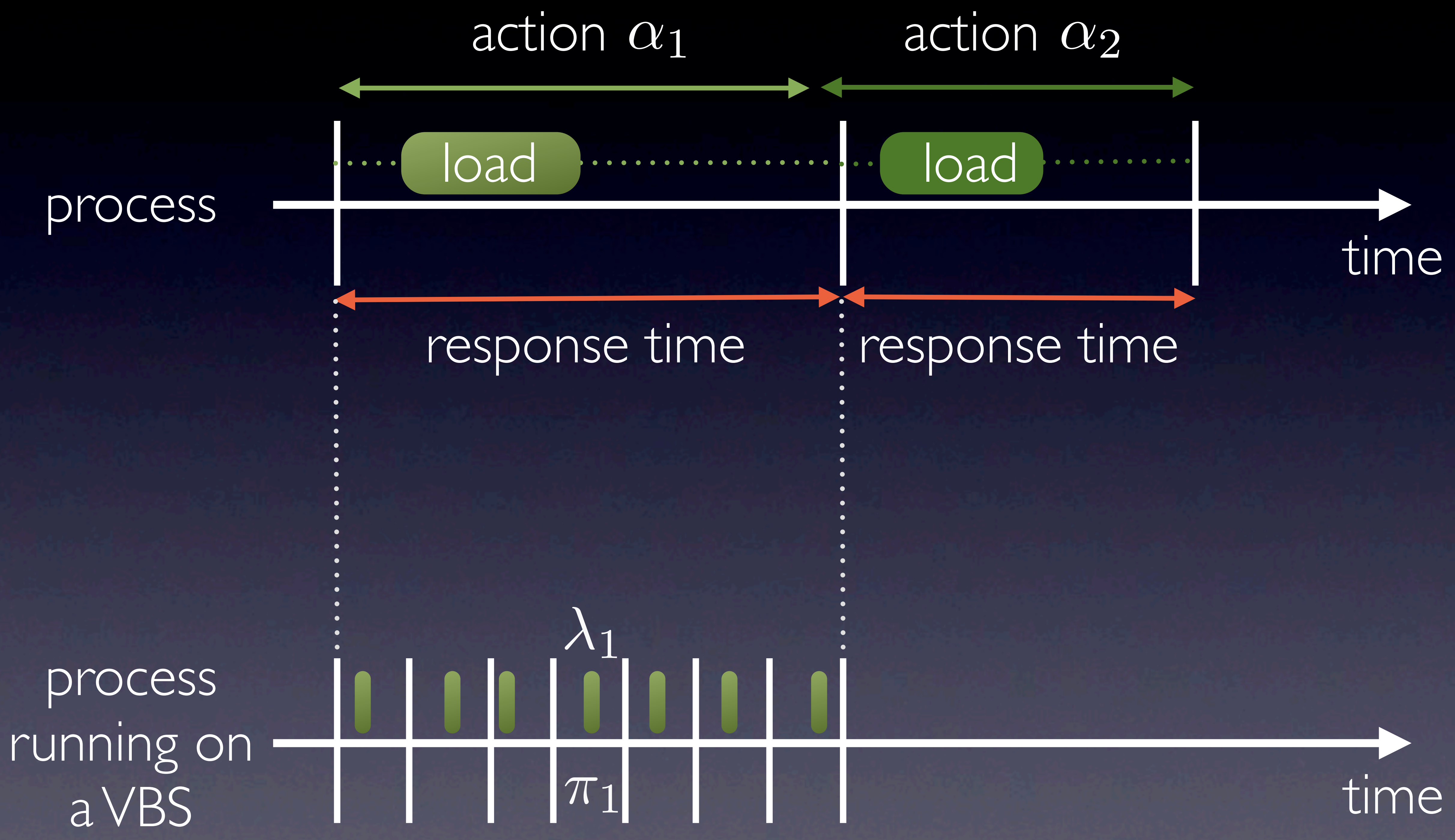

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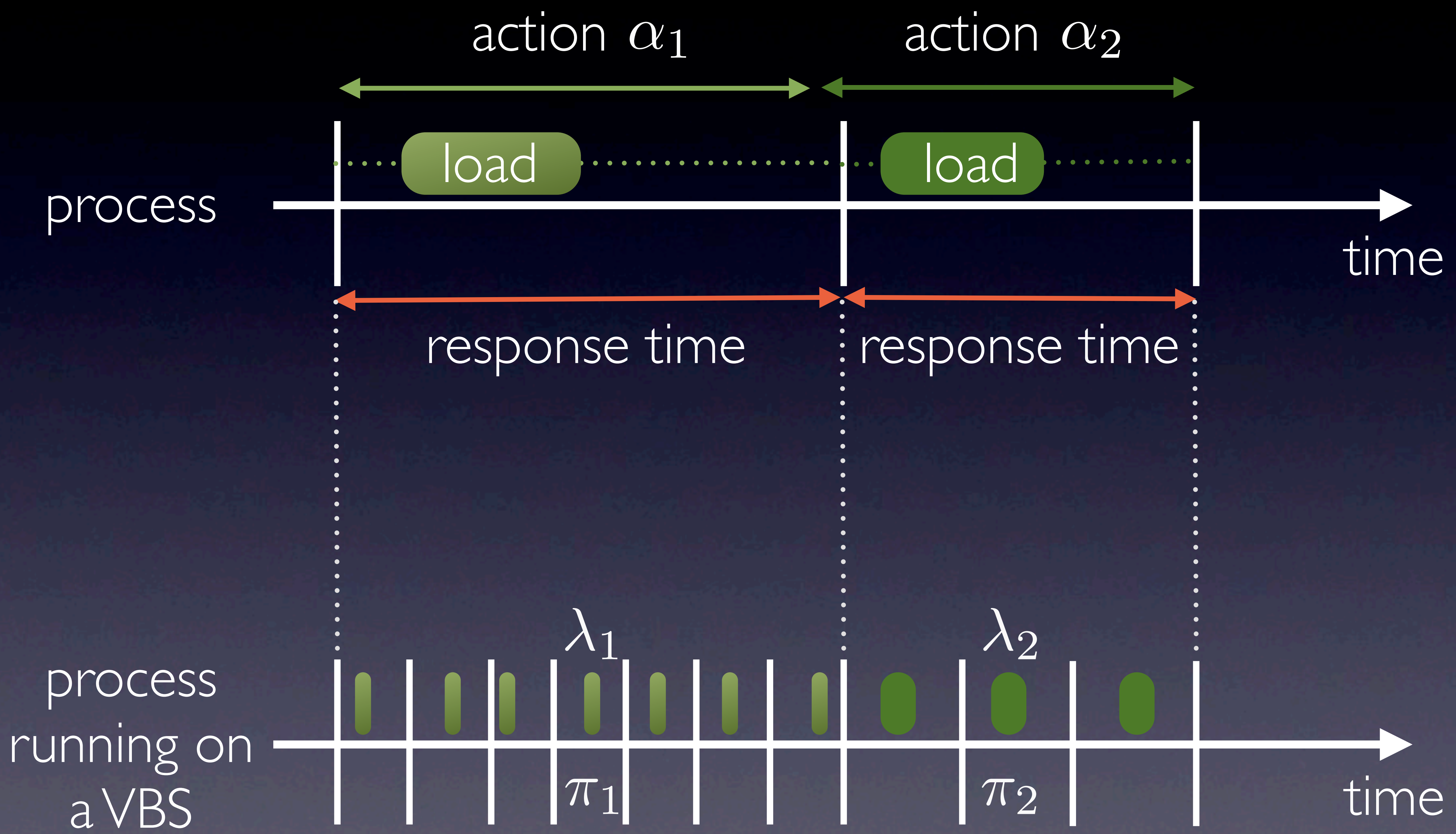

VBS

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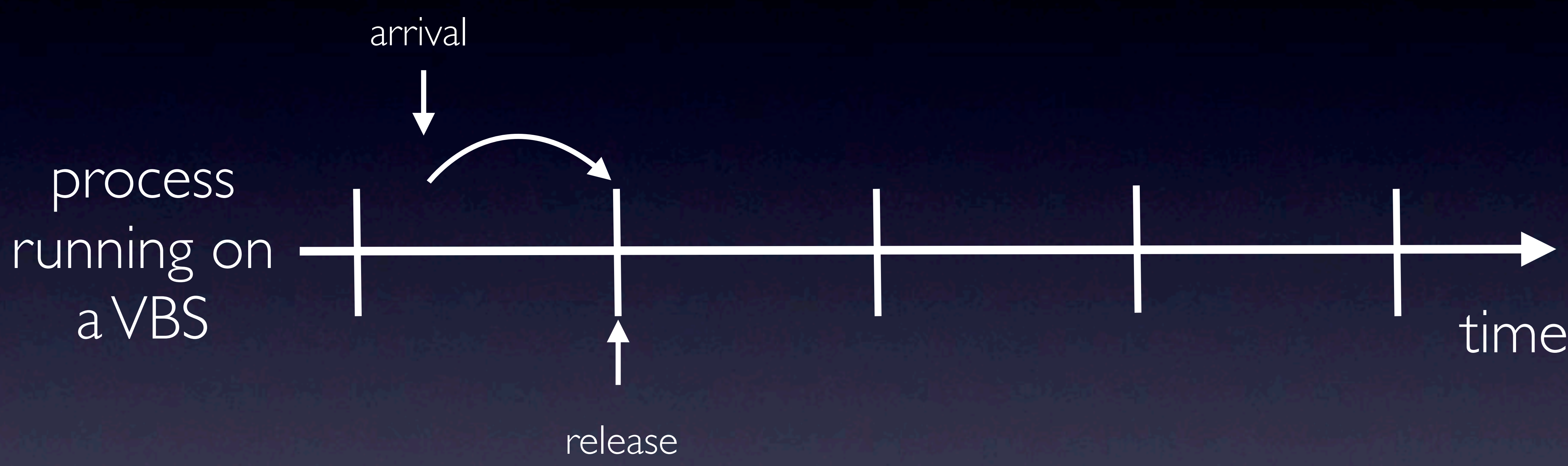

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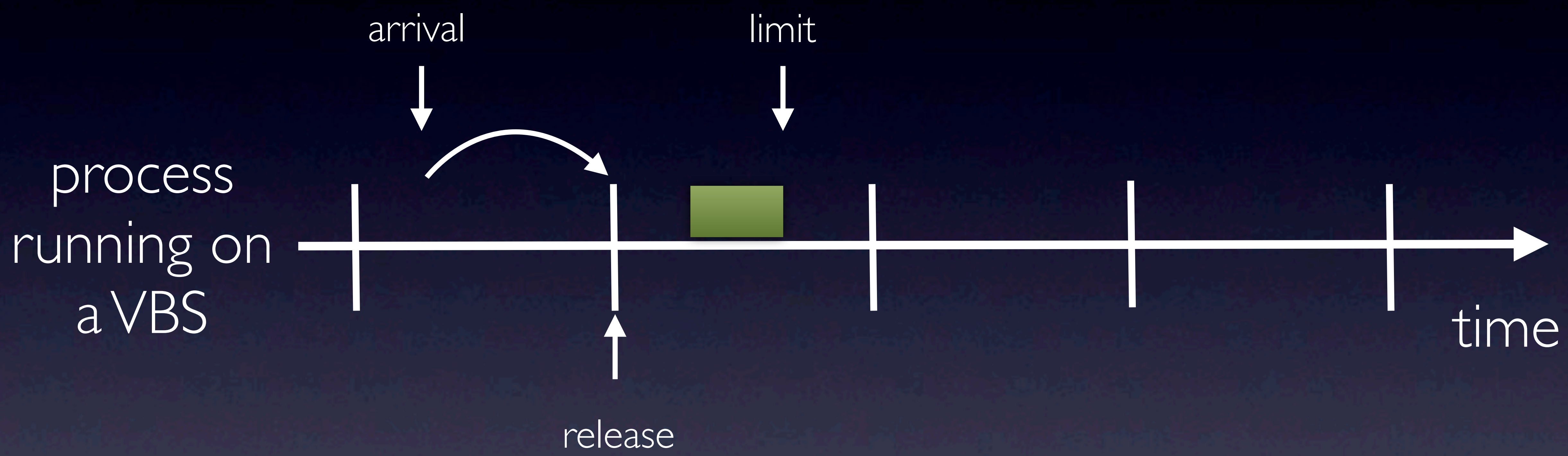

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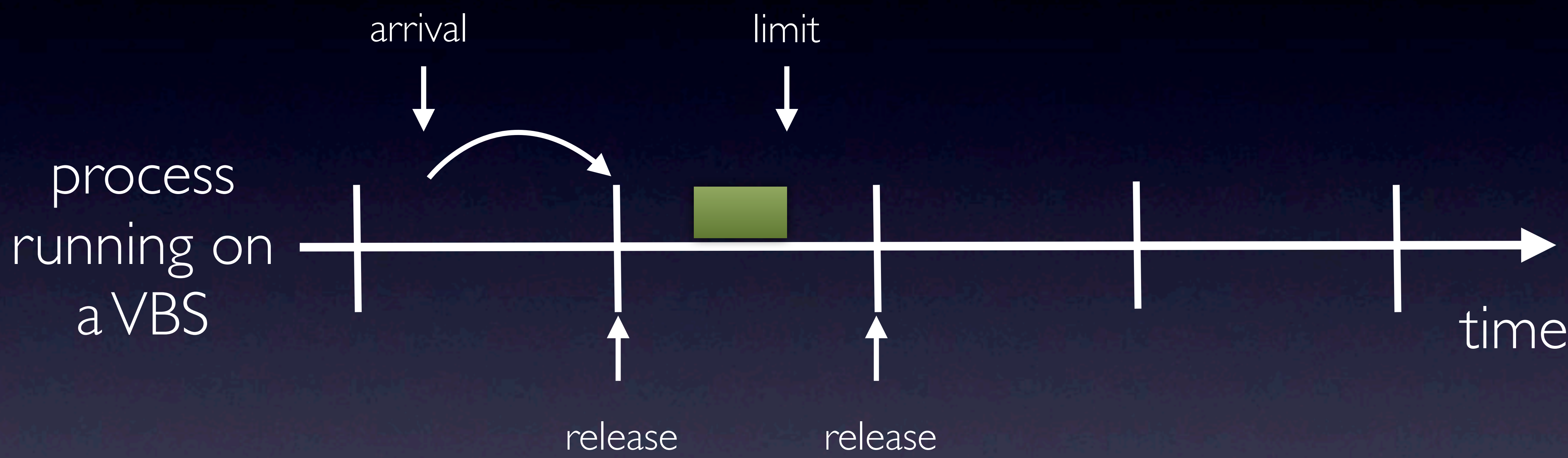
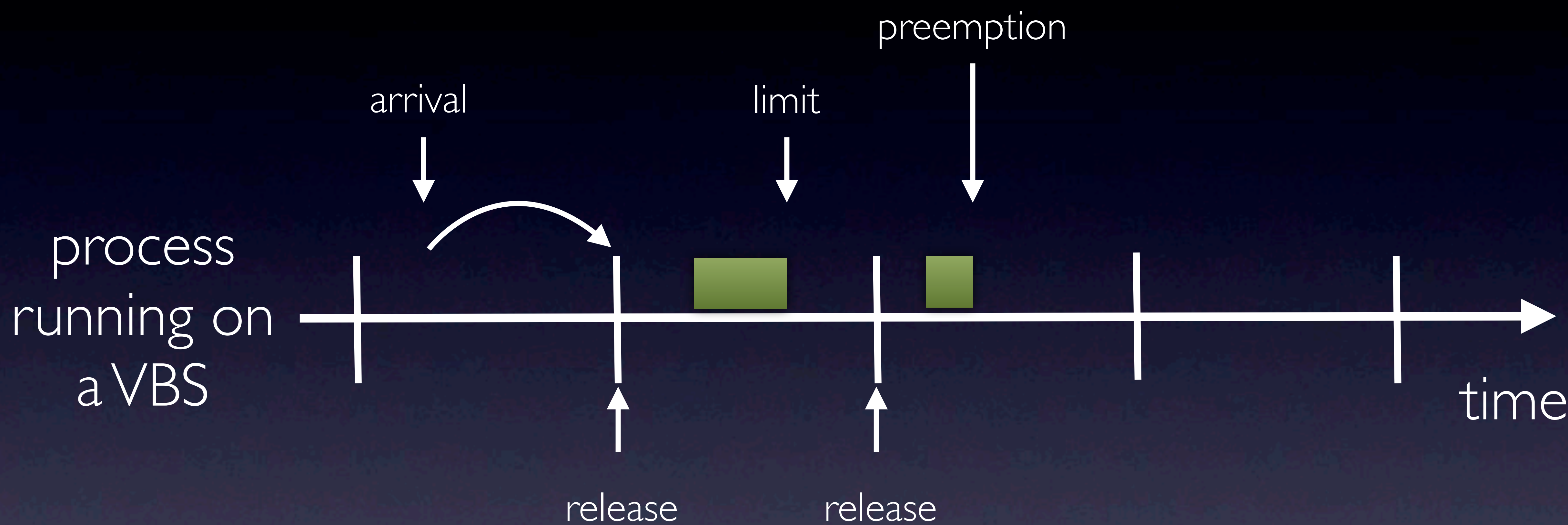

arrival
limit
process
running on
a VBS
time
release
release

VBS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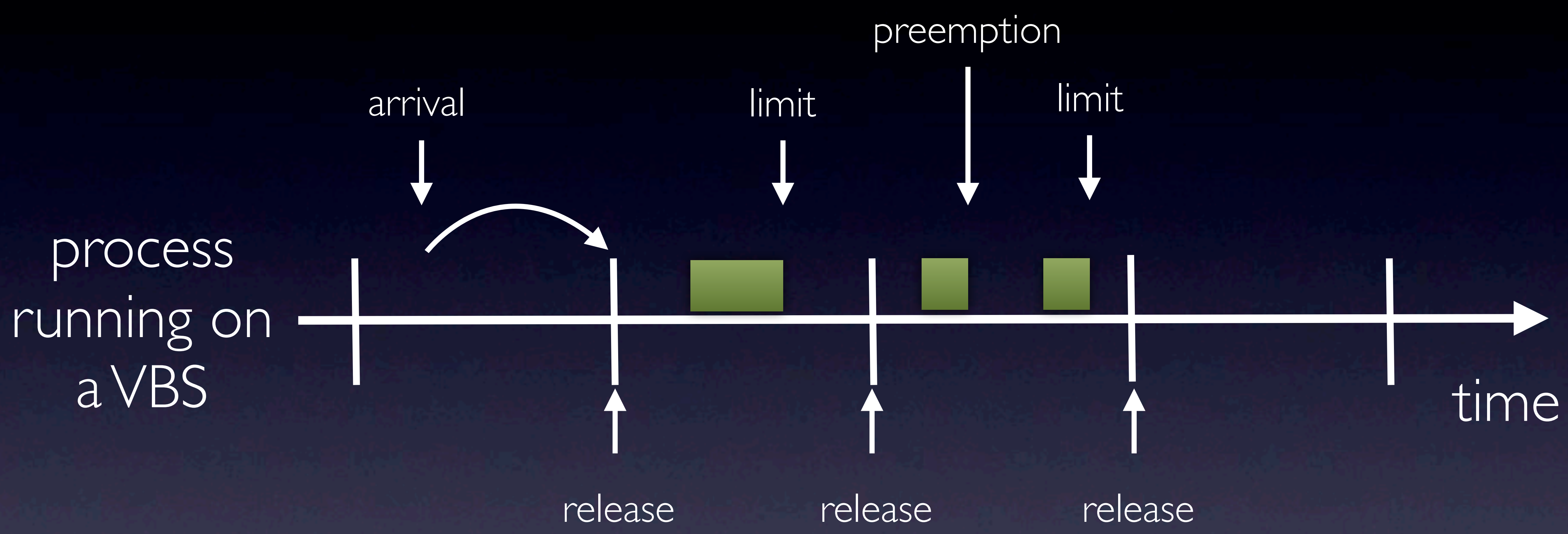
preemption
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VBS


preemption
arrival
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completion
process running on a VBS
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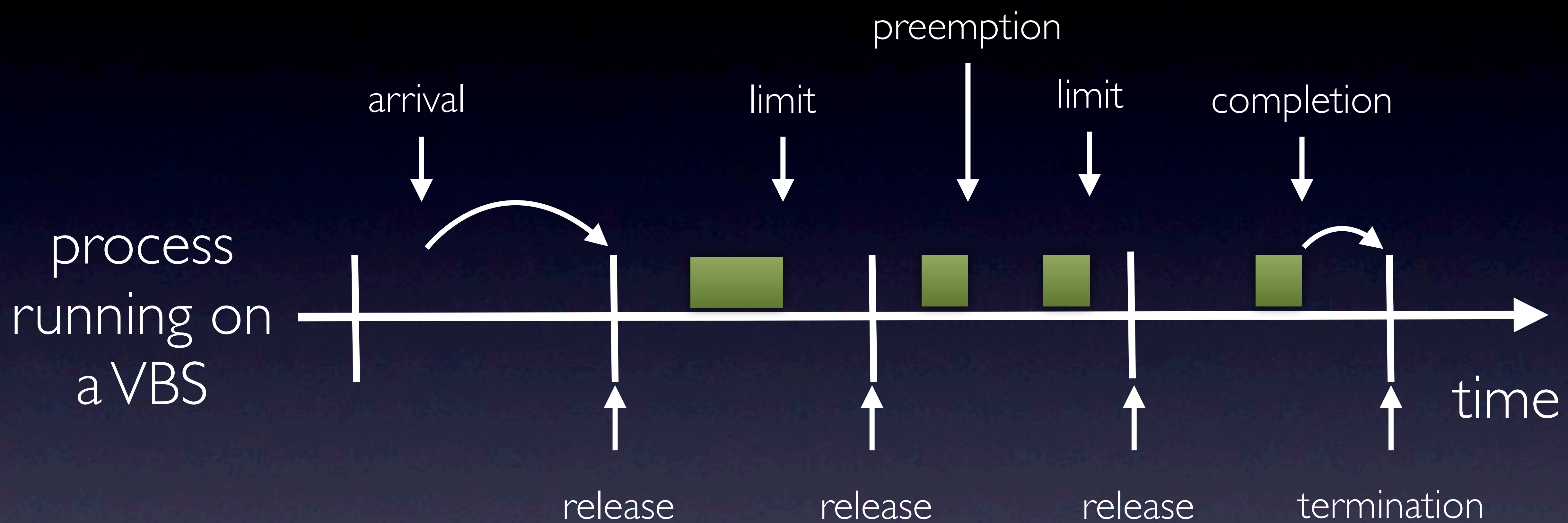
release
release
release

VBS


preemption
arrival
limit
limit
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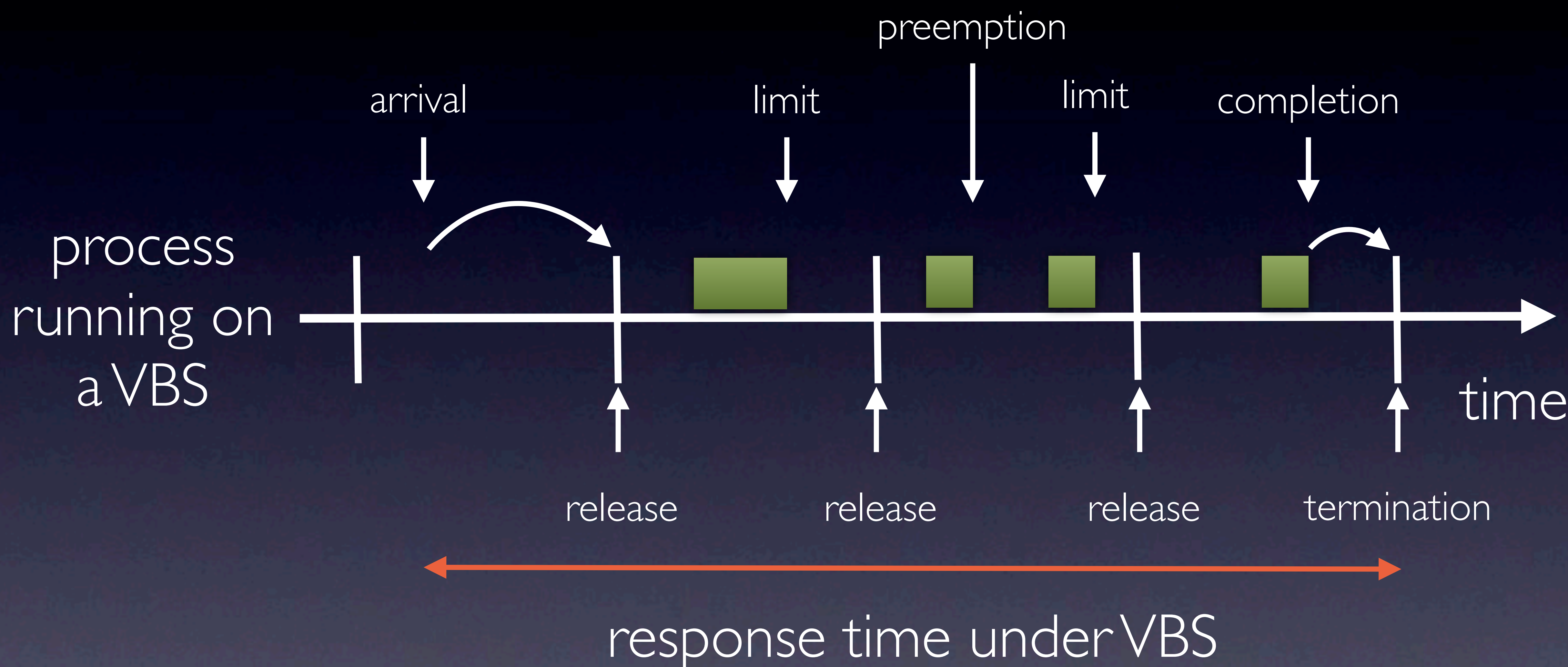
process running on a VBS
time
release
release
release
termination

VBS


preemption
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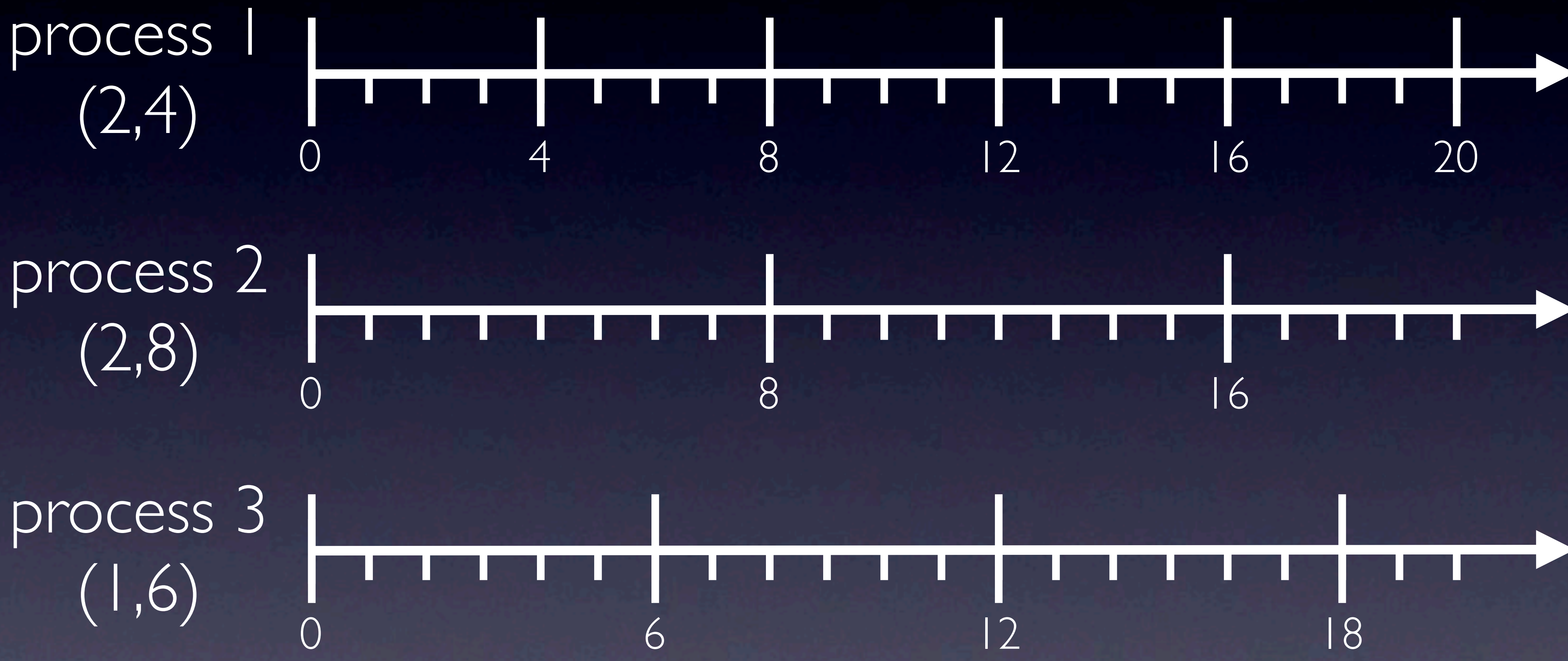
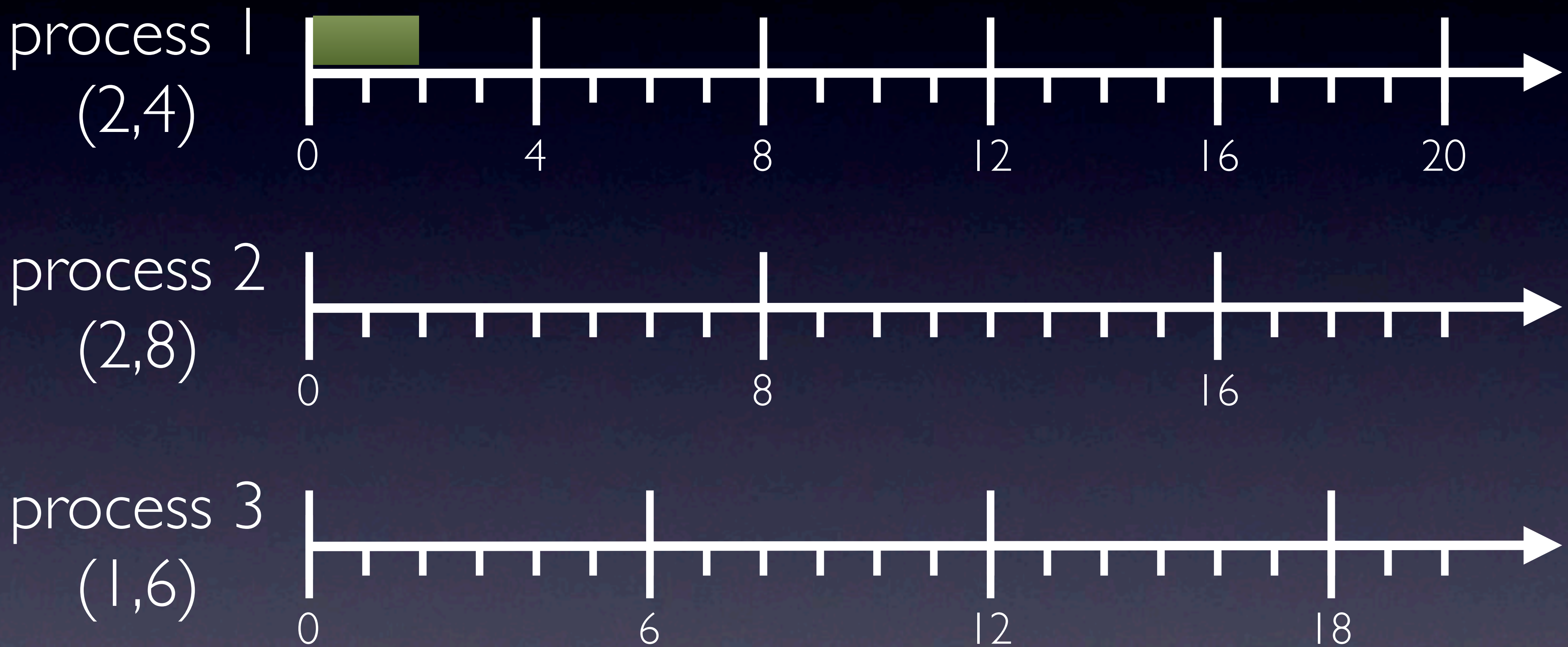
response time under VBS

VBS



multiple processes are EDF-scheduled

VBS



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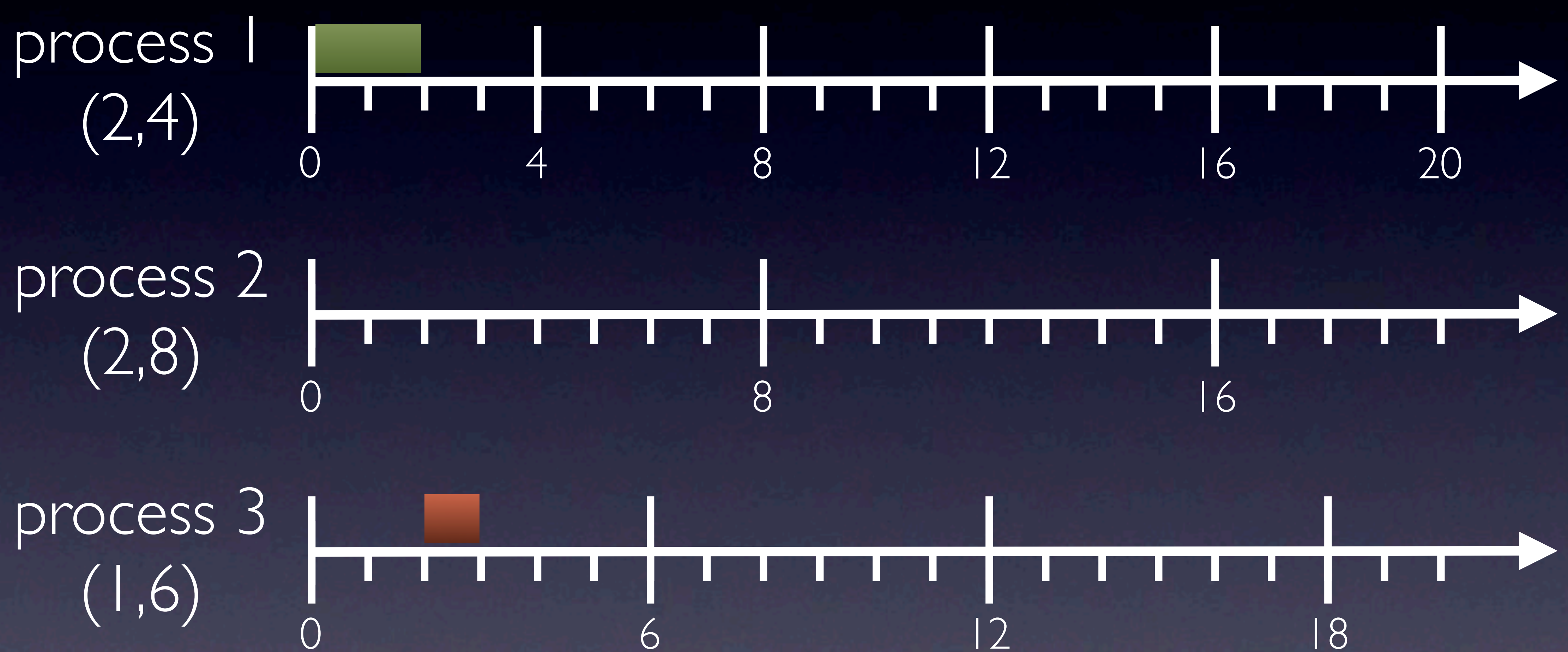

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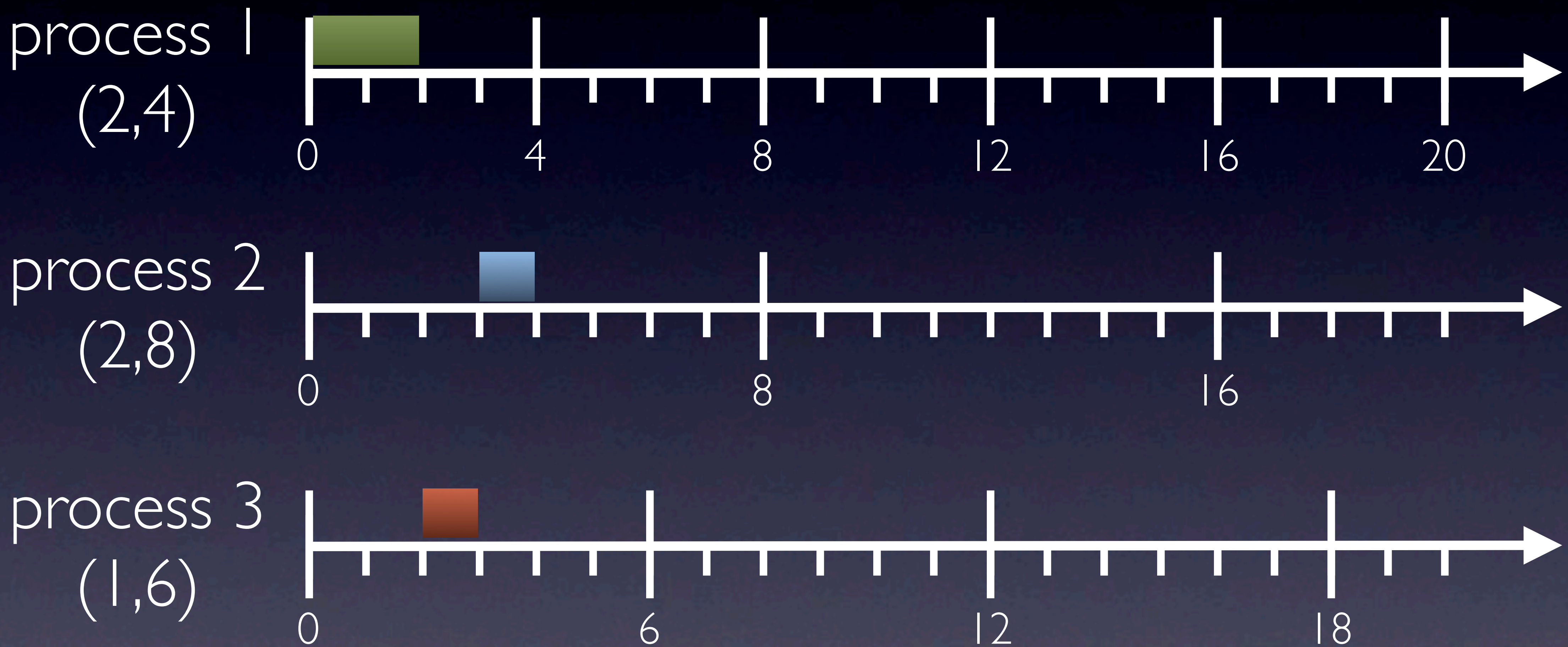

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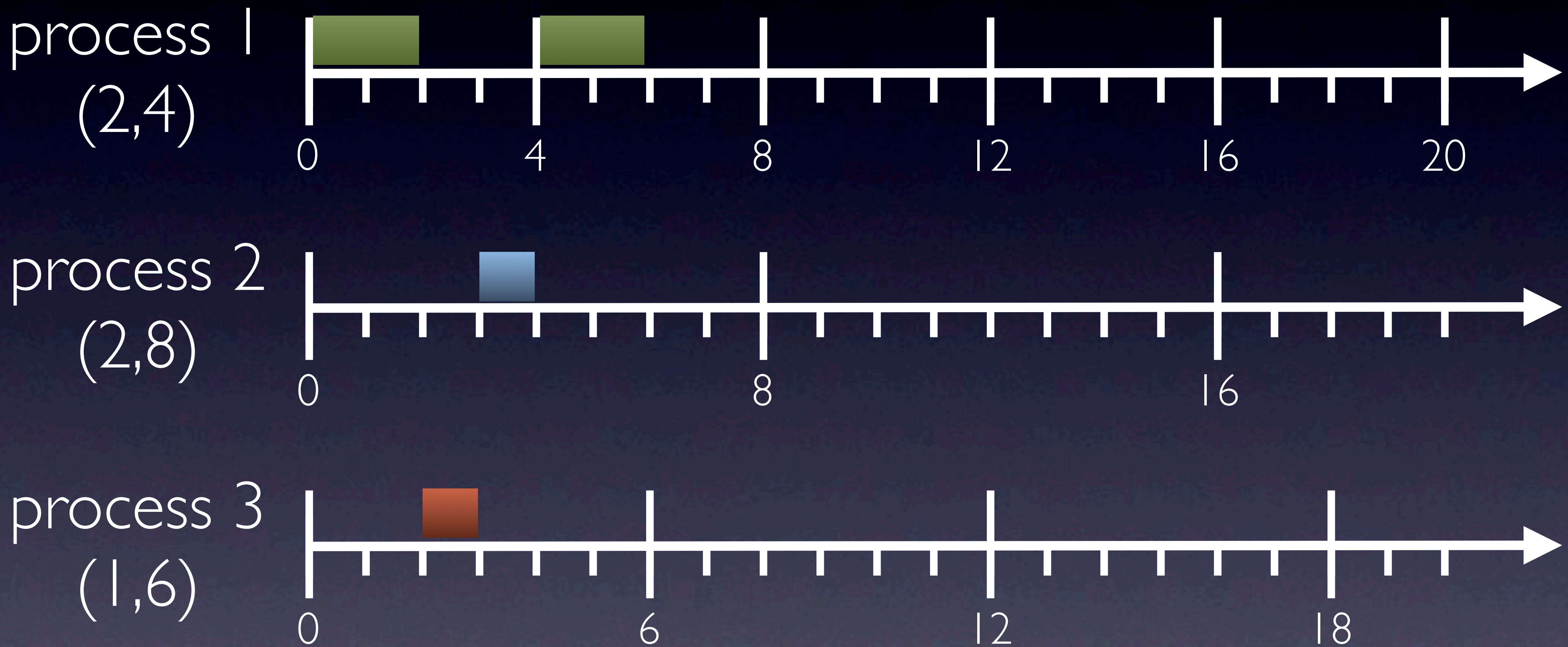

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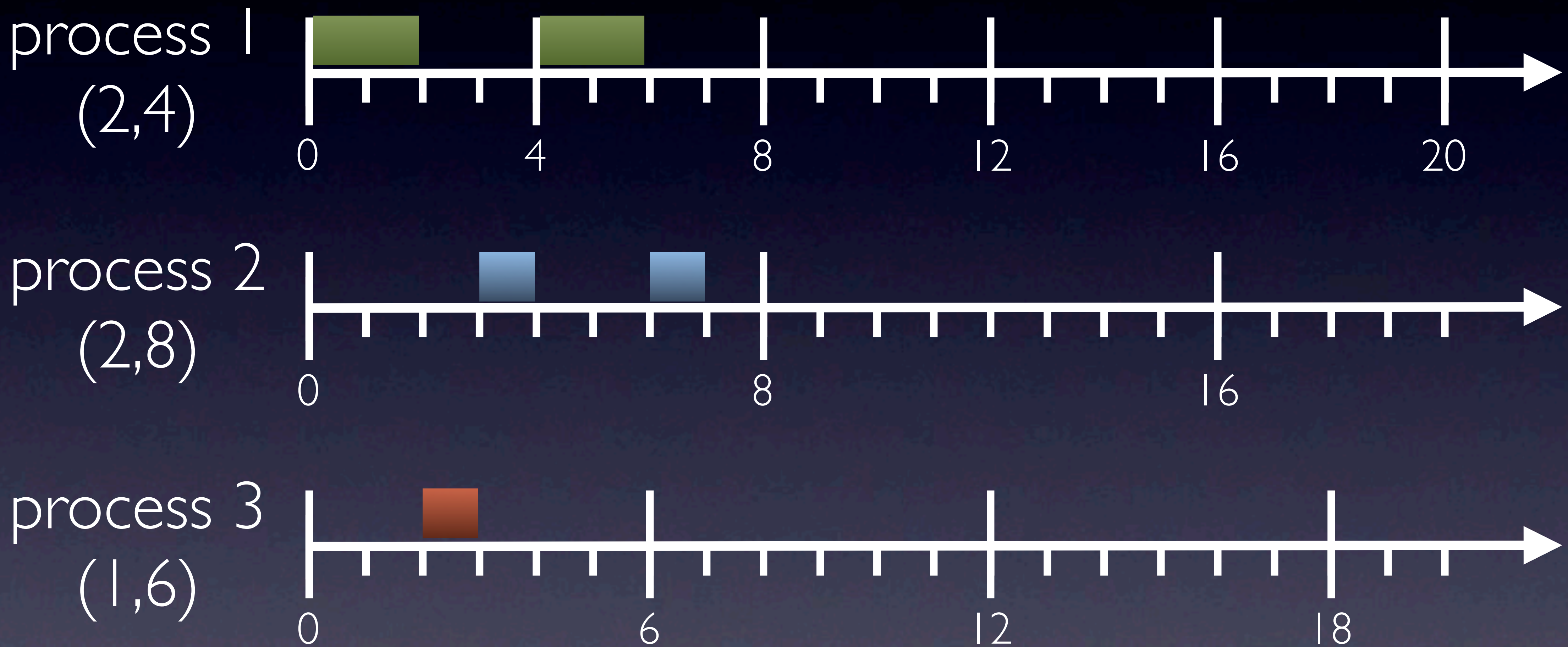

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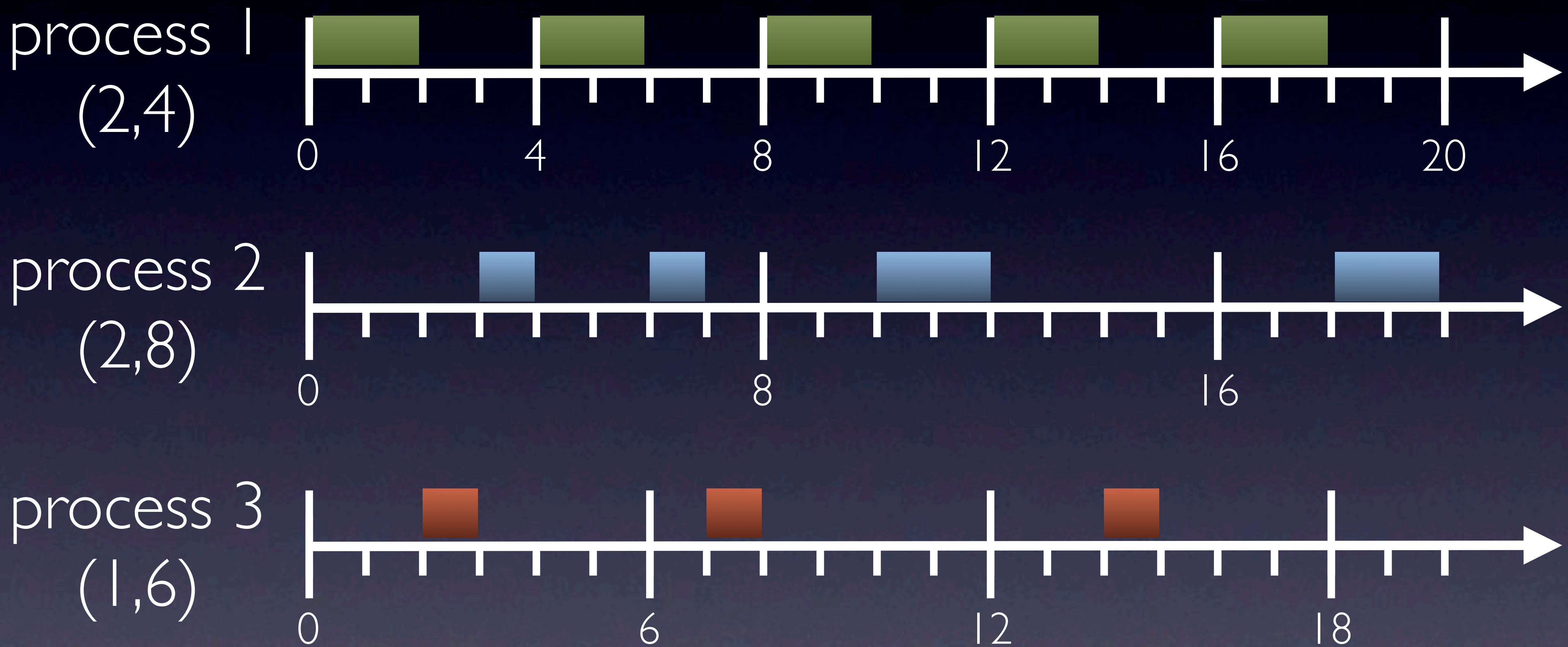

multiple processes are EDF-scheduled

Scheduling Result and Bounds

[SIES09]

Processes $P_1, P_2, \ldots, P_n$ on VBSs $u_1, u_2, \ldots, u_n$ are schedulable if $\sum_{i=1}^{n} u_i \leq 1$

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For any action α on a resource (λ, π) we have:

- upper response-time bound $\left\lceil \frac{load}{\lambda} \right\rceil \pi + \pi - 1$
- lower response-time bound $\left\lceil \frac{load}{\lambda} \right\rceil \pi$
- jitter $\pi - 1$

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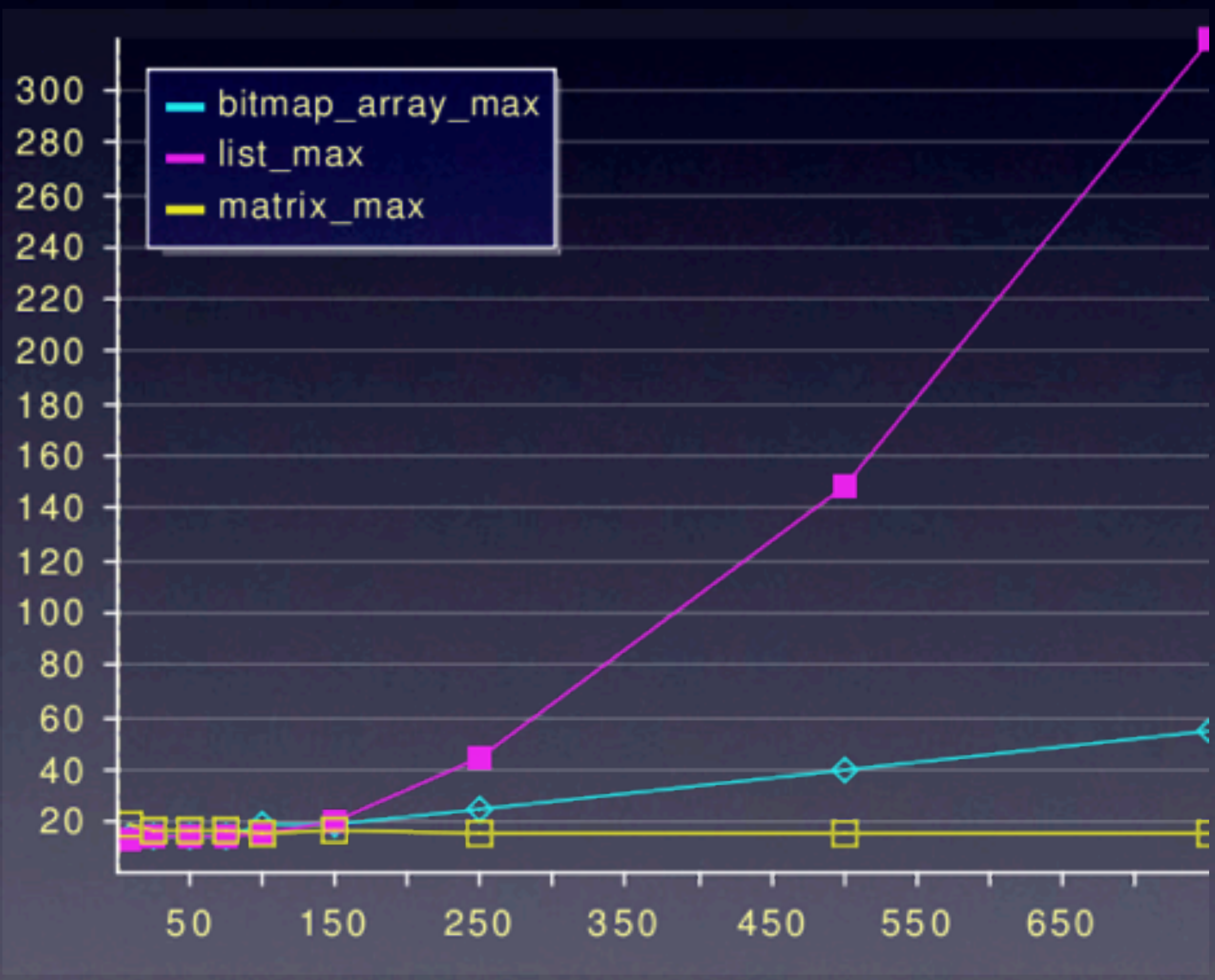
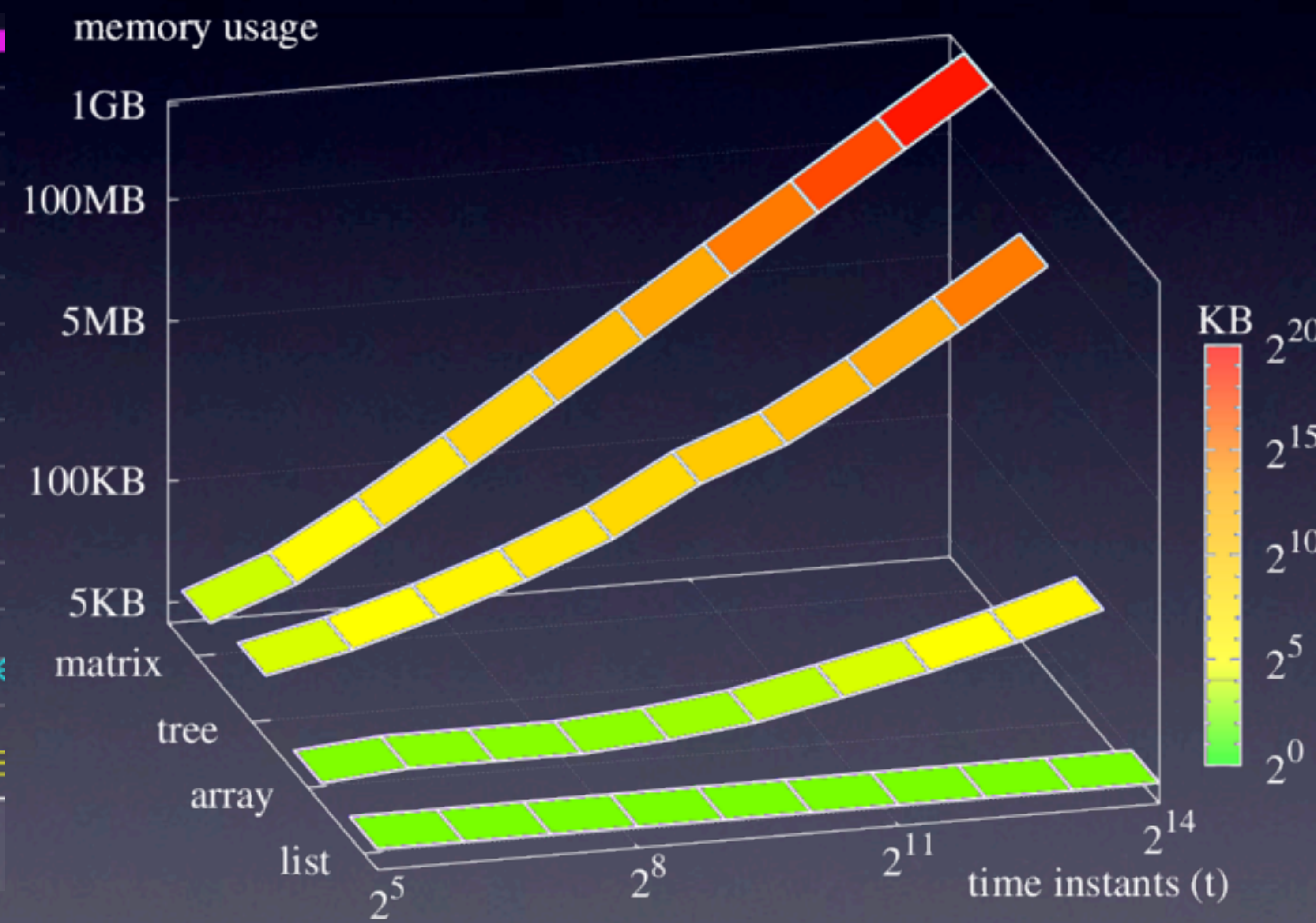
temporal isolation

Scheduler Overhead
[SIES09]





Power-Aware VBS

Dynamic Voltage and Frequency Scaling

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Maintain VBS properties (temporal isolation, bounds)

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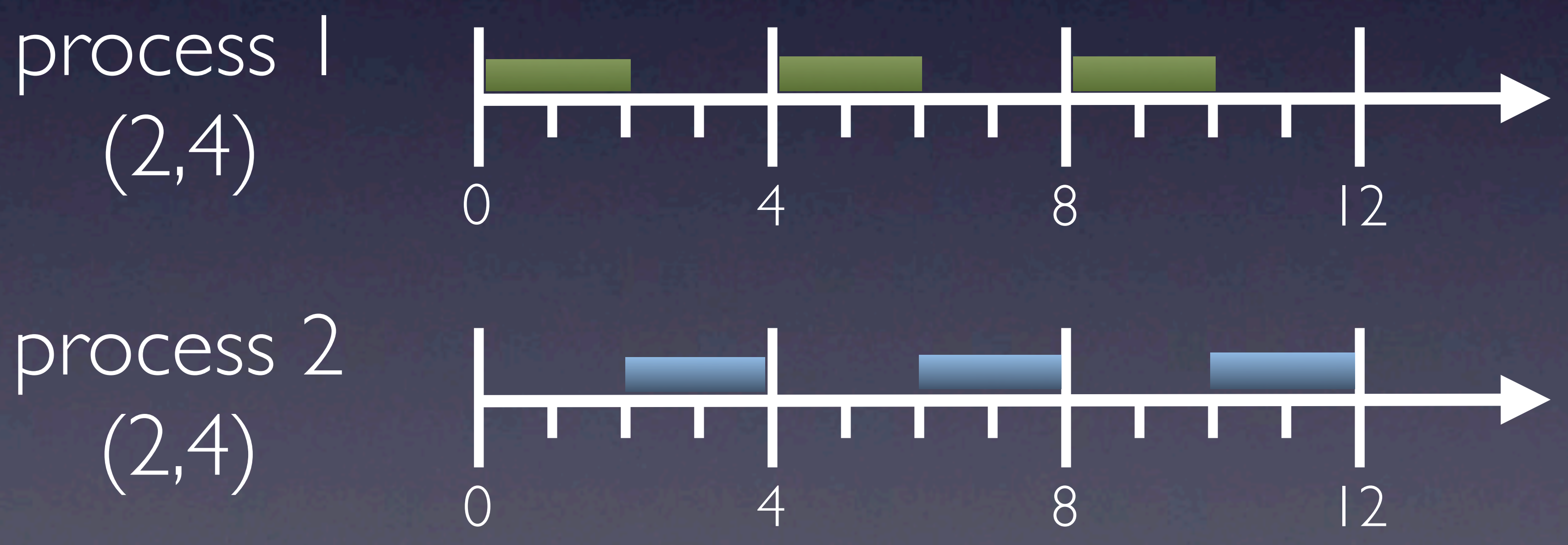


Power-Aware VBS

Dynamic Voltage and Frequency Scaling

Maintain VBS properties (temporal isolation, bounds)

Possible whenever there is slack in the system

Power-Aware VBS

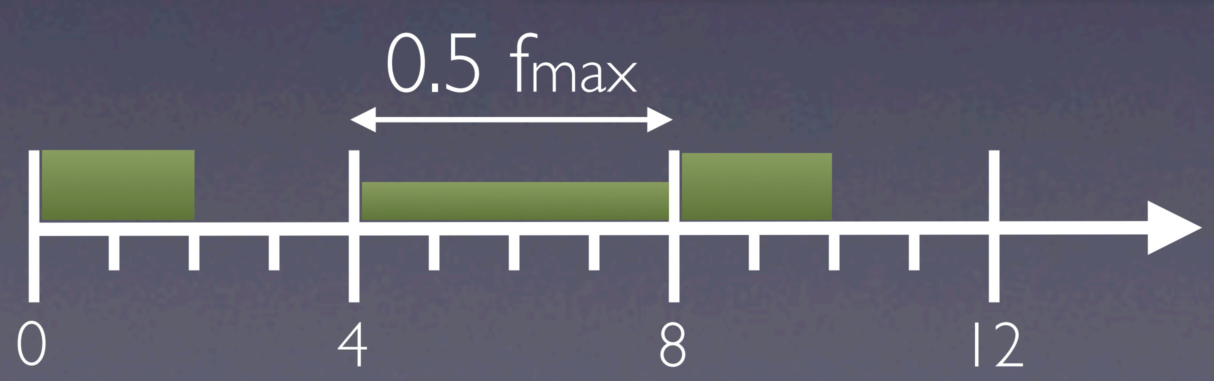
EDF frequency scaling result:

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

process 1
(2,4)



Frequency-scaling VBS

Slack

Frequency-scaling VBS

Static Slack

Slack

Action Slack

Dynamic Slack

Termination Slack

Frequency-scaling VBS

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

Slack

- Static Slack
- Dynamic Slack
  - Action Slack
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Frequency-scaling VBS

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

Static Slack

Slack

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

Action Slack

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Frequency-scaling VBS

Static Slack

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

Action Slack

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

Dynamic Slack

Termination Slack

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

Frequency-scaling VBS

Frequency-scaling VBS

Static slack

$$f = \sum_{i=1}^{n} u_i \cdot f_{max}$$

Frequency-scaling VBS

Static slack

$$f = \sum_{i=1}^{n} u_i \cdot f_{max}$$

Action slack

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

Frequency-scaling VBS

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$$f = \sum_{i=1}^{n} u_i \cdot f_{max}$$

Action slack

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

Termination slack

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

Frequency-scaling VBS

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Action slack

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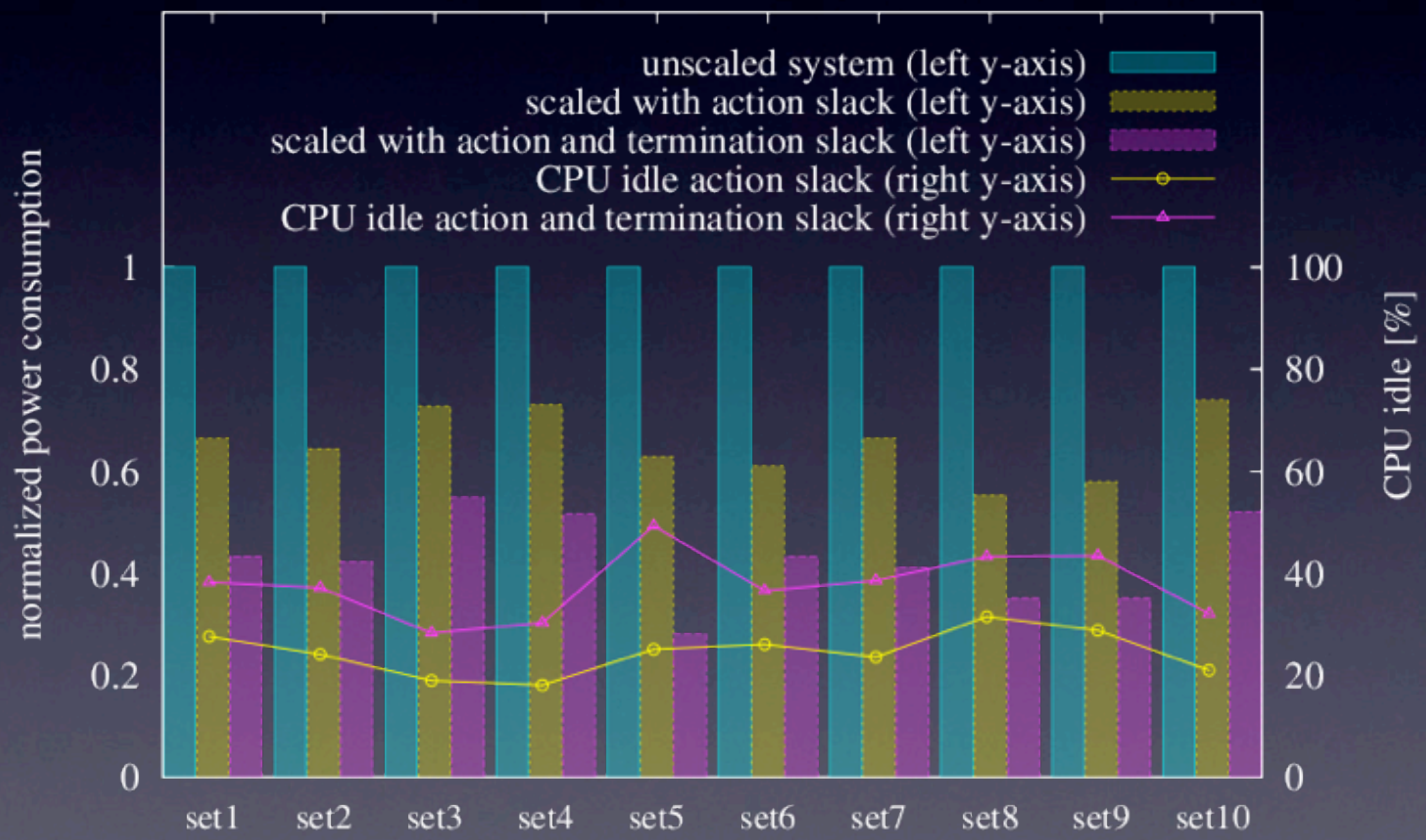
Termination and action slack can be used separately or together

Power-Aware VBS

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



Look-ahead FS-VBS

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With knowledge of future events:

- redistribute computation time between periods

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May help to handle:

more complex power models

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frequency switching cost (time and power)

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May help to handle:

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frequency switching cost (time and power)

- time overhead included using overhead accounting [RTAS10]

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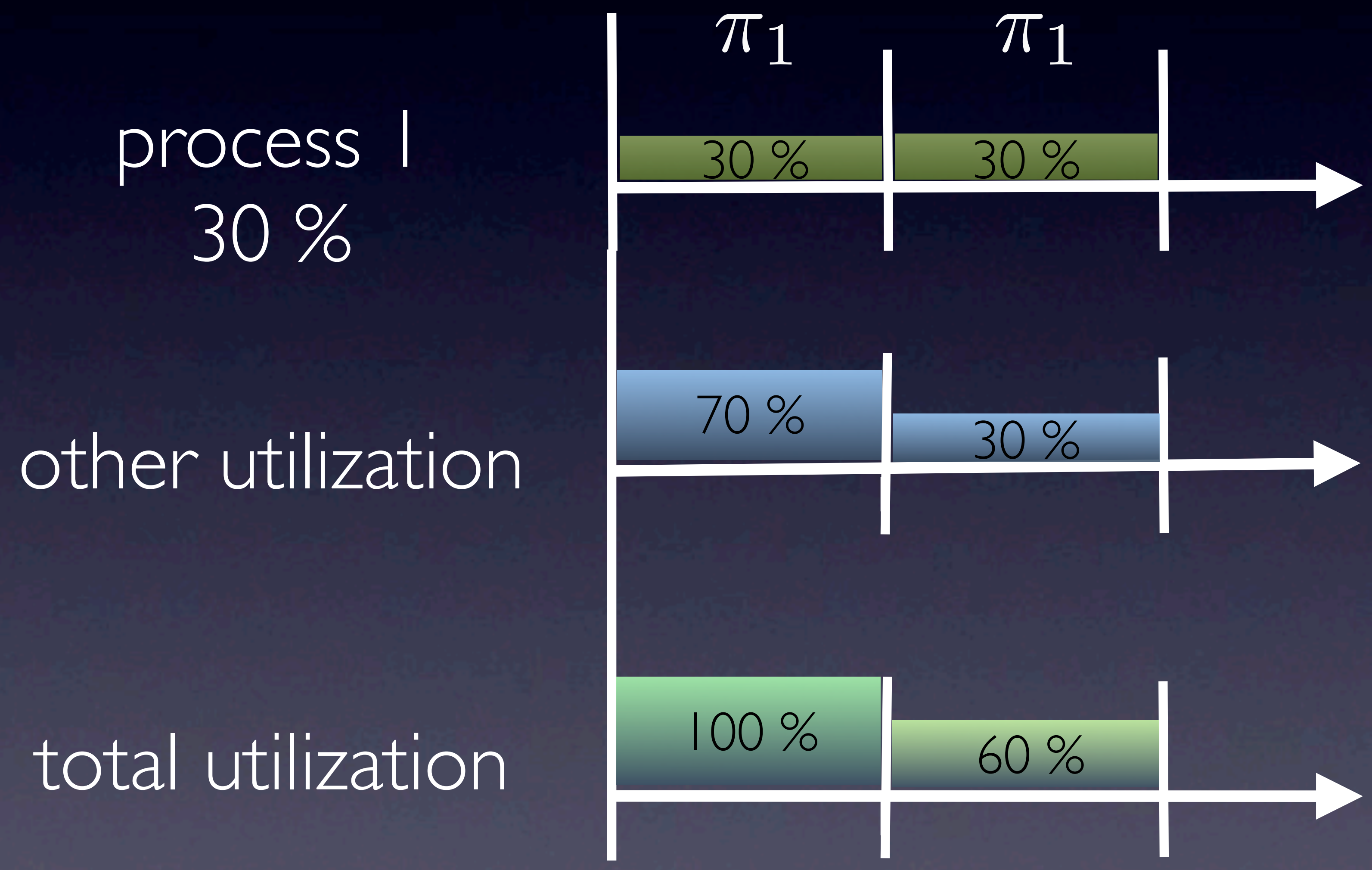

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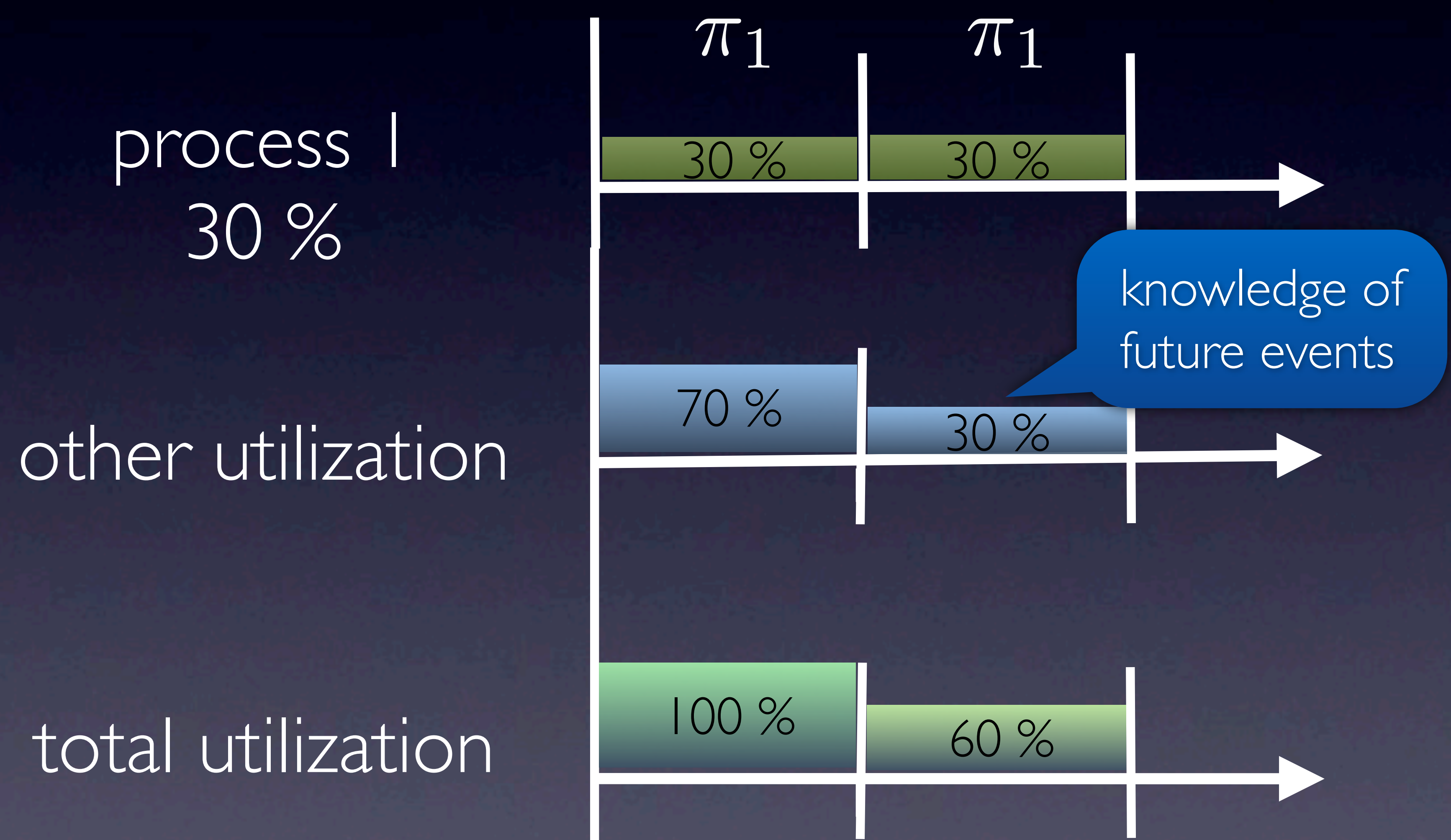

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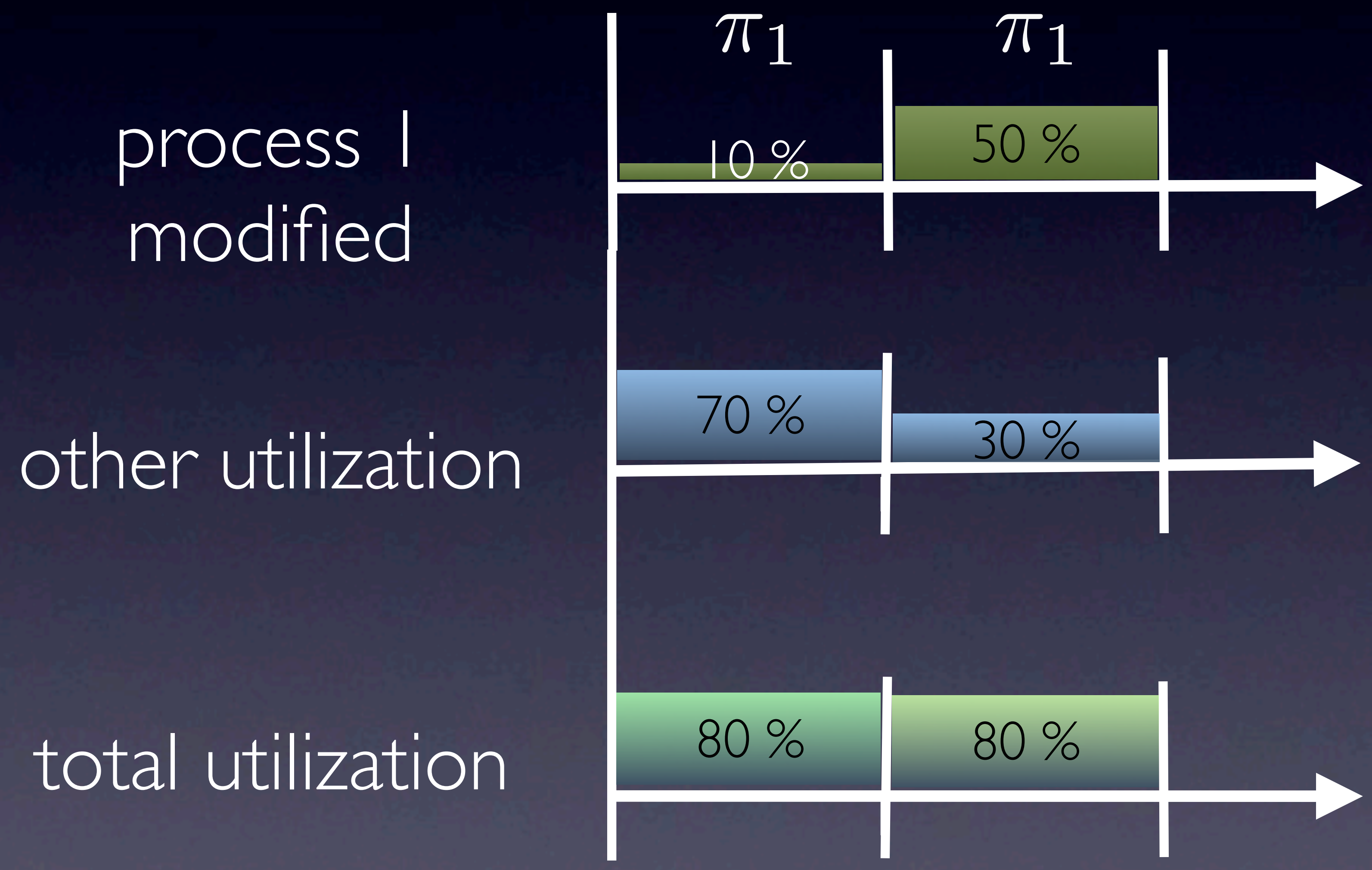

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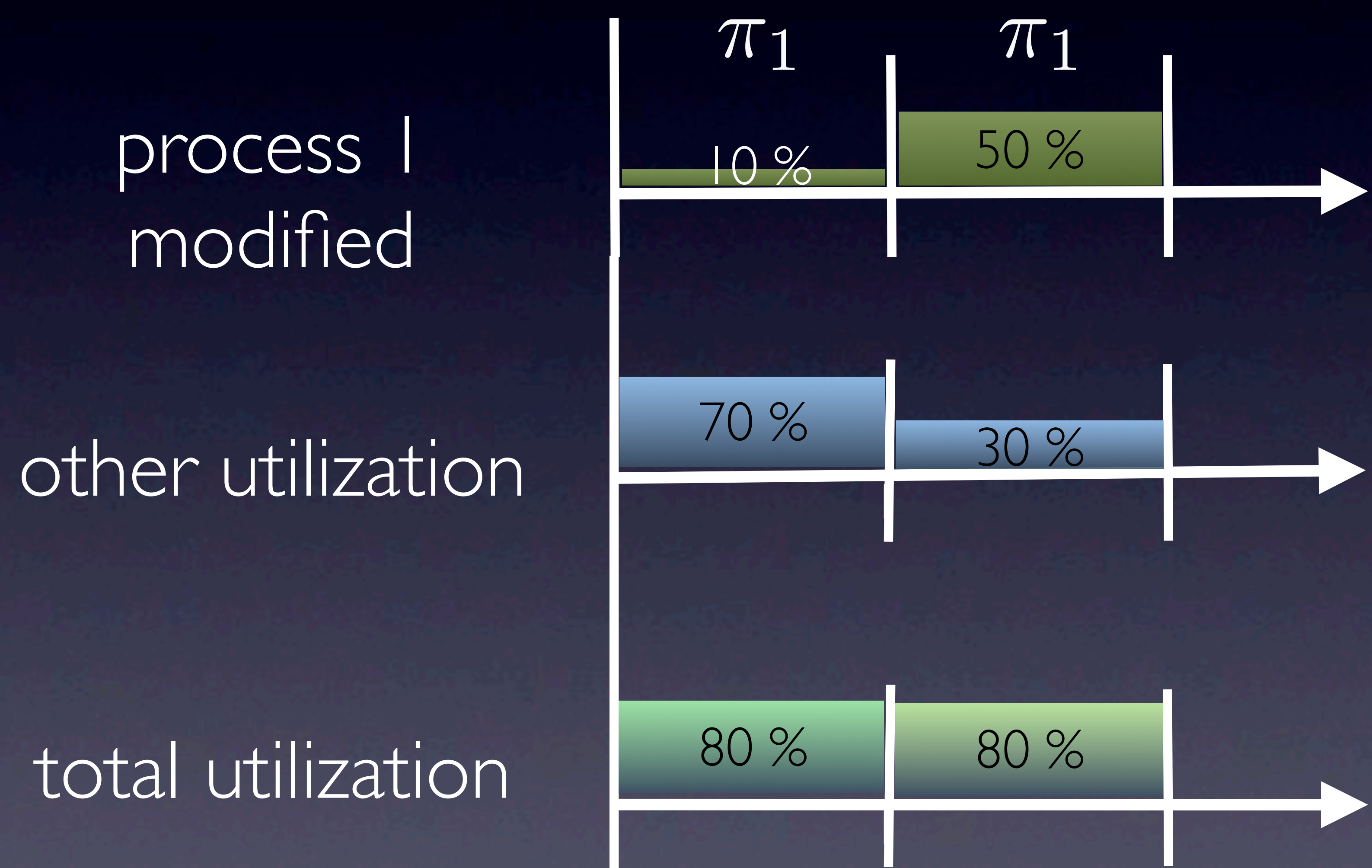

actual improvement depends on the power model

Look-ahead FS-VBS

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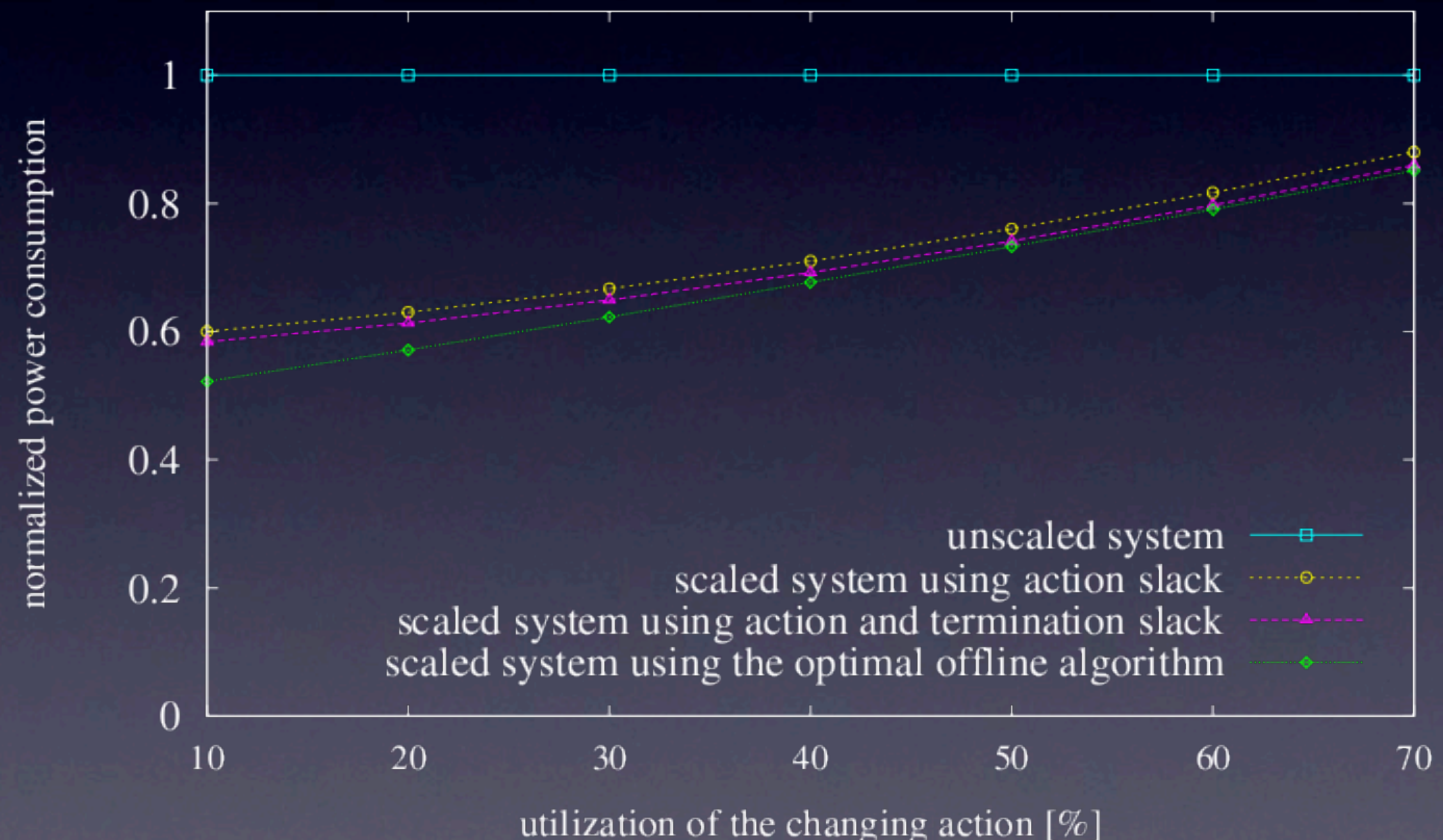

Look-ahead online FS-VBS

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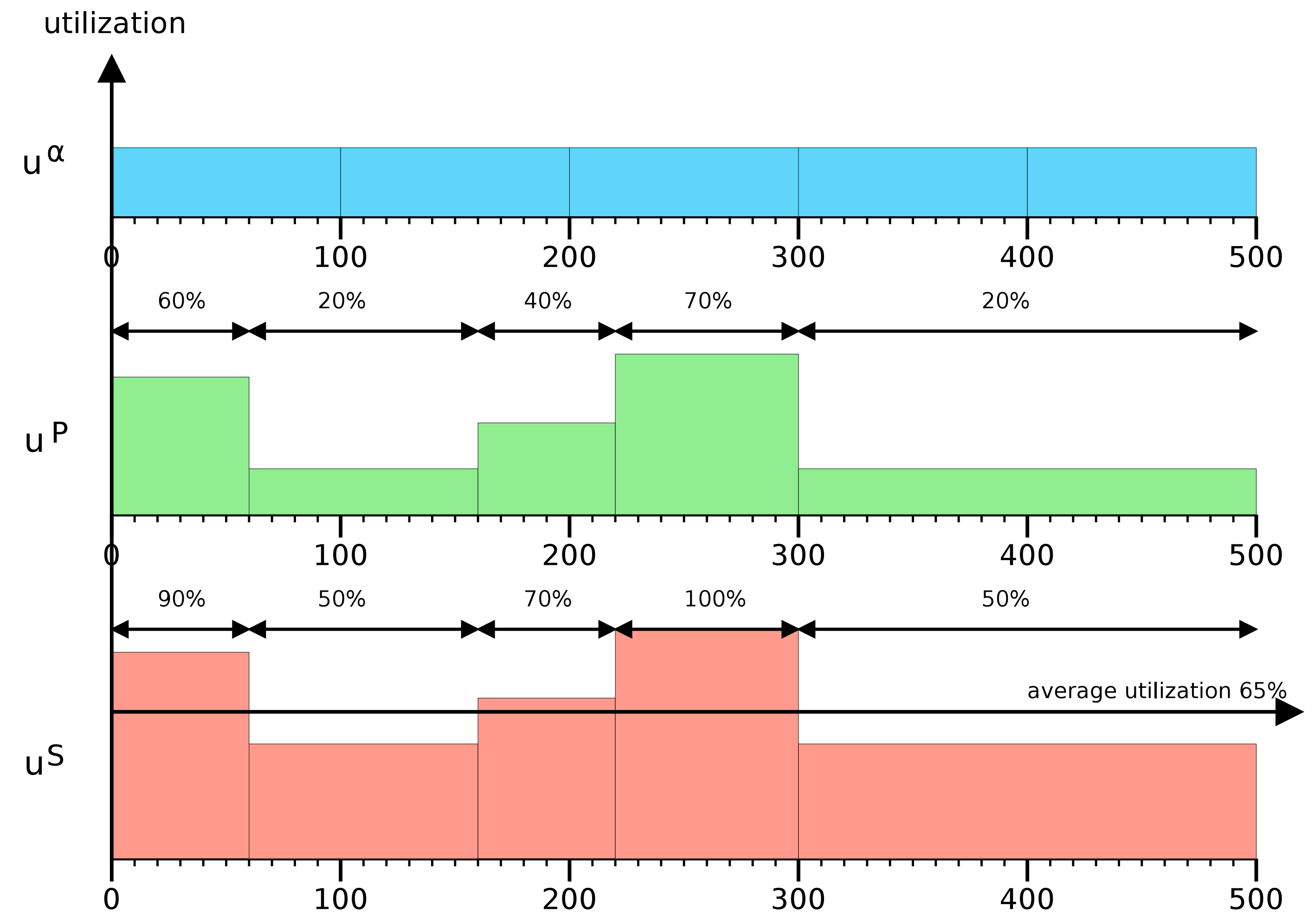

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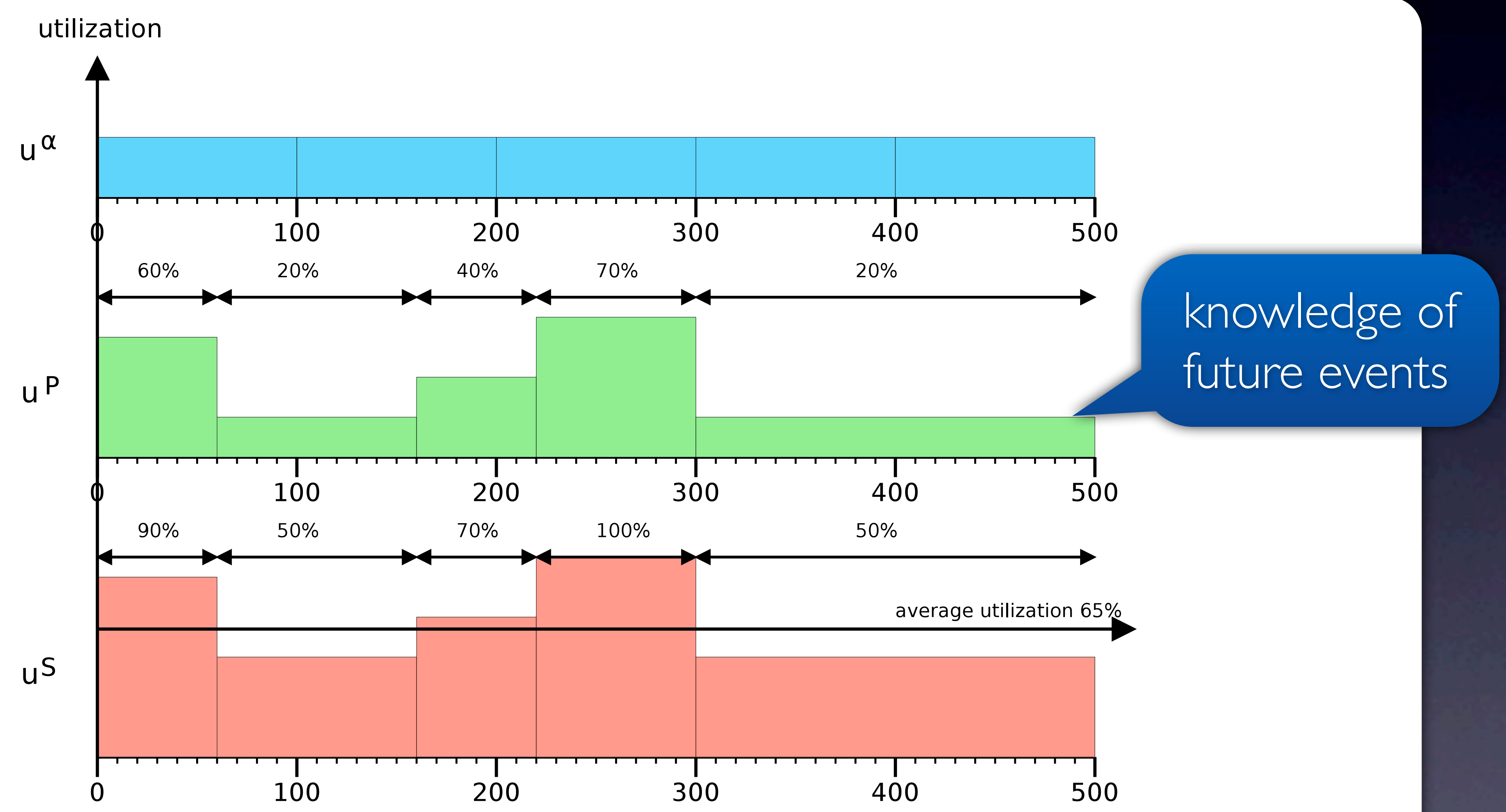

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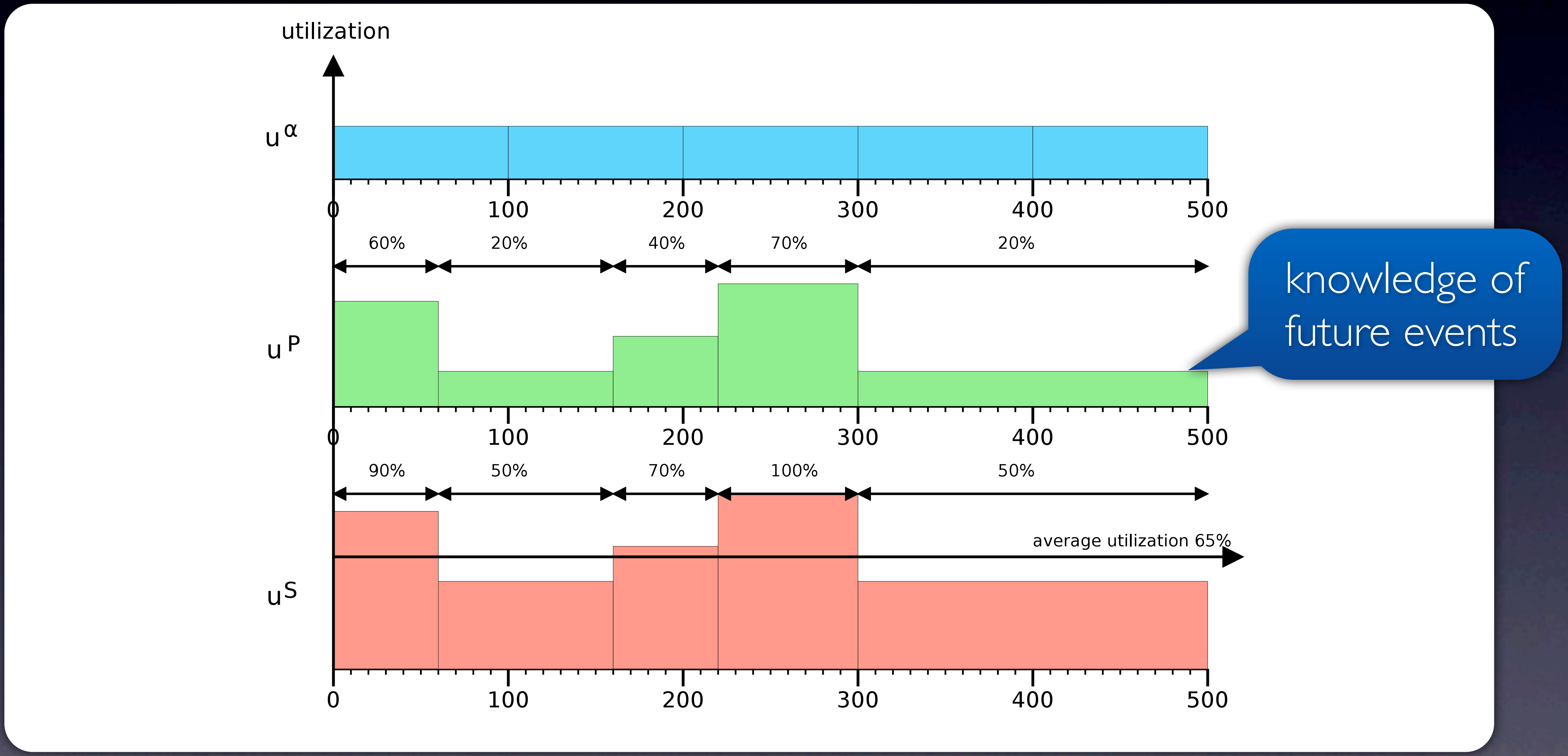

Modify the limits in each period (whenever possible) s.t. the utilization approximates the average utilization

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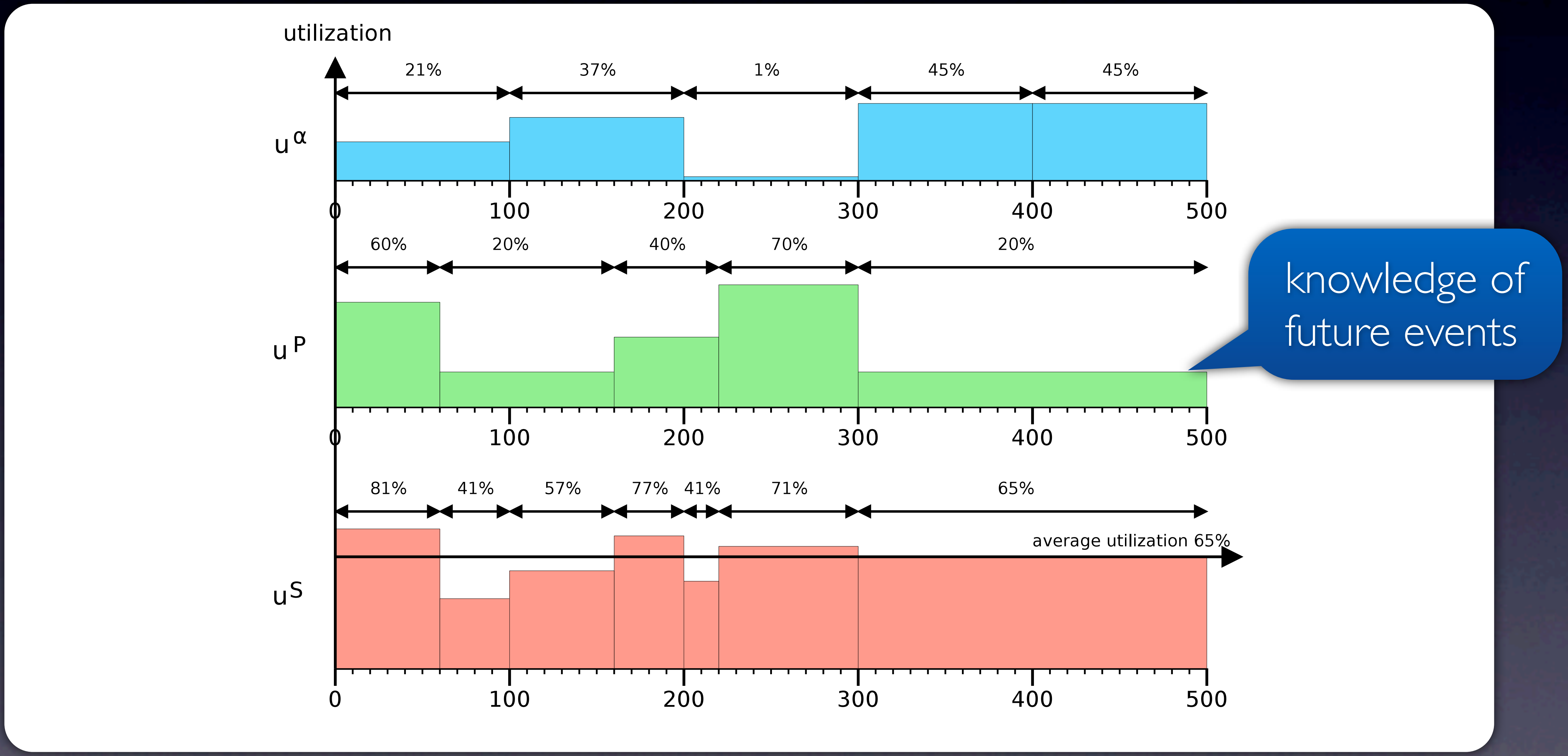

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Conclusions

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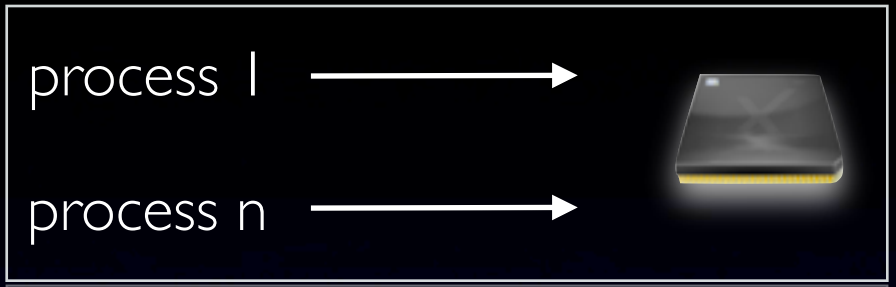
- Server-based scheduling for temporal isolation



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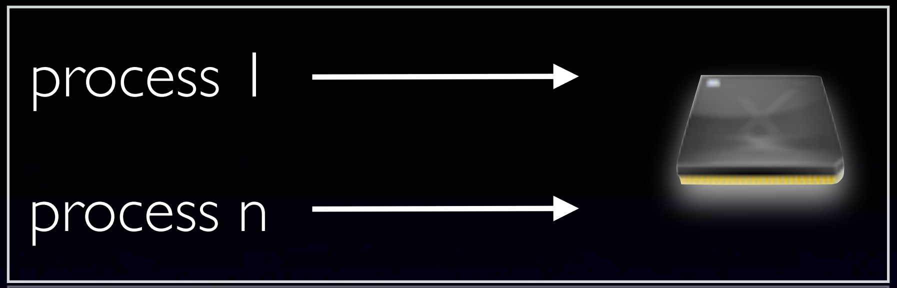
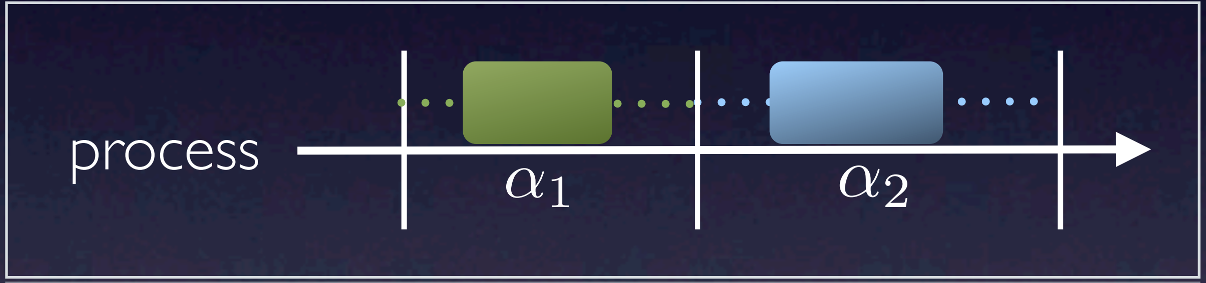


- VBS for variable execution speed



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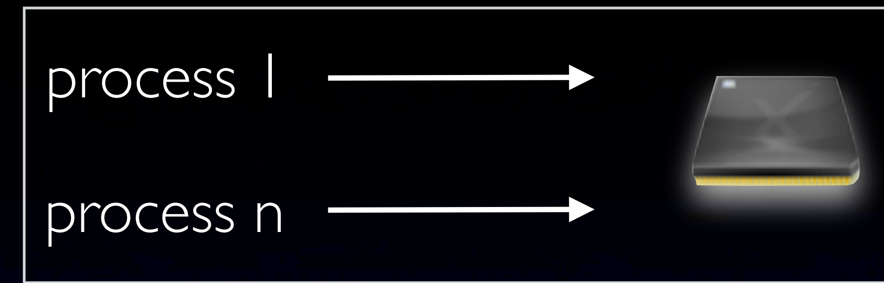

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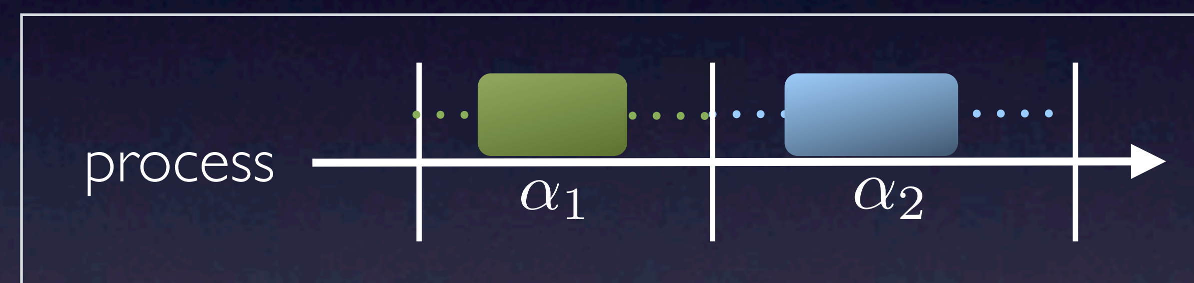

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optimal offline FS-VBS

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Termination Slack

Action Slack

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